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Jurassic sedimentation in the South Kitakami Belt, Northeast Japan

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Abstract: This paper describes the Jurassic clastic sequence of the South Kitakami Belt with special reference to the sedimentary facies. The strongly folded Jurassic formations comprise several basinal occurrences and are distributed in two nearly north-south trending synclinal subbelts, the Western and the Middle Subbelts. The Jurassic strata of the Western Subbelt consist predominantly of marine muddy deposits, whereas those of the Middle Subbelt consist of coarser clastics including abundant non-marine deposits. The latter added to the Lower Cretaceous clastic sequence are altogether about 1600 to 4200 m thick, that is, three to four times as thick as the former.

These Jurassic strata comprise the following six facies associations. 1) *Alluvial (Fluvial) Association* includes migrating fluvial, distributary-interdistributary complex and alluvial fan deposits. 2) *Lake Association*, which was derived from lake, marsh and fluvio-lake environments, represents deposits on relatively lower land and consists of finer clastics than the previous association. 3) *Beach Ridge-Coastal March Association* is mainly originated from coastal dunes. 4) *Shallow Marine Association* consists of coarse- to fine-grained sandstone occasionally accompained by sandy shale containing marine molluscan fossils. 5) *Flysch Association* consists chiefly of turbidite showing graded bedding and the Bouma sequence with subordinate fluxoturbidite. 6) *Basin Mud Association* consists mostly of monotonous bedded black shale including marine molluscan fossils.

The Jurassic to Lower Cretaceous formations of the Middle Subbelt, comprise three major cycles of sedimentation. Each cycle begins with a shallow marine facies, grades through quiet basin muds into flysch facies (partly lacking) and ends abruptly with thick alluvial associations of two types.

These deposits show approximately northward paleocurrent directions in the main. The longitudinal facies changes combined with the mode of deposition indicate that the Upper Jurassic sedimentation took place in response to northward progradation of deltaic deposition. On the other hand, it is suggested that a tectonic land existed to the east of the Jurassic basin of the South Kitakami Belt, from the mode of lateral facies changes in addition to the directional analyses of slump folds and submarine channel structures. As to the provenance, it is assumed to have been due to denudation of granitic rocks with subordinate metamorphic and sedimentary rocks during Jurassic time. The analysis of the combined data indicates that great differences of depositional environment and geohistory exist between the Western and Middle Subbelts, and that there is a close affinity in Jurassic sedimentation between the South Kitakami Mountains and the Soma area at the eastern margin of the Abukuma Mountains.

I. INTRODUCTION AND ACKNOWLEDGMENTS

Sedimentological studies including the elucidation of sedimentary environments and depositional processes of clastic sedimentary rocks have made remarkable progress in recent years. The earliest epoch-making contribution was the turbidity current theory proposed by KUENEN and MIGLIORINI (1950). The rapid progress in marine geology had a great impact on such studies around 1950 and active studies have been made of flysch type-deposits. Since the early 1960's, many studies have been directed toward deposits of continental and

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shallow water origin including fluvial and deltaic deposits. These sedimentological studies have clarified the depositional environment and thus it has become possible to reconstruct the ancient sedimentary basins and to establish their depositional history. This also has contributed greatly to the prospecting of underground resources.

Sedimentological studies in Japan have been concentrated on flysch-type basins and less on non-marine and shallow marine deposits compared with the western European countries.

The writer has made stratigraphical and sedimentological studies of the Mesozoic formations of the South Kitakami Belt, Northeast Japan. The Mesozoic formations of this region, especially of the Jurassic and Cretaceous formations are epicontinental deposits with alternation of marine and non-marine deposits. This paper analyzes the sedimentary facies of the Jurassic formations with the purpose of clarifying their sedimentary environments, depositional patterns, provenance and paleogeography. Some studies were also made briefly of the sedimentation of the Lower Cretaceous formations which conformably cover the Jurassic.

On the sedimentary facies which can be used as the basis of facies and basin analysis, SELLEY (1970) says as follows: "A sedimentary facies is a mass of sedimentary rocks which can be defined and distinguished from others by its geometry, lithology, sedimentary structures, paleocurrent pattern, and fossils." He considers paleoecology, petrography and geochemistry as important branches related to sedimentlogical studies (SELLY, 1976). After all, comprehensive studies from various angles would clarify depositional environment and history, and paleogeography. Here, the concepts of facies and basin analyses in this study are summarized in Table 1.

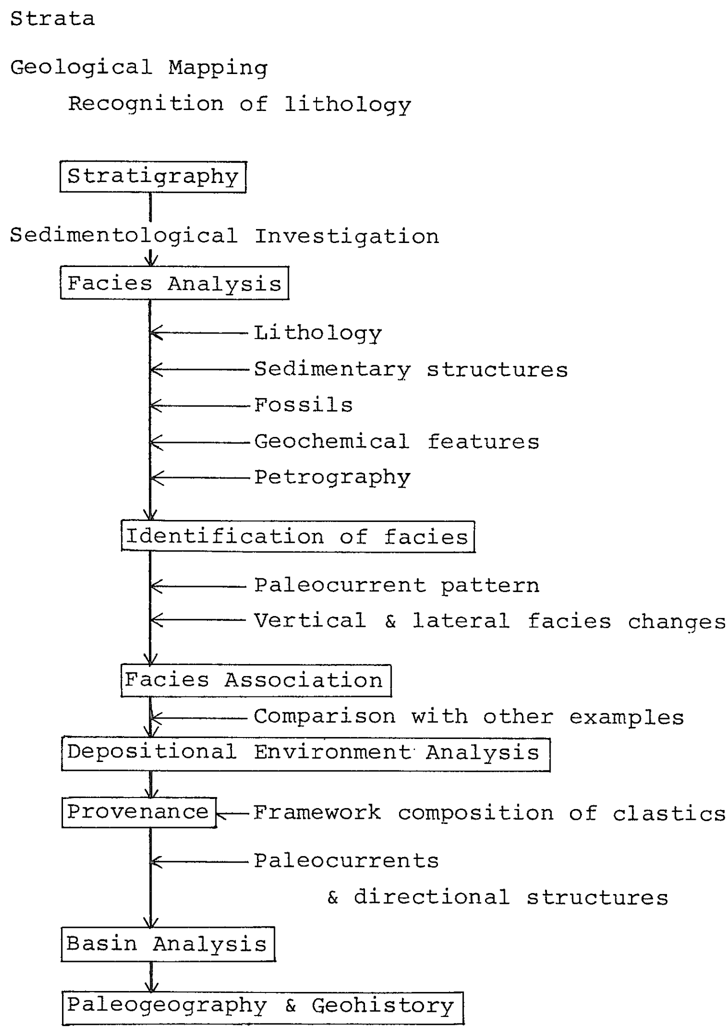
The measured sections as a key for the facies analysis have been correlated by mapping various sedimentary features. However, the following difficulties are encountered in the sedimentological study of this region: 1) These strata show a complex geologic structure and key beds are scarce. These factors make the correlation of strata and the establishment of geometry of beds or facies (e.g. solid feature of a sand body) difficult. 2) Strictly speaking, the most fundamental classification of marine or non-marine beds is not easy in certain cases.

Thus the region is in some difficulties for sedimentological studies and it is not possible to conduct detailed description and comprehensive discussion on all the strata constituting a maximum thickness of 4200 m in five areas. However, as no full-scale sedimentological study has yet been made on the whole Jurassic formations of the South Kitakami Belt, this is an attempt to provide the basis for more detailed studies in future.

The South Kitakami Belt is mostly floored by Mesozoic and Paleozoic formations which contain many standard stratigraphic successions of Japan. On the Jurassic strata many stratigraphical and paleontological contributions have been made since the 1880's. The past major stratigraphical studies were made by MABUCHI (1933) and INAI (1939) in the Shizugawa area, by MORI (1949) and KASE (1979) in the Hashiura area, by HAYAMI (1959a) in the Mizunuma area, by SHIIDA (1940, 1940–1941) and EHIRO (1974) in the Karakuwa area, by INAI and TAKAHASHI (1940), TAKAHASHI (1962) and TAKIZAWA *et al.* (1974) in the Oshika (Ojika) area, and by MASATANI (1950) and MORI (1963) in the Soma area. Syntheses of the above stratigraphical descriptions include those of ONUKI (1956, 1969) and HAYAMI (1961a). The past outstanding and important paleontological studies are those on ammonoids by SATO (1962) and TAKAHASHI (1969) and on marine bivalves by HAYAMI (1958, 1959b, c, d, 1961d) and TAMURA (1959).

The very few sedimentological studies carried out in the past include the facies analysis by TAKIZAWA (1975) on the Cretaceous formations of the Oshika area and that by TAKIZAWA (1976) on a part of the Jurassic formations of the same area. Apart from the above, descriptions of peculiar types of sedimentary structures were made by BANDO (1959, Cretaceous formation), TAKAHASHI (1964, Triassic)

Table 1 Course and method of the study.



and KAMADA (1979, Triassic). General summary was given by HAYAMI (1961b, c) and TAKIZAWA (1977) on the sedimentary facies and geological history of the Jurassic formations of the whole South Kitakami Belt.

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II. STRATIGRAPHY

1. General Remarks

The South Kitakami Belt as defined by YOSHIDA (1975) is one of the important geotectonic divisions of Northeast Japan. The belt consists mostly of Paleozoic and Mesozoic rocks ranging from Silurian to Cretaceous in age. It is bordered by the Hayachine Tectonic Belt on the northeast in the South Kitakami Mountains, extending southward to the Soma area, the eastern marginal part of the Abukuma Mountains bordered by the Hatagawa Tectonic Line on the west (Fig. 1). The Soma area (or "Soma Subbelt") is largely floored by Paleozoic and Mesozoic sedimentary rocks in addition to pre-Devonian metamorphic rocks and Cretaceous granitic rocks. These pre-Tertiary rocks have a close geologic relation to those of the South Kitakami Mountains. Besides, this belt includes as its southern extremity the Takakurayama area where late Paleozoic and metamorphic rocks are exposed.

The Paleozoic strata in the South Kitakami Belt have been regarded as deposits in the marginal area of a geosyncline (MINATO, 1966) or in a miogeosynclinal (NAKAZAWA and NEWELL, 1968) or in an epicontinetal area (YOSHIDA, 1975), and the Mesozoic strata in this belt most likely consist of non-geosynclinal deposits. In the southeastern part of the belt proper, the Mesozoic strata comprise Triassic, Jurassic, and Cretaceous (pre-Aptian) formations and are covered by Early Cretaceous volcanics and intruded by late Early Cretaceous granitic rocks.

Of the Mesozoic strata, the Jurassic to Lower Cretaceous formations consisting mostly of clastic sediments occur in three meridional subbelts (Fig. 2): the Western (Shizugawa-Hashiura), the Middle or Central (Karakuwa-Oshika) and the Eastern (Ofunato) Subbelts. The last subbelt consists only of the Cretaceous (probably Hauterivian to Barremian) accompanied by a large amount of volcaniclastics, and brackish to littoral faunas as described by ONUKI and MORI (1961) and NAKAZAWA and MURATA (1966). The Triassic strata are represented chiefly by the Scythian to Anisian Inai Group which widely envelopes the Jurassic to Cretaceous formations. They are generally of marine origin and are composed of shale and sandstone with conglomerate. They are divided from bottom to top into the Hiraiso, Osawa, Fukkoshi and Isatomae Formations, being 2000 m or more in total thickness. In addition, the Anisian to lower Ladinian Rifu Formation and the Carnian to Norian Saragai Group are narrowly distributed, the latter being covered by the Lower Jurassic strata in the Western Subbelt.

The Mesozoic and Paleozoic strata of the South Kitakami Belt are complicatedly deformed by folds of upright type and faults. Each Jurassic outcrop area is occupied by a single syncline or an assemblage of minor synclines. As an example, the structural elements in the Oshika area where the strata are most intensely folded are shown in Figure. 3. The structures with north-south trending fold were formed by compression in east-west direction and cut by strike slip faults of east-northeast and northwest trends.

The folds are classified into four or five orders according to the scale of wave lengths. They produced well-developed slaty cleavage in the strata. This should be taken into consideration in elucidating lateral changes in thickness of the folded strata (Fig. 4). Special attention should be given to the influence of such rotational deformation in measuring current directions of the sedimentary strucures. Deformation of the muddy rocks is remarkable as seen in the deformation (rotation) of fossils and calcareous nodules (Pl. VIII-3). The folds in the Oshika area are understood as flattened flexural folds with

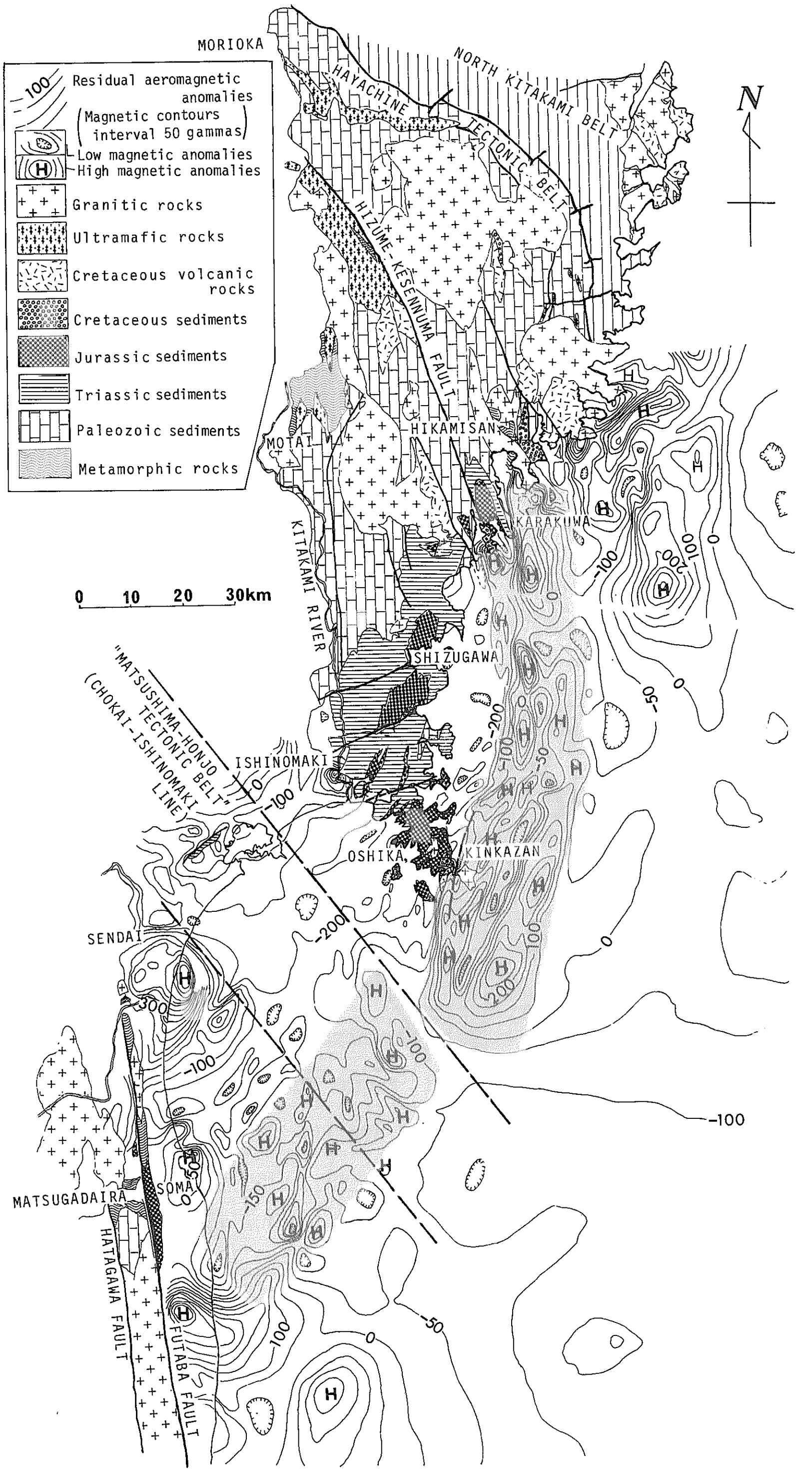


Fig. 1 Compiled geological map of the South Kitakami Belt, Northeast Japan. The belt comprises the South Kitakami Mountains (or South Kitakami region) and the eastern margin of the Abukuma Mountains. The boundary between both mountains is demarcated by a large northwest directional fault crossing Sendai Bay.

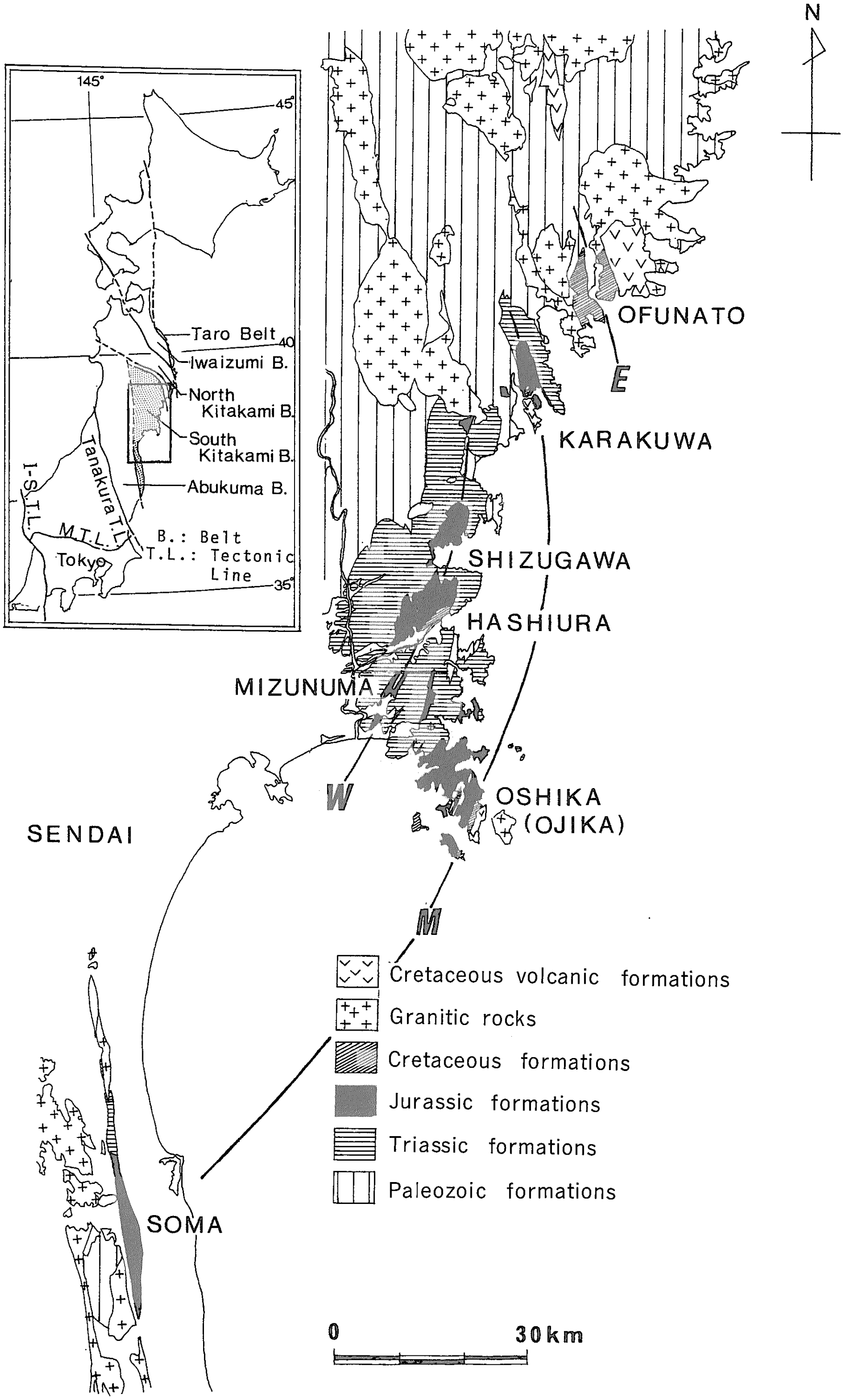


Fig. 2 Distribution of Mesozoic strata in the South Kitakami Belt. W, Western Subbelt; M, Middle Subbelt; E, Eastern Subbelt. M.T.L. and I-S.T.L. in the inset map indicate the Median Tectonic Line and Itoigawa-Shizuoka Tectonic Line respectively.

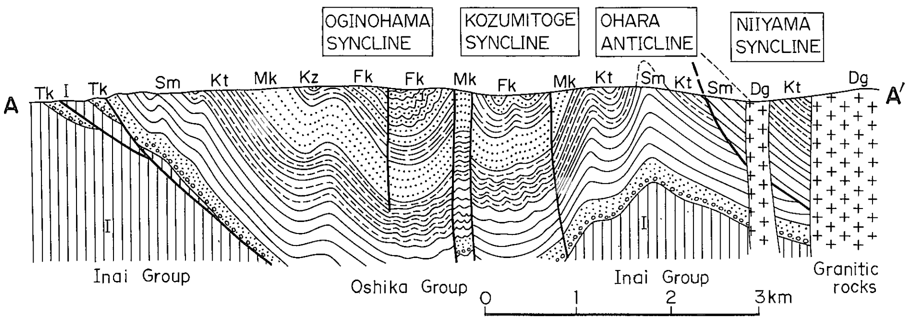


Fig. 3 Geological cross section of the Jurassic Oshika Group. The group forms three synclines and is regarded as flattened flexure folds. Line A–A′ indicates the position of the section given in Fig. 6. For abbreviations see Table 10.

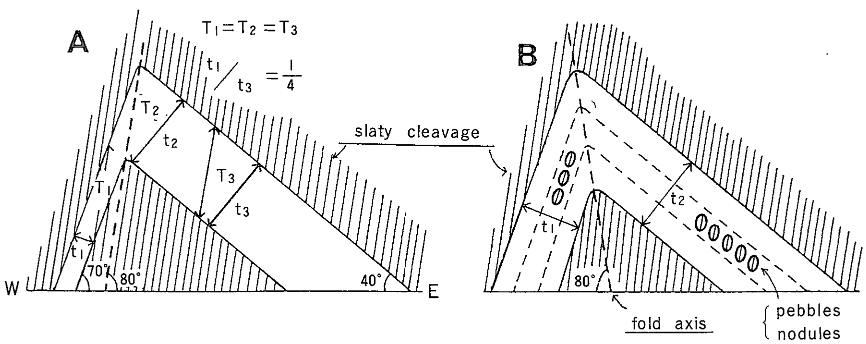


Fig. 4 Schematic profiles for the structural interpretation of the Ogachi Anticline. The left figure (A) is by the previous authors, and the right one (B) by the writer. Note the difference in thickness between both wings of an anticline.

estimated shrinkage of 50 percent or more in east-west direction (TAKIZAWA, 1981). Folding deformation is strongest in the Oshika area, and moderate in the Karakuwa, Soma and Mizunuma areas, becoming much weaker in the Shizugawa and Hashiura areas.

The major tectonic lines related to the South Kitakami Belt are the Hayachine Tectonic Line(Belt), Hizume-Kesennuma Line, Futaba Fault and Hatagawa Fault. All these tectonic lines are linear in north-northwest direction with the exception of the Hayachine Tectonic Line. The last three are considered to have been formed in the Cretaceous Period, and they control the distribution of the Mesozoic formations. The Hayachine Tectonic Line is curved and possibly originated in pre-Permian time.

There is a large and broad graben of northwest trend which is regarded as a kind of tectonic zone, near Sendai Bay. It probably separates the South Kitakami Mountains from the Abukuma Mountains by horizontal shifting. A right lateral dislocation of 20–30 km between the two blocks is inferred from the distribution of the older metamorphic rocks and the Mesozoic and Paleozoic formations. Moreover, such a dislocation is reflected in the distribution of an aeromagnetic anomaly zone, 20–30 km wide, just off the Kitakami Mountains.

The Mesozoic synclinal structures originally plunged to the north, but later tilted southward to show the present structural attitude.

2. Middle Subbelt

The Jurassic to Cretaceous formations in the Middle (or Central) Subbelt are distributed in three areas, the Karakuwa, Oshika and Soma areas from north to south. They comprise the Middle and Upper Jurassic strata, in addition to the lowest Cretaceous, and cover the Triassic Inai Group with an unconformity. Thus, the Upper Triassic and the Lower Jurassic formations are lacking in this subbelt. Compared with the sequence in the Western Subbelt, that in the Middle Subbelt is very thick and very abundant in granitic coarser material.

2-1 Karakuwa Area

This area is situated in the northern part of the Middle Subblet, where Middle Jurassic to Lower Cretaceous sequence is distributed. The stratigraphic succession and geologic map are shown in Table 2 and Figure. 5. The traditional two fold divisions of the Jurassic of this area are not available at present. Consequently, the newly defined Jurassic to Lower Cretaceous sequence is called the Karakuwa Group as a whole.

The Kosaba Formation rests unconformably upon the Triassic Inai Group, and consists mainly of massive arkosic sandstone. The basal part of the formation consists of conglomeratic sandstone containing fossils such as trigoniids and inoceramids. Sandstone is coarse- to medium-grained with frequent cross-bedding in the lower part of the formation and fine-grained with shaly intercalations in the upper part. Thickness of the formation is about 200 m in maximum, and thickens to the northeast. The Kosaba Formation grades into the Tsunakizaka Formation above.

The Tsunakizaka Formation, about 400 m thick, is composed mostly of massive or thick-bedded black shale or sandy shale in the main part, accompanied by stratified medium-to fine-grained sandstone in the upper part, the Sakaguchiirizawa Sandstone Member. The shale is very sandy and poorly sorted in the lower half of this formation, and contains occasionally plant fragments.

In the northern part of this area, Bajocian ammonites such as *Stephanoceras* cf. *plicatissimum*, *Sonninia* cf. *corrugata*, *Pelekodites* (*Spatulites*) *spatians*, *Otoites* sp. and *Strigoceras* cf. *languidum*. (SATO, 1962, 1972) and bivalves such as *Inoceramus karakuwensis*, *Inoceramus* cf. *lucifer*, and *Posidonia* sp. (HAYAMI, 1961a) occur in this formation.

The Ishiwaritoge Formation consists mainly of conglomerate and sandstone, being 130 to 190 m thick. In the northern part of the area, the conglomerate occupies about 45 to 65 percent of the total thickness of this formation. It is characterized by the abundance of large

Table 2 Stratigraphical succession of the Jurassic system in the Karakuwa area. Abbreviations for stratigraphic units are used in other tables and figures.

Geologic Age			Formation	Thickness (m)	Lithology
Cretaceous	Barremian, Hauterivian		Oshima Fm	ca 400	Calcareous sandstone and shale with tuff.
			Kanaigaura Fm	ca 1,000	Andesitic lavas and pyroclas-tic rocks
	Valanginian, Berriasian	Karakuwa Group	Isokusa Fm	150	Bedded shale with sandstone
Jurassic	Tithonian, Kimmeridgian		Kogoshio Fm	570-420	Massive coarse sandstone and shale
	Oxfordian		Mone Fm	150-360	Bedded shale and sandstone-shale alternation
	Callovian		Ishiwaritoge Fm	130-190	Conglomerate and sandstone with shale
	Bathonian		(Sakaguchiirizawa Mb)	(85)	(bedded medium sandstone)
			Tsunakizaka Fm	390	Massive sandy shale
	Bajocian		Kosaba Fm	200-40	Coarse to medium sandstone
Triassic			Inai Group	ca 1,200	Shale and sandstone

G: Group Fm: Formation Mb: Member

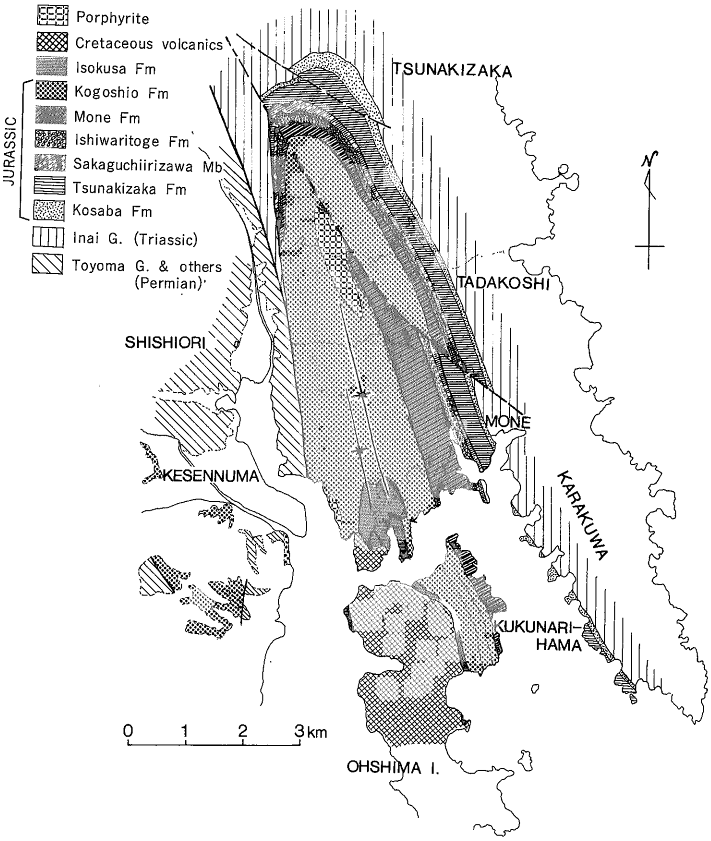


Fig. 5 Geological map of the Jurassic in the Karakuwa area.

boulders or cobbles of granitic rocks of which the largest is 60 cm across. On the other hand in the southern part, the conglomerate is thin and sandstone interbedded with shale is dominant. The conglomerate and sandstone beds frequently show penecontemporaneous erosion structures and cross-bedding.

It is considered that the Ishiwaritoge Formation is in conformable contact with the underlying Tsunakizaka Formation, in spite of the rapid change in lithology. Animal fossils are barren in this formation, but the shale occasionally yields plant fossils in the vicinity of Mone.

The Mone Formation consists mainly of bedded shale in its lower half and medium- to thin-bedded alternation of sandstone and shale in its upper half. The lowermost part is occupied by massive medium-grained sandstone which has a gradational contact with the underlying Ishiwaritoge Formation. This sandstone-shale alternation laterally changes into laminated shale in the northern part of the area. The thickness of the formation is 360 m in the southern part, but it shows a remarkable lateral change to be reduced to less than half northward.

A few fossils occur, and they comprise ammonites such as *Perisphinctes ozikaensis*, and bivalves such as *Myophorella* (*Haidaia*) *crenulata*, *Myophorella* (*Promyophorella*) sp. and *Nuculana* sp. (KATO *et al.*, 1977; HAYAMI, 1961a).

The Kogoshio Formation, about 500 m thick, is characterized by very coarse-grained whity arkose sandstone, which is massive or very thick-bedded accompanied by shale. The sandstone is well exposed for thickness of 5 to 20 m in a single bed and shows frequent cross-bedding. The basal sandstone of the formation contains abundant reworked pebbles of fossiliferous or oolitic impure limestone in the eastern edge of the islet of Oshima. Thin orthoconglomerate beds are present at several horizons, and they contain pebbels of granitic rocks, quartz porphyry, and metamorphosed quartzose rocks, hornfels and dacitic volcanic rocks.

The marine molluscan fossils are obtained at several horizons in this formation. They are *Astarte* sp. and *Nerinea* (?) sp. in the lower part, *Goniomya* sp. in the lower-middle part, and *Trigonia* sp., *Chlamys* sp., *Astarte* sp. and *Pygurus* (*Mepygurus*) sp. in the upper part (HAYAMI, 1961a, TAKAHASHI, 1973, EHIRO, 1974). Furthermore, the following bivalve fossils occur in the formation along Higashihama-Kaido; *Nuculana* (*Praesaccella*) sp. ex. gr. *yatsushiroensis*, *Pinna* sp., *Myophorella*(*Promyophorella*) *obsoleta* and *Astarte* cf. *spitiensis* (HAYAMI, 1961a).

The Isokusa Formation crops out at Isokusa (Wakagihama) and Nagasaki on the west and east coasts of the islet of Oshima, and another outcrop is newly found near Tsurugaura along the northern coast of the Oshima straight. This formation consists mainly of black shale partly intercalated with fine-grained sandstone. At the top of the formation there is very coarse arkosic sandstone near Tsurugaura, and it is correlative with the upper part of the Ayukawa Formation of the Oshika area. The base of this formation is defined by the sandy shale which conformably overlies the coarse sandstone in the uppermost of the Kogoshio Formation. The thickness of the formation is very variable as being 60 m at Wakagihama of the islet of Oshima and more than 150 m at Tsurugaura of the Karakuwa Peninsula. The detailed succession of the formation along the eastern coast of the islet was given by TAKAHASHI (1973). It yields many fossils such as *Thurmanniceras isokusense*, *Berriasella akiyamai*, *Kilianella* sp., *Olcostephanus* sp. and *Substeueroceras* sp. (SATO, 1958, 1962; TAKAHASHI, 1973), and *Parallelodon kesennumensis*, *P.* (*Torinosucatella*) *kobayashii*, *Grammatodon takiensis*, *G.* sp., *Gervillia* sp., *Pinna* sp., *Variamussium* cf. *habunokawense*, *Entolium kimurai*, *Mantellum akiyamae*, *Myophorella* (*Promyophorella*) *obsoleta*, *Astarte* cf. *spitiensis*, *A.* sp., *Coelastarte* sp. and *Pleuromya* sp. (HAYAMI *et al.*, 1960).

2-2 Oshika Area

The Oshika Group ranging from the Middle Jurassic to the Lower Cretaceous is divided stratigraphically into three formations, the Tsukinoura, the Oginohama and the Ayukawa Formations in ascending order, and is subdivided into 10 members (Fig. 6 and Table 3). The group is strongly folded and forms three south-plunging synclines. The group is distributed mainly in the Oshika Peninsula occupying most of the area, and the smaller outcrops occur in the Oura-Izushima and Urashuku areas to the north. The thickness and distribution of the Jurassic to Cretaceous sedimentary sequences of the South Kitakami Belt are the greatest in the Oshika areas.

The Tsukinoura Formation overlies the Triassic Inai Group with an unconformity in the Ishinomaki sheet-map area (TAKIZAWA *et al.*, 1984). This formation can be divided stratigraphically into two members. The lower member, Tsukinoura Sandstone, is more than 150 m thick, and consists of littoral or inner neritic sediments which comprise sandstone, sandy shale and conglomerate. It exhibits two sedimentary cycles with a decrease upward of grain size. The upper member, Samuraihama Shale, underlain by the Tsukinoura Sandstone with a gradual change of rock-facies, is represented exclusively by bedded black shale. The formation is referred to the Bajocian on the basis of the occurrence of ammonites such as *Stephanoceras* sp. and *Normannites* (*Itinsaites*) cf. *itinsae* (SATO, 1972).

The Oginohama Formation, about 1,400 thick, is conformable to the underlying Samuraihama Shale Member, and is divided into the following four members. The Kitsunesaki Sandstone and Shale Member, 350 m thick, is characterized by sandstone and shale in flysch-like, medium-bedded alternation, intercalated with conglomerate in the eastern part of the area. The Makinohama Sandstone Member, less than 380 m thick, is composed of coarse-grained sandstone and shale in very thick-bedded alternation with subordinate conglomerate. Plant fossils are contained in several shale beds (TAKAHASHI, 1941). A thick conglomerate bed rich in pebbles of granitic rocks crops out at the west of Shirahama. The Kozumi Shale Member, 150 to 200 m thick, consists dominantly of bedded black shale which is probably of neritic deposition. Some ammonoids and bivalves are found. The Fukkiura Shale and Sandstone Member, about 650 m thick, is composed mainly of shale and sandstone in medium-to thin-bedded alternation, exhibiting a flysch appearance.

From the occurrence of some ammonites such as *Perisphinctes* (*P.*) *ozikaensis*, *P.* (*Kranaosphinctes*) cf. *matsushimai*, *Lithacoceras onukii*, *Discosphinctes* sp., *Virgatosphinctes* aff. *communis* and *Aulacosphinctoides* sp. (FUKADA, 1950; SATO, 1962; TAKAHASHI, 1969), the geologic age of this formation is assigned to Late Jurassic (Oxfordian to Kimmeridgian or Early Tithonian age).

The Ayukawa Formation is underlain by the Oginohama Formation with a conformity, and is divisible into four members, the Kiyosaki Sandstone, the Kobitawatashi Sandstone and Shale, the Futawatashi Shale and the Domeki Sandstone Members in ascending order. Pale greenish felsic tuff occurs at several horizons, and the sandstone except for that of the Kiyosaki Member commonly contains volcanic rock fragments.

The middle part of the formation (Kobitawatashi and Futawatashi Members) contains ammonites such as *Thurmanniceras* cf. *isokusensis*, *Kilianella* sp. and *Berriassella* sp. (TAKIZAWA, 1970) and is assigned to Berriasian to Valanginian in age.

The Kiyosaki Sandstone Member, 640 m thick, consists of coarse-grained sandstone and shale in very thick-bedded alternation. Three of the five stratigraphic units composing the member are rich in sandstone, but the others dominated by shale.

The Kobitawatashi Member, 400 m thick, consists of coarse-grained sandstone and black or gray shale in very thick-bedded alternation. Its basal conglomerate contains abundant pebbles of dacitic to rhyolitic rocks, and the sand-

Table 3 Stratigraphical succession of the Jurassic System in the Oshika area.

Geologic Age		Formation, Member			Thickness (m)	Lithology
Cretaceous	Hauterivian		Yama-dori Fm	Basalt Mb	400	Basalt lava and tuff
				Andesitic Volcaniclastics Mb	1,200	Dacitic- Andesitic volcaniclastic -rocks
	Valanginian	Oshika Group	Ayukawa Fm	Domeki Sandstone Mb	600	Pebbly coarse sandstone
				Futawatashi Shale Mb	620	Bedded and laminated shale with sandy intercalations
	Berriasian			Kobitawatashi Ss & Sh Mb	400	Coarse sandstone and shale
Jurassic	Tithonian			Kiyosaki Sandstone Mb	640	Coarse sandstone and shale
	Kimmeridgian		Oginohama Fm	Fukkiura Sh & Ss Mb	650	Sandstone-shale alternation
				Kozumi Shale Mb	150-200	Thick-bedded shale
	Oxfordian			Makinohama Sandstone Mb	380	Coarse sandstone and shale
	Callovian			Kitsunesaki Ss &Sh Mb	350	Sandstone-shale alternation
	Bathonian		Tsukinoura Fm	Samuraihama Shale Mb	500	Massive or thick-bedded shale
	Bajocian			Tsukinoura Sandstone Mb	150-250	Massive sandstone with conglomerate and sandy shale
Trias.		Inai Group			ca 2,000	Sandy shale, slate, sandstone and conglomerate

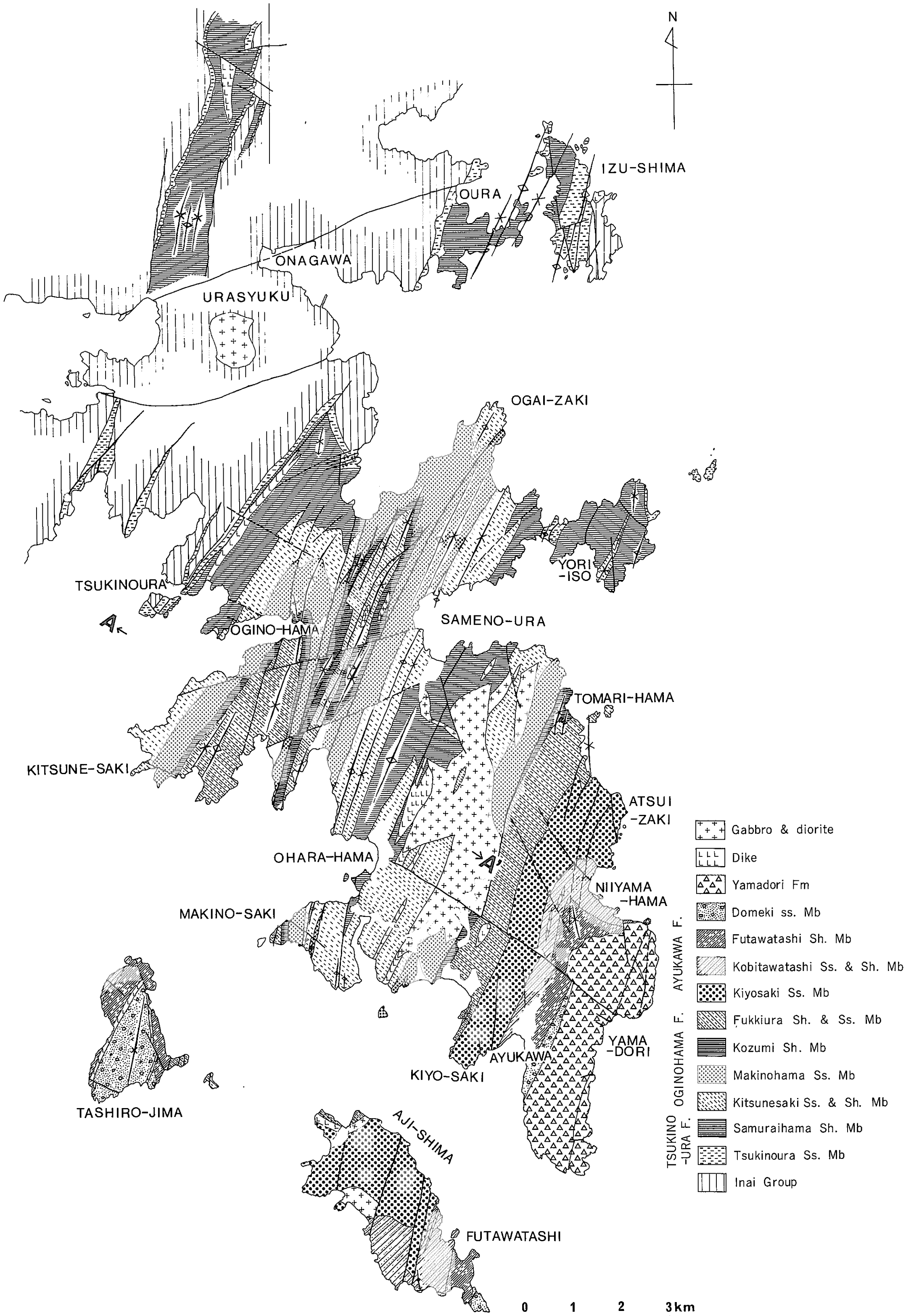


Fig. 6 Geological map of the Jurassic in the Oshika area. Geologic section (A-A′) is given in Fig. 3.

stone contains numerous rock fragments of the same kind. Cross-bedding is commonly developed in the sandstone. Neritic bivalves of the same kinds as those of the Isokusa Formation of the Karakuwa area occur in the shale beds (TAKIZAWA, 1970).

The Futawatashi Member, 620 m thick, consists chiefly of muddy flysch-like sediments which are represented by black, thin- to medium-bedded or laminated shale frequently interbedded with sandstone. The member is characterized by the frequent occurrence of disturbed beds as represented by slump overfolds and slump balls. Thin layers of fine-grained sandstone display various kinds of sole marks, cross-lamination and current ripples.

The uppermost Domeki Member consists mostly of very coarse-grained, feldspathic sandstone with subordinate conglomerate prevailing of felsic volcanic pebbles. Cross-bedding is common. Molluscan fossils are barren in this member. The member is mostly of non-marine origin.

2–3 Soma Area

The Middle Jurassic to Lowermost Cretaceous Soma Group crops out in a narrow zone along the eastern margin of the Abukuma Mountains forming a north-south trending anticlinorium. The Group is divided into seven formations as shown in Table 4 and Figure 7. Of these formations the lower three are distributed in the northern part and are disconformable with each other. The upper four formations are distributed more extensively in the central and southern parts. They form an anticlinorium of a nearly north-south trend with many strike-faults. The total thickness of the group is more than 1600 m. The thickness of each formation is given in Table 4.

The lowermost Kitazawa Formation consists mainly of coarse- to medium-grained arkosic sandstone and is similar in lithology to the probably pre-Jurassic Karosan Formation in the northern part of the mapped area. Its lower limit and thickness are unknown because of the fault, and exact age can not be determined because of no fossil evidence.

The Awazu Formation disconformably overlies the Kitazawa Formation to the west of Awazu and the Karosan Formation at the northern margin of its outcrop area (the upstream of the Shiiki-Gawa). Its basal conglomerate contains pebbles of adamellitic granite. This Formation, 160 m thick, consists mainly of black

Table 4 Stratigraphical succession of the Jurassic System in the Soma area.

Geologic Age		Formation		Thickness (m)	Lithology
Cret.	Berriasian	Soma Group	Koyamada Fm	160	Shale with sandy intercala-tions and dacitic tuff
Jurassic	Tithonian		Tomizawa Fm	400	Coarse sandstone and shale
	Kimmeridgian		Nakanosawa Fm	140	Coarse sandstone, limestone with sandy shale
	Oxfordian		Tochikubo Fm	Ca.350	Coarse to fine sandstone and shale
	Callovian		Yamagami Fm	Ca.200	Massive medium sandstone with shale
	Bathonian Bajocian		Awazu Fm	160	Shale or sandy shale, fine sandstone and conglomerate
			Kitazawa Fm	?	Coarse to medium sandstone
?			Karosan Fm Wariyama Fm	?	Coarse to medium sandstone with shale Pelitic schist with psamitic schist

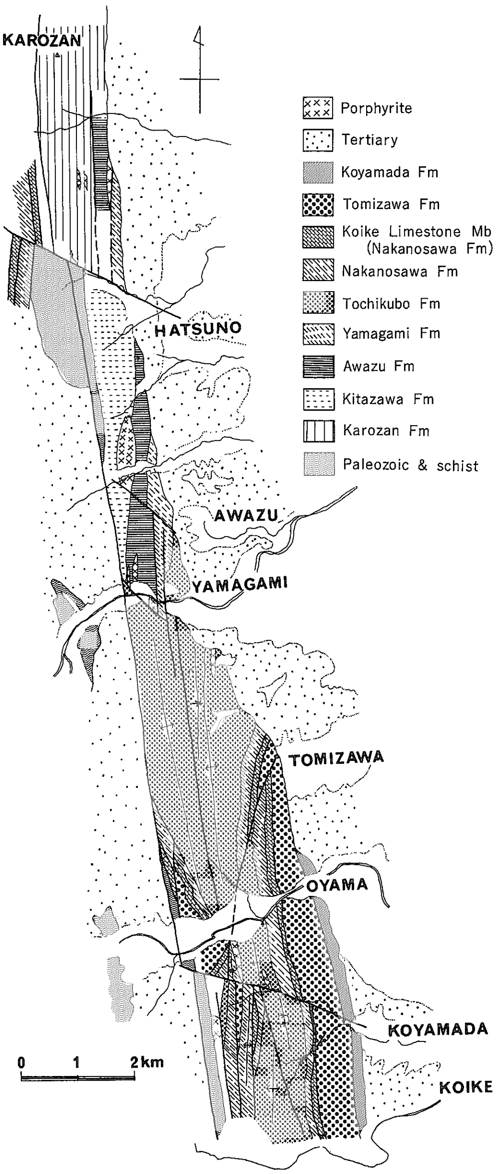


Fig. 7 Geological map of the Jurassic in the Soma area.

shale, which is similar in lithology of the Tsukinoura Formation of the Oshika area, but is thinner and the shales are more sandy than the Tsukinoura Formation. It yields bivalves such as *Chlamys awazuensis*, *Latitrigonia pyramidalis*, *Vaugonia awazuensis* (MASATANI and TAMURA, 1959) and *Bigotites* sp. (SATO, 1962). From these fossils, the formation is assigned to Late Bajocian or Early Bathonian in age.

The Yamagami Formation, about 200 m thick, consists mainly of massive medium-grained sandstone, accompanied by alternating sandstone and shale in the southern part of the outcrop area. Marine molluscan fossils occur rarely.

The Tochikubo Formation consists of arkosic sandstone and shale with coal seams. This formation yields abundant plant fossils, but lacks marine fossils, probably because of non-marine origin. The formation is similar in lithofacies to the Makinosaki Sandstone Member of the Oshika Group, but devoid of thick conglomerate beds.

The Nakanosawa Formation consists mainly of arkosic or calcareous sandstone accompanied by impure limestone in its upper part (Koike Limestone Member). The formation is characterized by the abundant occurrence of marine molluscan fossils (SATO, 1962; TAMURA, 1959, 1961). In addition, the Koike Limestone contains abundant fossils such as stromatoporoids and corals which are common to the Torinosu Fauna (MORI, 1963). This formation was considered to range in age from Oxfordian to Kimmeridgian by MORI (1963), but the Koike Limestone Member should be assigned to Early Tithonian in age because of the occurrence of *Aulacosphinctoides* cf. *steigeri* (SATO, 1967).

Tomizawa Formation is composed of arkosic sandstone and shale in very thick-bedded alternation, and is very similar to the Tochikubo Formation in lithology. The Formation which lacks marine fossils is considered to be mostly non-marine deposits.

The Koyamada Formation, the uppermost of the Group, is dominated by black shale with dacitic tuff interbeds. This formation is mostly assigned to Berriasian in age because it yields *Parakilianella umazawensis* and *Thurmanniceras* sp. (SATO, 1962).

3. Western Subbelt

In the Western Subbelt, Jurassic formations are distributed in four separated areas. The areas are the Chonomori, Shizugawa, Hashiura and Mizunuma areas, from north to south. The

Shizugawa and Mizunuma areas, among others, serve as the main sources of the stratigraphic descriptions of the present subbelt (Figs. 8 and 9). The Jurassic sequence in the Western Subbelt consists of two groups, the Lower Jurassic Shizugawa Group and the Middle to Upper Jurassic Hashiura Group. Besides these, probable lowest Cretaceous Jusanhama Group is distributed only in the Hashiura area.

The successions of the two major divisions of the Jurassic sequence are essentially the same throughout the Shizugawa and Mizunuma areas as shown in Tables 5 and 6. Therefore, the successions will be described together. The thickness of each formation is given in Tables 5 and 6.

Shizugawa Group This group overlies the Upper Triassic Saragai Group and the Uchinohara Formation, and the Middle Triassic Isatomae Formation with an unconformity, and is subdivided into the Niranohama Formation below and the Hosoura (Mizu-

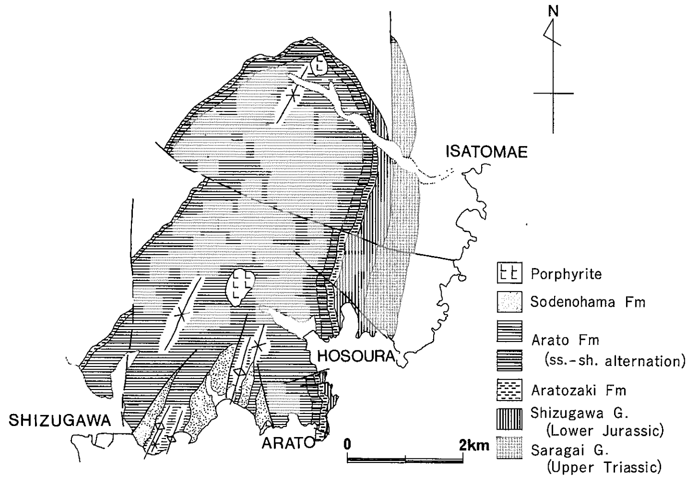


Fig. 8 Geological map of the Jurassic in the Shizugawa area.

Table 5 Stratigraphical succession of the Jurassic System in the Shizugawa area.

Geologic Age				Formation	Thickness (m)	Lithology
Jurassic	Upper	Tithonian	Hashiura G.	Sodenohama Fm	ca 200	Fine sandstone with sandy intercalations.
		Kimmeri-dgian (Bath. – Oxf.) Bajocian		Arato Fm	470	Thick-bedded shale and shale-sandstone alternation
				Aratozaki Fm	55	Coarse sandstone and conglom-erate
	Lower	Aalenian Toarcian	Shizugawa G.	Hosoura Fm	135	Bedded (sandy) shale
		Sinemurian Hettangian		Niranohama Fm	60	Fine sandstone and sandy shale
Triassic				Saragai Group	ca 500	Coarse to medium sandstone and sandy shale
				Inai Group	ca 1,500	Sandy shale, slate, sandstone and conglomerate

numa) Formation above. Its detailed succession and fossils were reported by HAYAMI (1959d, 1961a).

The Niranohama Formation consists of fine-grained sandstone and sandy shale which are frequently interbedded and interlaminated with each other in the main part. Moreover, massive medium- to fine-grained sandstone occurs in the lower and upper parts. A thin conglomerate bed is found in the basal part of the formation in the Mizunuma area. The formation contains very abundant bivalves such as *Burmesia japonica*, *Eomiodon vulgaris* and *Geratrigonia hosourensis*, and in its upper part, a Hettangian ammonoid, *Yebisites onoderai* and abundant bivalves such as *Vaugonia* and *Meleagrinella* occur. In the Mizunuma area, there are more than ten shell-beds, several tens of centimeters to 1 m in thickness.

The Hosoura(Mizunuma) Formation is composed mainly of black-bedded shale (or sandy shale) including calcareous nodules. The shale is finer grained than that of the Niranohama. In the Shizugawa area the formation yields abundant ammonoids indicating Sinemurian-Aalenian age, such as *Arnioceras yokoyamai*, *Hosoureites ikianus*, *Planammatoceras kitakamiense* and *Tmetoceras recticostatum* (SATO, 1958). In addition, some bivalves such as *Variamussium*, *Vaugonia* and *Inoceramus* are contained (HAYAMI, 1961a). The Mizunuma Formation is equivalent to the Hosoura Formation, but it does not contain ammonites in spite of the occurrence of brackish bivalves such as *Bakevellia*, *Isognomon* and *Eomiodon* (HAYAMI, 1959b).

Hashiura Group This group rests disconformably on the Shizugawa Group, and is subdivided into the Aratozaki(Ojima), Arato (Owada) and Sodenohama Formations in ascending order. The Sodenohama Formation is distributed only in the Shizugawa area. Along the western wing of the syncline this group rests immediately on the Triassic Inai Group.

The Aratozaki(Ojima) Formation consists of massive arkosic coarse-grained sandstone. In the Shizugawa area, it is accompanied by con-

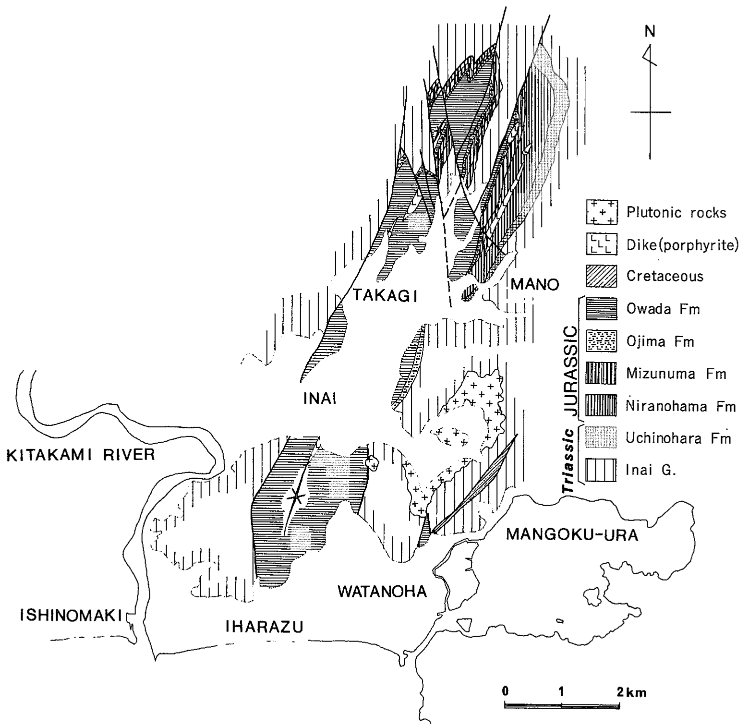


Fig. 9 Geological map of the Jurassic in the Mizunuma area.

Table 6 Stratigraphical succession of the Jurassic System in the Mizunuma area.

Geologic Age			Formation		Thickness (m)	Lithology
Jurassic	Upper	Kimmeridgian? Oxfordian	Hashiura G.	Owada Fm	420	Massive or thick-bedded shale
		Callovian Bajocian		Ojima Fm	20	Massive coarse sandstone
	Lower	(Aalenian) Toarcian	Shizugawa G.	Mizunuma Fm	65	Massive shale, occasional sandy
		(Sinemurian) Hettangian		Niranohama Fm	140–200	Coarse to medium sandstone (Upper part) Fine sandstone and sandy shale (Lower part)
Triassic				Uchinohara Fm	250	Massive medium sandstone
				Inai Group	Ca.2,000	Sandy shale, slate, sandstone and conglomerate

glomerate in parts and by fine-grained sandstone in the lowermost part. It contains abundant bivalves represented by *Trigonia sumiyagura* and other trigoniids. Also, *Cucullaea*, *Modiolus*, *Oxytoma*, *Inoceramus*, *Camptonectes*, *Entolium* etc. were obtained from the lowermost part and *Kobayashites*, *Isognomon*, *Eomiodon* and *Protocardia* from the uppermost part by HAYAMI (1958).

The Arato Formation is composed of sandstone-shale alternation, laminated shale and bedded shale from the base upward. The Owada Formation consists mainly of bedded shale. The sandstone-shale alternation is of flysch type showing distinct graded bedding and lamination. The laminated shale is rich in trace fossils in the Shizugawa area. The Arato and Owada Formations and their equivalents yield Bajocian ammonoids such as *Leptosphinctes* cf. *martiusi*, *Stephanoceras hashiurense* and *Cadomites bandoi*, Callovian *Kepplerites*(*Seymourites*) sp. and Oxfordian *Perisphinctes* (*Kranaosphinctes*) *matsushimai* (KOBAYASHI, 1947; SATO, 1958, 1962; TAKAHASHI, 1969). Furthermore, Kimmeridigian ammonoids such as *Idoceras* (?) sp. are known to occur in the Arato Formation, in addition to Tithonian or earliest Cretaceous ammonoids such as *Berriasella* sp. and *Olcostephanus* (?) sp. in the Hashiura area (KASE, 1979).

The Sodenohama Formation possibly rests disconformably on the Hashiura Group and consists dominantly of fine-grained sandstone intercalated with shale. Its detailed stratigraphic succession and upper limit are not known because of the complicated fold and fault structure and the scarcity of guide fossils. It yields *Aulacosphinctoides* of the Lower Tithonian.

Jusanhama Group This Group is probably referred to the Lower Cretaceous and is distributed only in the Hashiura area. It is subdivided into three formations each of which consists mainly of arkosic coarse- to medium-grained sandstone and carbonaceous shale. The Group covers unconformably the underlying Nakahara Formation which is nearly equivalent to the Arato Formation. In this group a diagnostic bivalve fanule represented by *Filosina jusanhamensis* (corbiculid), *Crenotrapezium kitakamiense*, *Protocardia morii* etc. are found (HAYAMI, 1960).

4. Stratigraphic Comparison Among the Jurassic Formations

The Lower Jurassic formations are distributed only in the Western Subbelt. On the other hand, the Middle to Upper Jurassic units ex-

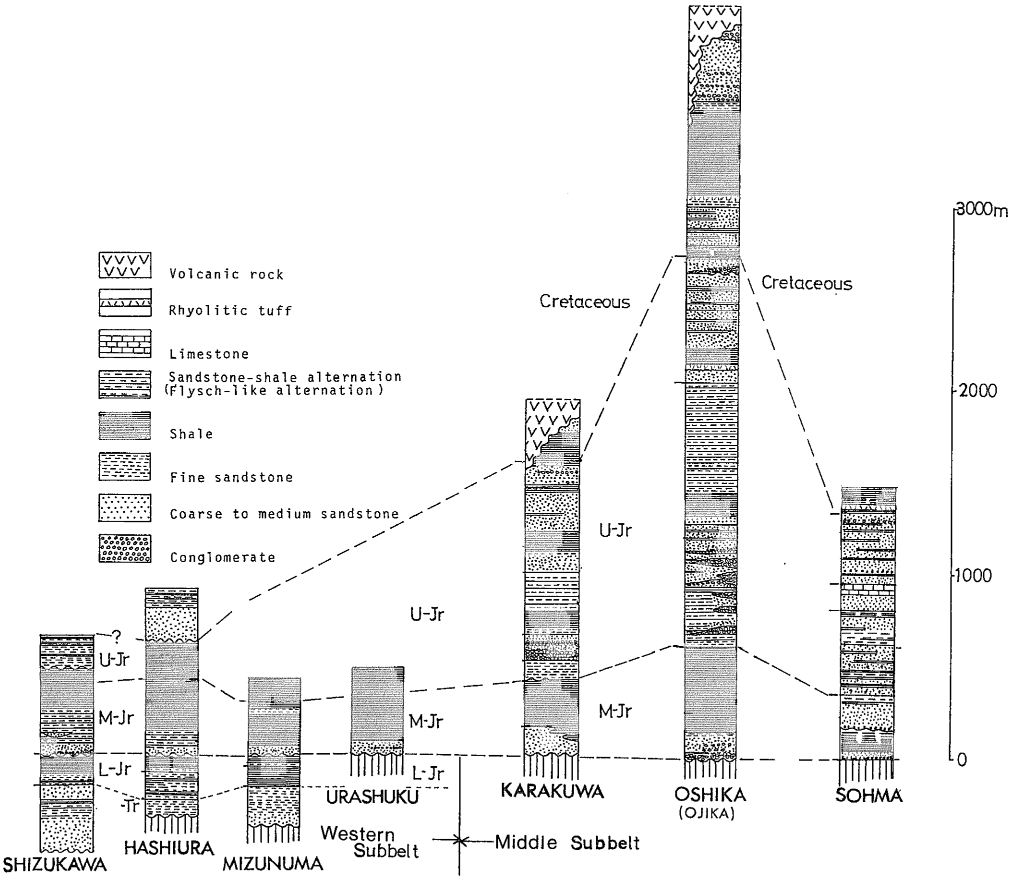


Fig. 10 Comparison of the Jurassic strata in the South Kitakami Belt.

tend over both the Western and the Middle Subbelts, and further south into the Soma area. The lithological comparison of these strata is shown in Figure 10. From the mode of development of the Jurassic formations between the subbelts, it can be recognized that the two subbelts were well differentiated during the Jurassic.

The Jurassic formations of the Western Subbelt, viz., the Shizugawa, Hashiura and Mizunuma areas, show more or less similar vertical changes of lithofacies and biofacies. They have two transgressive megacycles which are represented by the Shizugawa and the Hashiura Groups respectively. The Lower Jurassic megacycle is about two hundreds meters thick and the Middle to Upper Jurassic one exclusive of the Sodenohama Formation roughly four hundreds meters. The stratigraphic correlation of this subbelt is summarized in Table 7.

As suggested from the geological maps of the Shizugawa and Mizunuma areas (Figs. 8 and 9), the Hashiura Group is far more broadly distributed than the Shizugawa Group, markedly overlapping the latter toward the west. Thus, it is noted that the Middle Jurassic transgression was comparatively extensive.

On the other hand, the Jurassic formations of the Middle Subbelt including the Karakuwa and Oshika areas differ in lithofacies and successions from those of the Western Subbelt. Such is the case particularly with the Upper Jurassic formations. The Jurassic sequence of these areas, in addition, is several times as thick as

Table 7 Stratigraphic correlation of the Jurassic System in the Middle Subbelt.

Age		KARAKUWA	OSHIKA	SOMA	Selected ammonoid species
Cretaceous	Barremian	Oshima Fm			*Crioceratites ishiwarai*
	Hauterivian	Kanaigaura Fm	Yamadori Fm: Basalt Mb; Andesitic Volcaniclastics Mb		
	Valanginian	Karakuwa Group: Isokusa Fm	Oshika Group: Ayukawa Fm: Domeki Sandstone Mb		*Olcostephanus* sp. *Kilianella* sp.
		Isokusa Fm	Futawatashi Shale Mb		*Thurmanniceras isokusense*
	Berriasian	Isokusa Fm	Kobitawatashi Ss & Sh Mb	Soma Group: Koyamada Fm	*Protacanthodiscus akiyamai* *Berriasella* sp.
Jurassic	Tithonian	Kogoshio Fm	Kiyosaki Sandstone Mb	Tomizawa Fm	*Substeueroceras* sp. *Aulacosphinctoides* cf. *steigeri*
	Kimmeridgian	Mone Fm	Oginohama Fm: Fukkiura Sh & Ss Mb; Kozumi Shale Mb	Nakanosawa Fm	*Aspidoceras* sp. *Discosphinctes* cf. *kiritaniensis* *Lithacoceras onukii* *Perisphinctes ozikaensis*
	Oxfordian	Ishiwaritoga Fm	Makinohama Sandstone Mb	Tochikubo Fm	*Kranaosphinctes* cf. *matsushimai*
	Callovian	Sakaguchiirizawa Ss Mb	Kitsunesaki Ss & Sh Mb	Yamagami Fm	*Bullatimorphites* sp. *Choffatia*(?) *oginohamaensis*
	Bathonian	Tsunakizaka Fm	Tsukinoura Fm: Samuraihama Shale Mb	Awazu Fm	*Bigotites* sp. *Normanites(Itinsaites)* sp. *Pelekodites spatians*
	Bajocian	Kosaba Fm	Tsukinoura Sandstone Mb	Kitazawa Fm ?	*Otoites* spp. *Stephanoceras* cf. *plicatissimum*
Triassic		Inai Group	Inai Group	Karosan Fm (?)	

Table 8 Stratigraphic correlation of the Jurassic System in the Western Subbelt.

Age		Area	SHIZUGAWA		HASHIURA		MIZUNUMA		Selected ammonoid species
Early Cretaceous					Jusanhama G.	Tsukihama Fm			Filosina jusanhamensis
					Jusanhama G.	Tategami Fm			
					Jusanhama G. ?	Yoshihama Fm			
Jurassic	Late	Tithonian	Hashiura G.	Sodenohama Fm	Hashiura G.	Nagao Fm			*Aulacosphinctoides* sp.
		Kimmeridgian	Hashiura G.	Arato Fm	Hashiura G.	Nagao Fm			*Taramelliceras* sp.
		Oxfordian	Hashiura G.	Arato Fm	Hashiura G.	Nagao Fm	Hashiura Fm	Owada Fm	*Kranaosphinctes* cf. *matsushimai*
	Middle	Callovian	Hashiura G.	Arato Fm	Hashiura G.	Nagao Fm	Hashiura Fm	Owada Fm	*Hecticoceras* sp. *Kepplerites* sp.
		Bathonian	Hashiura G.	Arato Fm	Hashiura G.	Nagao Fm	Hashiura Fm	Owada Fm	
		Bajocian	Hashiura G.	Aratozaki Fm	Hashiura G.	Nakahara Fm	Hashiura Fm	Ojima Fm	*Garantiana* sp., *Parkinsonia* sp. *Cadomites* sp., *Leptosphinctes* sp. *Stephanoceras* sp.
	Early	Aalenian	Sizugawa G.	Hosoura Fm	Sizugawa G.	Hosoura Fm	Shizugawa G.	Mizunuma Fm	*Trigonia sumiyagurai* *Planammatoceras kitakamiense* *Hammatoceras kitakamiense*
		Toarcian	Sizugawa G.	Hosoura Fm	Sizugawa G.	Hosoura Fm	Shizugawa G.	Mizunuma Fm	*Hosoureites ikianus*, *Harpoceras* sp.
		Sinemurian	Sizugawa G.	Hosoura Fm	Sizugawa G.	Hosoura Fm	Shizugawa G.	Mizunuma Fm	*Arnioceras yokoyamai*
		Hettangian	Sizugawa G.	Niranohama Fm	Sizugawa G.	Niranohama Fm	Shizugawa G.	Niranohama Fm ?	*Yebisites onoderai* *Burmesia japonica*
Triassic	Late			Saragai Group		Uchinohara Fm		Uchinohara Fm	
	Middle			Inai Group		Inai Group		Inai Group	
	Early								

the corresponding strata of the Western Sub-belt. Special emphasis must be made on the fact that the Jurassic strata of the Karakuwa and Oshika areas bear resemblance to the Soma Group of the Abukuma region in the lithofacies and biofacies in addition to the mode of their vertical changes, as HAYAMI (1961c) and MORI (1963) have also strongly pointed out.

The sequence of arkosic sandstone and black shale in the Middle Jurassic of the Karakuwa and Oshika areas, viz., the Kosaba, Tsunakizaka and Tsukinoura Formations is well compared with that of the Awazu Formation in the Soma area. The Ishiwaritoge Formation of the Karakuwa Group and the Makinohama Member of the Oshika Group are likewise compared with the Yamagami and Tochikubo Formations of the Soma area. These strata of probably Oxfordian age are characterized by pebbly arkosic sandstone containing plant beds. The occurrence of *Perisphinctes* and *Myophorella* is common in the Mone, Oginohama and Nakanosawa Formations. The arkosic very coarse sandstone of the Tomizawa Formation are very thickly bedded and its weathered color is characteristically whity. It is quite comparable to the sandstone of the Kogoshio Formation and the lower part of the Ayukawa Formation. The uppermost Koyamada Formation, moreover, can be correlated with the Isokusa Formation and the middle part of the Ayukawa Formation based on the lithological and faunal resemblance. The respective lowermost parts of the Kogoshio and Ayukawa Formations have intraformational conglomerate composed of limestone pebbles. And they can be roughly correlated with the Koike limestone of the Nakanosawa Formation in the Soma area.

Thus, judging from the similarity of the lithology and fossil content, it will be said that the Middle to Upper Jurassic series of the Soma area is quite identical with that of the Karakuwa and Oshika areas in the Middle Sub-belt, and consequently the Jurassic correlation of these three areas can be summarized in Table 8. It is considered that the three areas were originally included in one and the same sedimentary trough. The Soma area, therefore, will be treated in the capacity of the Middle Sub-belt of the South Kitakami Belt.

III. FACIES

Most of the Jurassic formations are composed of clastic sedimentary rocks with a small quantity of tuff and limestone. Lithologically, these rocks fall into five facies groups: sandstones, shales, sandstone-shale rhythmic alternations, conglomerates and calcareous rocks in order of abundance.

The framework of classification of facies to be presented in this chapter is based mainly on the features of these lithologies in addition to the sedimentary structures (containing stratification style) and fossils. Besides, petrological and geochemical properties are available for the recognition of facies, as the case may be.

The classification of stratification according to thickness is given in Table 9.

1. Sandstone Facies

Sandstone, together with shale is the main

Table 9 Thickness classes of stratification in this study.

1. Bedding

Type of bedding	*Thickness in cm*
Massive-beded(non-repeated)	> 300
Very thick-bedded	> 300
Thick-bedded	100 — 300
Medium-bedded	30 — 100
Medium thin-bedded	10 — 30
Thin-bedded	3 — 10
Very thin-bedded	1 — 3
Laminated	< 1

2. Horizotal stratification

Horizontal-bedded	> 1
Parallel-lamination	< 1

3. Cross-stratification

Cross-lamination	< 4
Cross-bedding	> 4
Small-scale	4 — 10
Medium-scale	10 — 30
Large-scale	> 30

constituent rock of the Jurassic strata of the South Kitakami Belt. As the result of the field and microscopic observations, five sandstone-dominated facies are recognized as mentioned below (Facies a, b, c, d and e). Facies c, d and e are accompanied by only a small amount of shale in comparison with the others. The classificatory scheme proposed by OKADA (1971a) is used basically for the sandstone classification in this study. Commonly used term "arkose series" of sandstone is applicable in some cases, according to PETTIJOHN's scheme (PETTIJOHN, 1975).

The grain size as well as the matrix content of the sandstone is quite variable. It is noted that poorly cemented coarse- to very coarse-grained sandstone which is partly disseminated with granules occurs commonly in the Upper Jurassic and Lower Cretaceous strata of the Middle Subbelt. This sandstone belongs mostly to arenite whose clay matrix is usually less than 10 percent. As the sandstone contains more than 25 percent of feldspar in general, it belongs to typical arkose or feldspathic arenite. But a small amount of quartzose sandstone and quartz arenite exist in part. On the other hand, medium- to fine-grained sandstone which is rich in matrix (more than 15 percent), that is, feldspathic wacke, is also commonly found in the rhythmically alternating beds of the Upper Jurassic.

The differences of sandstone-types mentioned above, especially in round volume of matrix, will give an important significance to examine the sedimentation of these strata.

Facies a: Massive Coarse-grained Sandstone (containing marine fossils)

The massive coarse-grained sandstone appears to be structureless, but it often shows cross-bedding (Pl. III-2) and parallel lamination. This type of sandstone is poor in muddy matrix to be referred to arenite and is occasionally calcareous. Trigoniids, as a representative of the bivalve fauna, occur in the sandstone.

Based upon the above-mentioned features, sandstone of this facies indicates that the sediments were transported by traction currents under a shallow sea environment.

This facies occurs in the Kosaba, Tsukinoura, Awazu and Nakanosawa Formations of the Middle Subbelt, and also in the Aratozaki and Ojima Formations in the Western Subbelt.

Facies b: Massive or Thick-bedded Medium- to Fine-grained Sandstone (Arenite)

This facies is similar in stratification and sedimentary structure to the massive coarse-grained sandstone noted above except for the grain size. It should be noted that the well-sorted feldspathic arenite is very common in this sandstone facies but does not show graded bedding in spite of occasional alternating with bedded sandy shales (Facies g). This facies is subdivided into two types, namely Subfacies b_1 and b_2.

Subfacies b_1 shows the same sedimentary features as Facies a except for the grain size of sandstone and also yields marine bivalve fossils. Thus Subfacies b_1 sandstone is clearly of shallow marine origin. The transitional phase from Facies a is recognized commonly in Facies b_1. This subfacies is found in the same formations as Facies a in addition to the Kogoshio, Oginohama (Kozumi M.) and Sodenohama Formations.

On the other hand, **Subfacies b_2** does not contain marine molluscan fossils and it is difficult to clarify environmental conditions clearly. The exposures of the subfacies are found in the Yamagami and Tochikubo Formations in the Soma area.

Facies c: Very Thick-bedded Coarse-grained Sandstone Intercalated with Shale (containing plant fossil beds)

This facies consists of very thick-bedded alternating coarse-grained sandstone and shale. Each bed measures from 5 to 30 m in unit-thickness as shown in Figure 11. The sandstone shows conspicuous cross-stratification (Fig. 12; Pl. I and II). It also contains exotic pebbles and/or intraformational shale clasts which measure a few tens of centimeters in diameter (Fig. 17). The compactly aggregated shale

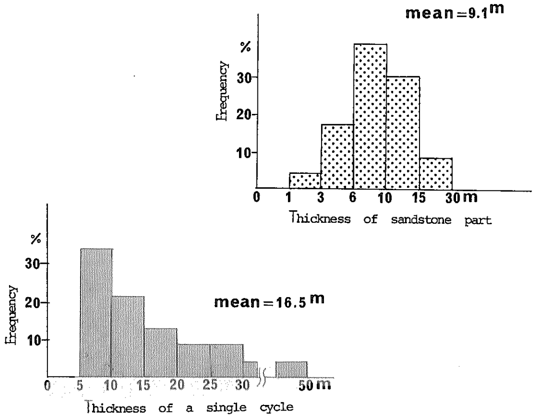


Fig. 11 Thickness distribution of fining-upward cycles in the Makinohama Sandstone Member of the Oshika Group. These cycles are represented by Facies c_1.

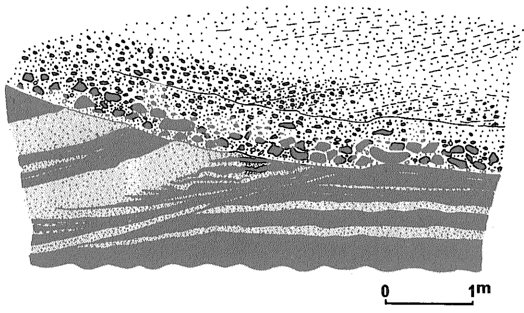


Fig. 12 Epsilon cross-stratifications (lower half of the figure) and intraformational shale clast conglomerates (upper half) in the Makinohama Sandstone Memaber of the Oshika area. Dotted area, sandstone; black area, shale.

clasts are occasionally recognized as intraformational conglomerate beds. Shale is generally gray to dark gray and partly black, and yields plant fossils, thus being very similar to that of Facies h. Furthermore, the shale of Facies c contains occasional intercalations of carbonaceous or coaly shale.

Based on the mode of vertical grading within a single unit bed of sandstone, Facies c is subdivided into two subfacies as follows.

Subfacies c_1: This subfacies is characterized by that the sandstone bed becomes upward finer grained and finally grades up into the shale bed. The bottom surface of sandstone bed shows contemporaneous erosional structures and its basal part consists of intraformational conglomerate less than 1 m thick. The cross-stratification within a sandstone bed tends to decrease upward in scale from large-scale cross-bedding through small-scale cross-bedding to ripple-drift cross-lamination.

The carbonaceous shale interbeds yield many plant fossils. There are occasionally thin intercalations of fine- to medium-grained sandstone in the shale of Subfacies c_1. The sandy intercalations show well-developed lamination of various kinds such as parallel and wavy laminations and ripple-drift cross-lamination.

Subfacies c_2: This subfacies is characterized by alternation of sandstone and shale, in which sandstone below pass abruptly into shale above. Large-scale cross-bedding is often found, but small-scale cross-bedding or cross-lamination is uncommon. The shale is similar to that of Subfacies c_1, but laminations and thin sandy intercations are worse developed therein.

Of these two subfacies (c_1 and c_2), Facies c_1 is probably attributable to meandering river deposition (TAKIZAWA, 1975, 1976). A part of Facies c_2 was considered by the writer (op. cit.) to have accumulated in a sandy belt along the coastal line, but is now regarded as including also deposits under distributary and interdistributary environments as will be discussed later.

The sandstone of the above two subfacies is very common in the Ishiwaritoge (in the southern part of its outcrop area), Kogoshio, Oginohama (Makinohama Sandstone), Ayukawa (Kiyosaki Sandstone), Tochikubo and Tomizawa Formations of the Upper Jurassic.

Facies d: Bedded and Laminated Fine- to Medium-grained Sandstone Interbedded with Shale (containing plant beds)

The sandstone bed generally has conspicuous stratification represented by association of smaller-scale cross-bedding and cross-lamination (Pl. II-1B) either of which is well developed according to grain size. The sandstone is mainly referred to arenite. This facies appears to have no features of flysch-type sequence in spite of the sandstone being frequently intercalated with shale. There are many cases of fining- or thinning-upward and some of reverse cases (Pl. II-1A). This facies has in part coaly shale and plant fossil beds.

Facies d is considered to be mixed load (traction and suspension) deposited under a non-marine environment based on its close association with Facies c which has no marine indication.

The Tochikubo Formation and the Sakaguchiirizawa Sandstone Member include a large amount of this facies.

Facies e: Thick- to Medium-bedded Medium-grained Sandstone (wacke)

This facies consists of relatively thick sandstone beds associated with Facies j represented by flysch-type alternation. The sandstone bed is usually 30 to 300 cm thick (Pl. IV-3) and occasionally attains several meters thick. Composite bedding (Fig. 13) is very common. Sandstone of this facies consits mostly of wacke, of which matrix makes up 13 to 20 percent of the total volume of the sandstone. The sandstone is commonly massive and structureless, but shows appreciable parallel lamination and poorly graded bedding. Dish structure (Pl. V-3) is characteristically observed only in sandstone beds of this facies (more than 15 percent of total sandstone

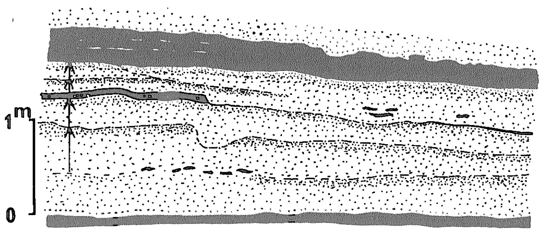


Fig. 13 Composite sandstone beds of the Kitsunesaki Sandstone and Shale Member, Oshika. Graded bedding is well developed in the uppermost part of each bed. Each arrow indicates a single graded unit.

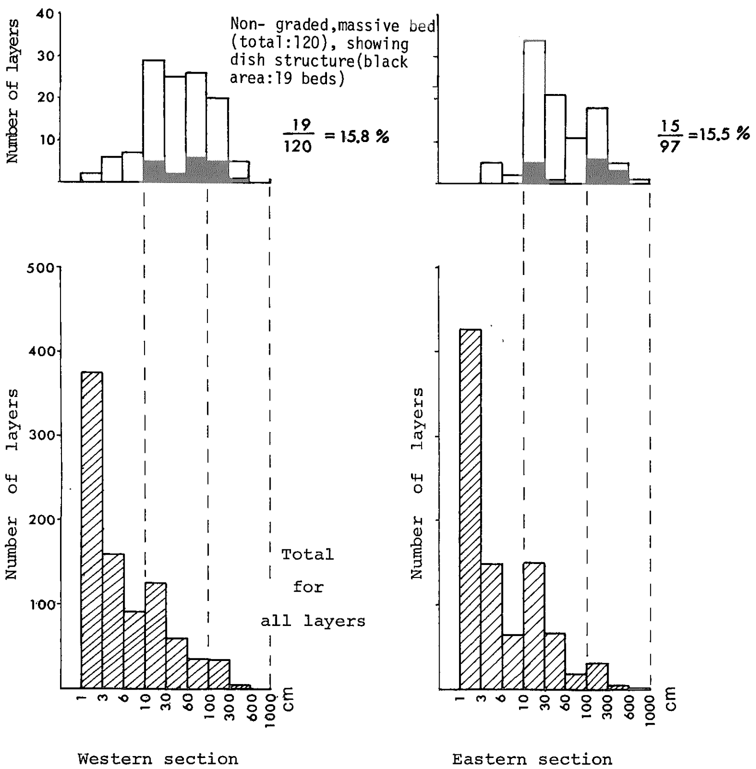


Fig. 14 Thickness distribution of Facies e (white area) and dish structure-bearing sandstone (black area) in the Fukkiura Shale and Sandstone Member of the Oginohama Formation of the Oshika Group.

beds: Fig. 14). Channel structure and intraformational shale-clasts conglomerate (Pl. VIII-2) are sometimes observed in the sandstone.

The sandstone of this facies has no evidence of traction current activity and shallow water origin. From this combined with the sedimentary features, Facies e is referable to the fluxoturbidite (DZULYNSKI *et al.*, 1959; STANLEY and UNRUG, 1972). It is suggested that highly concentrated sands accumulated in a condition of rapid transportation and deposition in relatively deep-water. This facies frequently occurs in the upper part of the Mone Formation and the Oginohama Formation (Kitsunesaki and Fukkiura Members).

2. Shale Facies

There are several characteristics relating to stratification, granularity, fossils and color tones in the shales of the Jurassic System. The shale of one type is usually black and contains marine fossils such as bivalves and ammonites, abounding in iron sulfides. The other type of shale is gray to dark gray and sometimes black, its color tone being very variable from horizon to horizon within a shale sequence. In the shale of the latter type no marine fossils occur, but occasionally plant fossils are found. Concerning slaty cleavages, the shale of the former type is often broken into very thin leaves along the slaty cleavages, whereas the latter breaks into blade flakes or irregular and angular granules in many cases. Therefore, the two types of shale are clearly different from each other, and it is considered that the former is of marine origin, while the latter is of non-marine origin. However, difficult problems remain to determine the origin uniquely.

According to KEITH and DEGENS (1959) and ITIHARA and ITIHARA (1971), sulfur content is different between marine shale and non-marine one. The latter authors concluded that the marine clay of the Plio-Pleistocene Osaka Group is distinguished by containing much sulfur and pyrite (FeS_2) from the fresh-water clay. According to DEGENS (1965), about 30 different sulfides are known to be present as authigenic low temperature minerals in sedimentary rocks, and quantitatively most important are the two polymorphs of FeS_2, i.e. pyrite and marcasite. He also points out that marcasite is wide-spread in fresh water, coal, peat and swamp environments which are acid in nature, while pyrite is abundant in marine sediments that provide a neutral or alkaline.

The distinctive marine black shale in the Jurassic of the South Kitakami commonly contains fine-grained pyrite with a little aggregative pyrite (nodule-like), while probable non-marine gray shale rarely. The shale samples from the Jurassic of the South Kitakami treated in this study were analyzed for sulfur and carbon contents. The sulfur was

Table 10 Contents of total sulfur and total carbon (%) in the Jurassic and Cretaceous shales of the Oshika area. Based on the preliminary analyses of 30 samples, most of total carbon is regarded as organic carbon. Numeral in parenthesis shows number of samples.

Formation	Member	Total carbon		Total sulfur	
		Mean	Standard deviation	Mean	Standard deviation
Ayukawa F.	Futawatashi Mb Ft (4)	0.678	0.161	0.232	0.164
	Kobitawatashi Mb Kb (7)	0.604	0.151	0.470	0.322
	Kiyosaki Mb Ky (27)	0.902	1.233	0.058	0.024
Oginohama F.	Fukkiura Mb Fk (9)	0.747	0.200	0.121	0.122
	Kozumi Mb Kz (10)	0.668	0.388	0.193	0.118
	Makinohama Mb Mk (31)	1.267	1.408	0.073	0.031
	Kitsunesaki Mb Kt (10)	1.266	0.597	0.244	0.327
Tsukinoura F.	Samuraihama Mb Sm (6)	0.991	0.194	0.487	0.240
	Tsukinoura Mb Kd	–	–	–	–

Marine type (Kz, Sm, Kb) (23)	0.733	0.265	0.354	0.212
Flysch type (Ft, Fk, Kt) (23)	0.961	0.294	0.194	0.218
Alluvial type (Ky, Mk) (58)	1.097	1.327	0.066	0.028

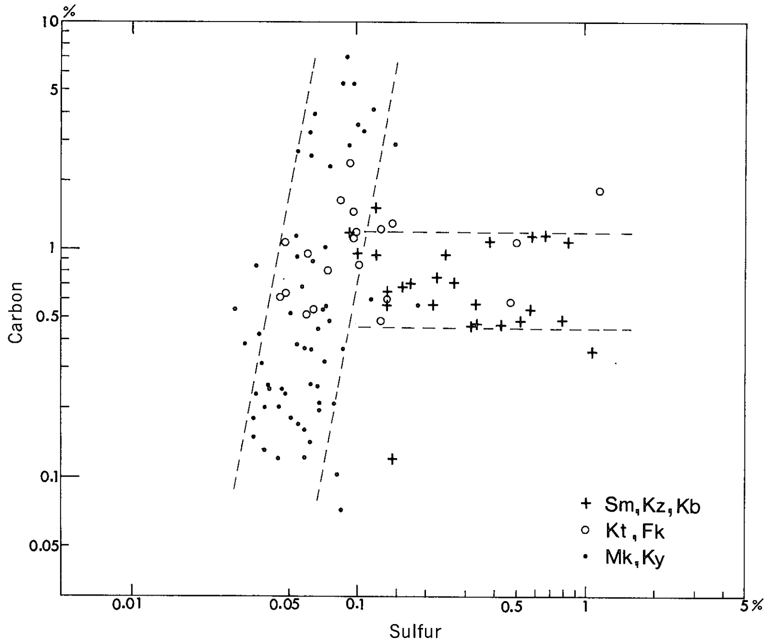


Fig. 15 Relation between total carbon and total sulfur in Jurassic and Cretaceous shales of the Oshika Group. Most of total carbon is regarded as organic carbon. For abbreviations of stratigraphic units as given in Table 10.

analysed by the coulomatic titration analyzer (VK-3B) and the carbon by the CHN coder. The results of the chemical analysis are shown in Table 10 and Figure 15.

The total carbon content of the marine shale greatly differs from that of the non-marine one, particularly in the dispersion of the analyzed values. This supports the writer's classification of the shales into marine and non-marine types based on the field observations.

The shale of marine deposits contains 0.5 to 1.0 percent carbon and this value is confined to a narrow field of variation. On the other hand, the carbon content of the non-marine shale varies widely from 0.1 to 5 percent with more than 10 percent in the coaly shale samples. In accordance with the color tones, the black or dark gray shale has a larger amount of carbon, whereas the gray shale have less than 0.5 percent carbon.

There is also a great difference in sulfur content between the two types of shale. The mollusca-bearing marine shale have more than 0.1 percent of sulfur, while the non-marine shale contains less than 0.1 percent. The average values of the two types of shale differ by a magnitude of about 5.4. This is very close to the magnitude of 6.1 which was estimated by KEITH and DEGENCE (1959) for the shales from the Carboniferous of the Appalachian in the United States.

The results of these analyses show that the discriminations between marine and non-marine shales based on the field observations especially on color tones of shale beds and cleavage flakes is of significant value and is in accordance with the geochemical considerations. Generally, the estimation of marine or non-marine shale from field observation is most valuable in determining depositional environments.

The shales of the Jurassic treated in this study are classified into the following four facies based on the lithological features, fossils and geochemical properties.

Facies f: Bedded black shale (containing marine fossils)

This facies is a typical marine shale facies and consists of monotonous rocks, which yield bivalves and ammonites. Lamination of sandstone or siltstone is generally poor, but there is a development of lamination in very restricted areas. The calcareous nodule in the bedded black shale measures 5 to 10 cm in tangential diameter and up to 80 cm in maximum (Pl. VIII-3). Stratification is generally well visible, but is occasionally obscure, being even imperceptible under the influence of slaty cleavages. This facies generally occurs as fairly thick sequences ranging in thickness from 100 to 650 m.

The absence of any features indicative of current activity combined with the fine-grained nature of the sediments suggests that the facies was deposited largely from suspension in a quiet water environment.

This facies is found in the Tsunakizaka Formation, the lower part of the Mone Formation, the Samuraihama Shale and Kozumi Shale Members of the Ojika Group, the Awazu Formation, the Arato Formation, the Owada Formation and the Hosoura Formation.

Facies g: Massive Sandy Shale (containing marine fossils)

The massive sandy shale is similar to the shale of Facies f, but it differs from the latter in its coarser-grained and poorly sorted silty or very fine sandy nature. The massive sandy shale is generally black or dark gray, structureless and is very poor in laminations and stratifications. The slaty cleavage of this sandy shale is poorly developed in comparison with that of Facies f shale.

Marine bivalves are abundant in this shale and also various kinds of vertical and oblique burrows frequently occur. The inky black shale become reddish brown on their weathering surface, and pyrite grains which are sometimes made of nodule-like aggregative pyrites are commonly contained in this shale facies. Laterally or vertically, the massive sandy shale easily changes to somewhat carbonaceous shale in the Western Subbelt.

It seems unlikely that sediments can be moved as bed load, without ripple formation (SIMONS *et al.*, 1965) though sediments contain some fine or very fine sands. From the absence of current-formed structures, the sediments of Facies g were deposited from suspension, and probably originated from a higher concentration of fine-grained sediment and of more proximal deposition than the sediments of Facies f. Facies g as a whole is regarded as the transitional facies between Facies f and Facies b.

This facies occurs in the same fomations with Facies f.

Facies h: Massive or Bedded Gray, Partly Black Shale (containing plant fossil beds)

This shale facies is similar in grain size to Facies f, but differs from the latter in its color tones and the lack of marine fossils. It is gray to dark gray. Well-preserved plant fossils are found in the bedded or laminated shale. The massive shale is clayey in some places and yields less plant fossils.

The shale of this facies is usually placed above and below either Facies c sandstone, or Facies d sandstone in contact with the two sandstone facies. Occasionally, the facies has sandy or silty intercalations which show ripple-cross-lamination and parallel lamination. As the result of much increasing of the intercalations, the facies grades into Facies d. The sulfur content of this shale is low and pyrite micrograins which are well known to be commonly included in marine shale are also few.

Thus this shale is recognized as being of nonmarine origin. The lack of current structures suggests that the facies was deposited mainly from suspension. The sandy intercalations and fluctuations in grain size probably reflect sediment supplies which were related to flood currents or climatic factors on the land. This facies mostly occurs in the strata adjacent to Facies c sandstone as beds which are less than several tens of meters thick.

Coal seams in this facies are found at the several horizons of the Tochikubo and Tomizawa Formations in the Soma area. Also carbonaceous shale which, here defined, contains organic carbon more than 3 percent and plant fragments, is inserted into the many beds of the above two formations added to the Kogoshio, Oginohama and Ayukawa Formations. Examples of the occurrence of the carbonaceous shale are shown in Figure 28.

Facies i: Laminated Shale

This shale has a great amount of sandy or silty lamina to show a streaky appearance in the field, and includes frequent intercalations more than 1 cm thick as well. Graded bedding is seen in some intercalations, but not in others. The laminated shale is subdivided into the following three subfacies on the basis of sedimentary features such as internal sedimentary structure, thickness of streaks or intercalations and sand-mud ratio. The rapid interbedding of different rock types on a small (cm-dm) scale is frequently observed.

Subfacies i_1: Thinly Laminated Shale

This shale has a great number of sandy or silty intercalations which are generally less than 1 cm in thickness. Intercalations, several millimeters thick, are very commonly observed in this shale. Therefore, this shale shows a very streaky appearance. This streaky bed frequently shows parallel lamination or graded bedding, but cross-lamination is rather poorly developed.

Subfacies i_1 can be subdivided into two varieties on the basis of bedding features as shown in Table 11. One variety, Subfacies i_{1a} is characterized by very thinly and very closely developed silty streaks embedded in shale. It is predominant in parallel-lamination, but does not always show graded bedding. In the other variety, Subfacies i_{1b}, the intercalations are comparatively less close than those of Subfacies i_{1a} and usually display graded bedding. In thickness and grain size the streaks in Subfacies i_{1a} are inferior to the intercalations in Subfacies i_{1b}. It frequently occurs, however, that these two varieties resemble considerably each other and then the discrimination between both

Table 11 Classification and sedimentary features of laminated shales.

FEATURES	Laminated Shales		
	Subfacies i_1, var. a	Subfacies i_1, var. b	Subfacies i_2
Interval of streaks	Very close (a few-10 mm intervals)	Close or wide (1-5 cm intervals)	Wide (5-15 cm intervals)
Thickness of sandy or silty intercalations	Few to 10 mm	Several to 10 mm	10-30 mm
Bedding feature	Well-developed parallel lamination occasionally with very small cross-lamination	Faintly parallel lamination, usually sharp based	Well-developed cross-lamination subordinately with parallel lamination
Graded bedding	Occasionally observed	Commonly observed	non-existent
Grain size of intercalations	Mostly silt, with a small amount of very fine-grained sand	Very fine-grained sand and coarse silt	Fine to very fine-grained sand
Accompanied lithofacies	Fluxoturbidite and turbidite sandstone, laminated shale of Subfacies i_2 type	Sporadic turbidite sandstone	Fluxoturbidite and turbidite sandstone
Ripple marks	non-existent	few or no	abundant
Sole marks	non-existent	few	few or no
Characteristic trace fossils	*Chondrites*	*Cosmorhaphe, Phycosiphon Neonereites*	*Zoophycos*
Interpretation	Suspension currents deduced from storm, flood and tide	Distal turbidity currents	Bottom tractional currents
Example of outcrops	Mone Formation (southern facies) Fukkiura Member Niranohama Formation	Mone Formation (northern facies) Lower part of Arato Formation	Mone Formation (southern facies) Fukkiura and Kitsunesaki Members

varieties is rather difficult in field. Therefore, they did not permit their separate depiction on the columnar sections. Subfacies i_{1a} is considered to be deposits probably deduced from a fluctuated suspension current, whereas Subfacie i_{1b} a distal part of turbidity current. Fluctuations of the former type current may have been caused by storms, tides, or variations in river discharge as mentioned by De RAAF *et al.* (1965), READING (1970) and TAKIZAWA (1975).

Thick beds of the thinly laminated shale are typically found in the lower part of the Arato Formation and the Mone Formation. This subfacies often alternates with Facies j to form sandstone-shale rhythmic alternation (Pl. V-2). Moreover, the subfacies is sometimes inserted in Facies b and in Facies f represented by bedded shale of the Lower Jurassic formations of the Western Subbelt.

Subfacies i_2: Shale Intercalated with Thin Sandstone Layers

This type of shale is characterized by frequent intercalations of thin very fine- to finegraind sandstone in black shale as in the case of Subfacies i_1. These sandy intercalations are usually 1 to 3 cm thick and are thicker than those of Subfacies i_1 (Table 11). They occur rhythmically in the shale and show the appearance of streaky shale (Pl. V-1A). Most of the intercalations show cross-lamination and parallel lamination. The intercalations occur generally at intervals of over 3 cm. Sometimes, there are sporadic intervals of 10 cm. Therefore, the subfacies is similar to Facies j_2 marked by thin-bedded shale-sandstone alternation, but can be distinguished from the latter by the absence of graded bedding.

The subfacies forms a part of the flysch facies association mentioned later. The thickness of a single unit of this subfacies is generally 0.5 to 10 m, rarely up to about 20 m. In a flysch type sequence of the Fukkiura Member at Koamikura in the central part of the Oshika area, this subfacies occupies about 70 percent of the total thickness. This subfacies is regarded as a very conspicuous or unique facies as compared with the flysch type sequences of many other areas in Japan.

The origin of the cross-laminated sandstone layers within the subfacies could either be bottom tractional currents or turbidity currents. It should, however, be noted that the thin sandstone layer sometimes has current ripple marks of lingoid or undulatory type on its top surface (Pl. V-1B), particularly where it has sharp contact with the overlying shale, and that the distribution pattern of the grain-size analysis is different from that of cross-lamination in turbidite as mentioned later.

The subfacies is contained as a supplemental facies of the Mone Formation, the Kitsunesaki Member and the Fukkiura Member.

Subfacies i_3: Sandy Laminite (sandstone interlaminated with shale)

The sandy laminite is laminated rocks consisting of dominant volume of cross- or parallel laminated sandstone or coarse siltstone as against Facies i_1. Generally, this subfacies occurs as an intercalation within Facies c or Facies d (Pl. II-1B). But the Jurassic contains a small quantity of this subfacies. This is largely distributed in the Cretaceous marine strata in the Oshika area and the writer once designated this subfacies as "Sandstone interlaminated with shale" (TAKIZAWA, 1975). This subfacies is distributed rarely in the Lower Jurassic formations of the Western Subbelt.

The sandy laminite should be classified as sandstone in terms of facies, but it is tentatively classified as the shale in this paper, because of being similar to other laminated shale facies in sedimentary features.

3. Sandstone-Shale Alternation Facies

Facies j. Medium- to Thin-bedded Sandstone-Shale Alternation

This facies consists of the flysch-type alternation accompanied by marine beds with a small amount of bivalves and ammonites. It shows graded bedding and a medium- to thin-bedded and rhythmic appearance. Each sandstone layer is marked by a sharp base occasionally with sole marks, and commonly ranges in thickness from 1 to 150 cm (Fig. 16). Based on the ratio of sandstone and shale, the alternation is subdivided into two subfacies as follows.

Subfacies j_1: Sandstone-shale Alternation (sandstone dominant)

Subfacies j_2: Shale-sandstone Alternation (shale dominant)

In the case of thin-bedded alternation, shale is dominant over sandstone (Pl. IV-1), while sandstone is dominant in medium-bedded alternation (Pl. IV-2). The sandstone shows distinct graded bedding and characteristic internal sedimentary structures of the "Bouma sequence" (BOUMA, 1962) as shown in Table 12. The complete five-fold Bouma sequence (T a-e) consists of a lower division (Ta) which is usually graded or massive, overlain by a parallel laminated division (Tb), in turn followed by a ripple cross-lamination division (Tc) which occasionally displays convolute lamination. The topmost two divisions (Td and Te) are seldom separable in outcrop. Not all sandstone beds display the complete sequence, and bottom truncation of the sequence is most common as given in Table 12. A given sandstone bed begins with the lower parallel lamination division or even with the ripple cross-laminated division. Sole marks are occasionally recognized and trace fossils are commonly found in the alternation. Also, this facies alternates with Facies i_1 and i_2 (Pl. V-1, 2). Some of the sandstone beds consist of two to three sedimentation units to show composite bedding. This composite bedding occurs at maximum rate of 10 percent in the sandstone beds of this facies.

The sandstone consists of medium- to fine-grained sand material and belongs to wacke (matrix: 15-35%). The matrix is generally composed of sericite and clay minerals and sometimes is very limy. The sandstone occasionally contains fossil wood fragments about 80 cm in maximum length and defaced molluscan fragments (Pl. VIII-I).

The fact mentioned above indicates that most of the sandstone beds constituting the facies are considered to be turbidite. On the other hand, most of the shale beds are considered to be of the same origin as Facies f, but some others could be formed by turbidity currents.

This facies is developed in the upper part of the Mone Formation, the Kitsunesaki Sandstone and Shale Member, the Fukkiura Shale and Sandstone Member and the lower part of the Arato Formation, but can not be observed in the Mizunuma and Soma areas.

Graded Bedding

Graded bedding is usually recognized in the sandstone beds of Facies j. The sandstone is generally medium-grained and sometimes fine-grained. The lowermost part of graded sand-

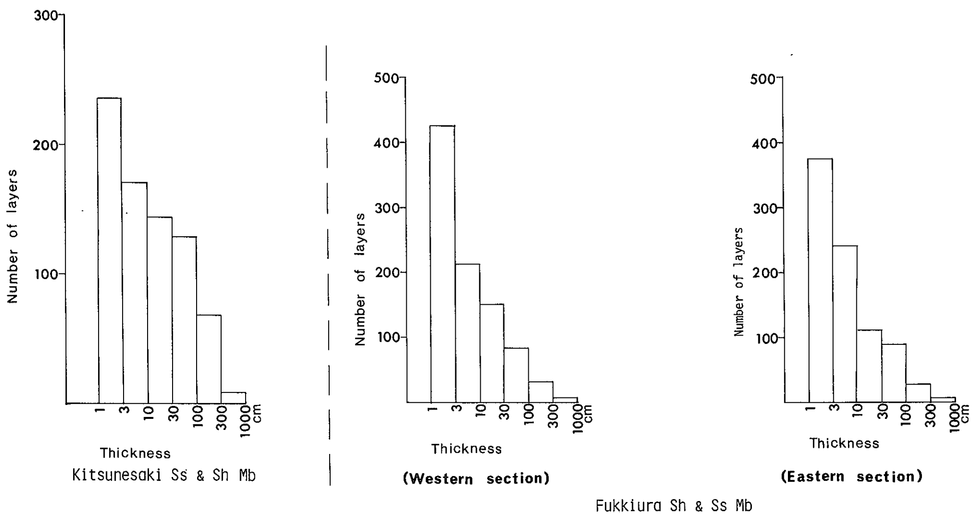


Fig. 16 Thickness distribution of sandstone layers in Facies j, sandstone-shale rhythmic alternation in the Oginohama Formation of the Oshika Group.

Table 12 Relationship between sequence type and layer thickness in the Fukkiura Shale and Sandstone Member of the Oshika area. Numerals in parentheses indicate the number of dish structure bearing beds. Sequence types refer to BOUMA's sequence type; Ta: massive (graded) sandstone division, Tb: lower parallel laminated sandstone division, Tc: cross-laminated sandstone division, Td: upper parallel laminated siltstone division.

Western, Fukkiura Section

Thickness in cm	Number of beds	No grading (massive)	Ta	Tabc, abcd	Tab,abd	Tac,ad	Tbc,bcd	Tb,bd	Tc,cd,d	mud-conglo.
0–1		—	—	—	—	—	—	—	—	
1–3	427	—	4	—	—	—	6	7	410	
3–6	148	5	22	1	14	—	27	24	55	
6–10	65	2	16	4	4	2	21	9	4	3
10–30	150	$34_{(5)}$	29	31	9	7	25	8	3	4
30–60	66	$21_{(1)}$	14	14	13	1	—	1	—	2
60–100	18	11	2	3	2	—	—	—	—	
100–300	31	$18_{(6)}$	7	2	2	2	—	—	—	
300–600	5	$5_{(3)}$	—	—	—	—	—	—	—	
600–1000	1	1	—	—	—	—	—	—	—	
Total	911	$97_{(15)}$	94	55	44	12	79	49	472	9

Eastern, Tomari Section

Thickness in cm	Number of beds	No grading (massive)	Ta (mass.)	Tabc, abcd	Tab,abd	Tac,ad	Tbc,bcd	Tb,bd	Tc,cd,d	mud-conglo.
0–1		—	—	—	—	—	—	—		
1–3	375	2	8	—	—	—	6	2	357	
3–6	158	6	17	3	7	3	51	9	62	2
6–10	82	7	9	4	4	2	40	3	13	
10–30	$121_{(6)}$	$29_{(5)}$	17	$19_{(1)}$	12	1	28	11	4	4
30–60	$55_{(2)}$	$25_{(2)}$	13	13	3	1	—	—	—	3
60–100	$34_{(6)}$	$26_{(6)}$	5	3	—	—	—	—	—	
100–300	$28_{(5)}$	$20_{(5)}$	5	3	—	—	—	—	—	1
300-600	$6_{(1)}$	$5_{(1)}$	1	—	—	—	—	—	—	
Total	$859_{(20)}$	$120_{(19)}$	75	45	26	7	125	25	436	10

stone bed is composed of very coarse- or coarse-grained in some cases. In such cases the bottom surface of the sandstone bed is remarkably uneven because of the occurrence of sole marks. The graded beds intercalated in Facies f generally show an uneven bottom surface.

The degree of the development of grading is different among the four flysch-type formations of the Jurassic mentioned earlier. The graded bedding observed in the lower part of the Arato Formation is of straight type showing a relatively consistent grading from the bottom upward. Facies j in the Fukkiura Member and the Mone Formation shows complete "Bouma sequence" (Table 12), but division Ta of the sequence frequently shows crude or obscure grading, while clear grading is generally observed above division Tb.

The sandstone bed of the Kitsunesaki Member is thicker and worse laminated than that of the Arato and the Mone Formations and the Fukkiura Member. Therefore, in the Kitunesaki Member a few complete Bouma sequence can be observed and the sandstone commonly consists of division Ta or Tab. Generally, the sandstone bed of the Kitsunesaki Member frequently shows composite bedding compared with that of the other flysch-type formations.

Convolute lamination exists in graded beds with considerably high appearance rates. It is abundant in graded beds of the sequence type Tabcd or Tabc. The thickness of convolute lamination is about 5 to 8 cm, but sometimes it is about 15 cm or more.

Sole Marks

The sole marks observed in the sandstone-shale alternation facies are of two principal types. One is of tool marks such as groove casts, striation casts and bounce casts. The other is of current scour marks such as flute casts, rill marks, and longitudinal furrows and ridges, most of them being ill defined and of small scale. Especially, the morphology of the flute casts is immature in most cases. The tool marks are seen much more frequently than the current scour marks. The appearance rate of current scour marks against the number of sandstone beds is less than 5 percent.

The groove casts are most typical of tool marks and is most numerous in all of the sole marks. Generally, the groove casts measure 3 to 7 cm wide and less than 3 cm deep, and are sometimes superimposed by minor furrows or striation casts.

The sole marks are usually found in the division Ta-bearing sandstone beds, but there are a few cases of sole marks recognized in the division Tb- or Tc-starting sandstone. Sometimes, small flute casts are observed even in the thin Tbc type sandstone bed about 1.5 cm thick. A similar situation is recognized in the Cretaceous of the Oshika area (TAKIZAWA, 1975).

4. Conglomerate Facies

Although conglomerate occupies less than 5 percent of the whole sedimentary rocks in every area, it is very important in pursuing the sources of sediments and in analyzing the sedimentary environments and paleogeography.

A few meters thick conglomerate occurs in the Jurassic formations of the Western Subbelt, while in the Middle Subbelt conglomerate with larger-sized pebbles is exposed abundantly 10 times as much as that of the Western Subbelt. The classification of conglomerate follows PETTIJOHN's scheme (1975).

Facies k: Orthoconglomerate (Petromict-conglomerate)

The orthoconglomerate occurs at the base of or within a given stratigraphic unit and consists of exotic pebbles and cobbles with some boulders from various source rocks. It is usually grain-supported. The boulder-sized gravels are occupied by granitic rocks and can be easily found in the Upper Jurassic formations of the Middle Subbelt. The rounding of pebbles, cobbles and boulders is generally well.

The formation of a grain-supported conglomerate is attributed to the winnowing activity of a strong current enough to carry all but the coarsest fraction of load in rapid transport by saltation. Mass flows such as debris flow may have partly participated in the deposition of conglomerate. It is difficult for this conglomerate to interpret their depositional environments satisfactorily based only on the lithological features. Nevertheless, the following explanations can be given by an examination of the sedimentary features of the associated strata.

The following conglomerates are considered to have been deposited in a shallow marine environment; the basal conglomerate and the Owandawan conglomerate of the Tsukinoura Formation, the basal conglomerate of the Awatsu and Yamagami Formations, the conglomerate of the Aratozaki Formation, and the conglomerate of the middle part of the Ayukawa Formation. The conglomerate of the Kitsunesaki Sandstone and Shale Member of the Oginohama Formation is judged to be deposits in a deeper environment such as a basin-slope, because it is inserted into the flysch type sequence and is accompanied by slump folds.

Poorly sorted orthoconglomerate several tens of meters thick occurs as an interformational conglomerate in the Ishiwaritoge Formation and the Makinohama Sandstone Member of the Oginohama Formation (Pl. I-4). It can be regarded as being of non-marine origin.

Facies l: Paraconglomerate (pebbly mudstone)

The paraconglomerate is defined as conglomeratic mudstone which mudstone matrix is more than clasts in total volume, and is referable to the pebbly mudstone of CROWELL (1957). There are a few outcrops of this facies in the Jurassic strata.

The paraconglomerate is recognized in the lower part of the Oginohama Formation and the upper part of the Tsunakizaka Formation. Generally, exotic pebbles of granite, volcanics, porphyry and other rocks are sporadically included in ill-sorted sandy mudstone. Slump folds are associated with the paraconglomerate of the two formations mentioned above.

Facies m: Intraformational Conglomerate

Most of the intraformational conglomerate and breccia consist of sandy matrix and shale clasts which were reworked from the contemporaneous beds. However, some intraformational conglomerate and breccia include considerable amount of sandstone clasts of contemporaneous origin. This facies is recognized in the non-marine deposits having large clasts reaching several tens of centimeter in diameter (Fig. 17). On the other hand, the intraformational conglomerate in the sandstone facies (Facies e) of flysch type has generally smaller shale clasts reaching several centimeters in diameter. In the conglomerate of this type, there are a small number of exotic pebbles. Roundness of the embedded shale and sandstone clasts varies from angular to sub-rounded class depending on distance of transportation.

Generally, the intraformational conglomerate and breccia are considered to be deposits which were due to contemporaneous erosion of the underlying strata. In rare cases, limestone-clast conglomerate exists in the Kogoshio and Ayukawa Formations (Pl. III-1) and such limestone clasts were derived from the coeval limestone.

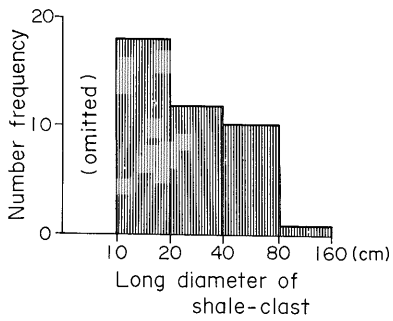


Fig. 17 Size distribution of shale clasts in the intraformational conglomerates of the Makinohama Sandstone Member, Oshika.

5. Limestone and Calcareous Rock Facies

Limestone facies is found only in the Koike Limestone Member of the Nakanosawa Formation of the Soma area. It is well known that the Koike Limestone belongs to the Torinosu-type Limestone which is sporadically exposed in the late Mesozoic strata of the Chichibu Terrane in the Outer Zone of Southwest Japan and also in the late Mesozoic strata along the Pacific coast of Northeast Japan. What is here referred to calcareous rock facies comprises calcareous sandstone and intraformational limestone-clast conglomerate. In actual fact, these rocks are occasionally seen in other facies (e.g. Facies b and m). These calcareous rocks are observed in the Upper Jurassic formations.

Facies n: Limestone facies

The Koike Limestone consists mainly of thick-bedded dark gray oolitic and micritic limestones containing abundant corals, molluscs and other fossil fragments. However, there are found neither bioherms nor biostromes as pointed out by previous authors (e.g. MORI, 1963). MORI suggests that the Koike Limestone is not a true reef limestone. Compared with the Trinosu-type limestone in other areas of Japan, the characteristic feaure of the Koike Limestone, about 50 m thick, is extensive in distribution, being traced for a long distance of about 9 km in meridional direction. Sedimentological and petrographical studies of the limestone have been reported in detail by KIMURA (1954) and EGUCHI and SHOJI (1965).

Calcareous sandstone is usually gray to dark gray, and has a matrix volume of calcite greater than 30 percent. Calcite-matrix constituent makes up more than 50 percent of the total volume in some cases. Such a sandstone has a dispersed framework as if the framework grains float in a calcite matrix. Calcareous sandstone is often found in the Nakanosawa Formation, and the upper part of the Oginohama Formation (Fukkiura Member), which are nearly contemporary with each other.

Calcareous sandstone in the middle part of the Nakanosawa Formation is more than 30 m thick and fine- to medium-grained, with abundant molluscan fossils in the central part of the Soma area. The calcareous sandstone of the Fukkiura Member occurs as small lenses about 1.8 m in maximum thickness or nodular bodies.

A peculiar type of calcareous sandstone showing oolitic texture occurs at two horizons within the lower part of the Kogoshio Formation. One of them has been reported by HAYAMI (1961b), and is in the lower part of Unit Kg-1 of the writer's scheme of subdivisions (Fig. 32). The other occurs in the lowermost part of Unit Kg-2, and is about 5 m thick. This oolitic calcareous sandstone is rich in well-developed ooliths which are usually 3 to 6 mm in diameter. It contains a small amount of quartz and feldespar grains.

Intraformational limestone-clast conglomerate contains abundant limestone clasts more than 50 percent of the total volume, its matrix being coarse- to very coarse-grained sandstone with a small volume of cemented calcite. This conglomerate occurs in the lowermost parts of both the Kogoshio and the Ayukawa Formations (Pl. III-1) and is about 10 m and 15 m thick, respectively. The aggregative clasts of the conglomerate are usually pebble- or cobble-sized, but scarcely exceed 30 cm in diameter. The limestone clasts are dark gray impure limestone, either oolitic or micritic. Some of them contain corals, calcareous algae, crinoids, spines of echinoids, gastropods and bivalves. It is noted that the features of these limestone clasts are fairly similar to those of the Koike Limestone Member mentioned earlier.

IV. FACIES SEQUENCE

The vertical and horizontal changes of the sedimentary facies and some of sedimentary environments of the Jurassic formations are described in this chapter. The recognition of sedimentary environments is based on the syntheses of types of facies, properties of sedimentary structures and attributes of clastic sediments, characters of small-scale sedimentary cycles, and biofacies, in conjunction with the mutual relationships among sedimentary facies.

The geologic columnar sections showing the occurrence of facies in each area are given in Figure 18 to 26. The alphabetical symbols in parentheses attached to the types of lithofacies in the following descriptions are the same as those of facies descriptions in the preceeding chapter.

1. Facies Sequence of the Jurassic in the Middle Subbelt

1-1 Middle Jurassic

The Kosaba Formation of the Karakuwa area, the Tsukinoura Sandstone Member of the Oshika area and the lower part of the Awazu Formation of the Soma area consist mainly of three facies, orthoconglomerate (Facies k), massive coarse-grained sandstone (Facies a) and massive to thick-bedded medium- to fine-grained sandstone (Facies b) in ascending order. Especially, very coarse-grained sandstone prevails in the Tsukinoura Sandstone Member which comprises two or three sedimentary cycles and is associated with sandy shale (Facies g). *Trigonia*, *Inoceramus* and other bivalves occur in this member. The sandstone is poor in matrix and frequently shows cross-bedding. Therefore, the Tsukinoura Sandstone Member is considered to have been deposited in a nearshore shallow marine environment with active wave action.

The massive to thick-bedded sandy shale (black or dark gray in color) (Facies g) and the thick to medium-bedded black shale (containing marine fossils) (Facies f) conformably overlie the above sandstones (Facies a and b). They constitute the Tsunakizaka Formation of the Karakuwa, the Samuraihama Shale Member of the Oshika and the main part of the Awazu Formation of the Soma. These shales are monotonous but generally stratified at intervals of more than several dozen centimeters thick. They include molluscan fossils such as ammonites and bivalves, though scarcely. The

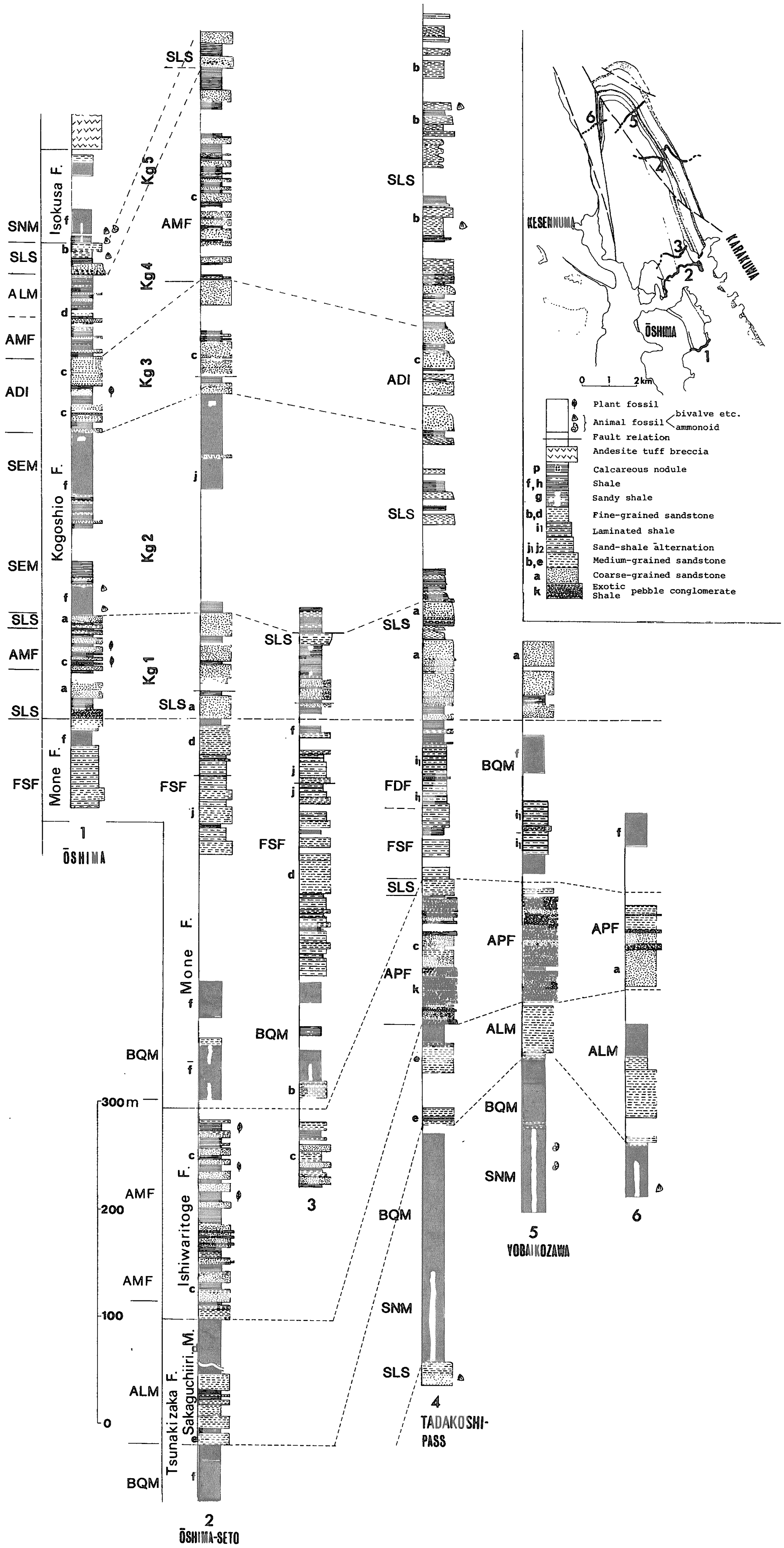


Fig. 18 Columnar sections of the Jurassic formations of the Karakuwa area showing facies sequences. Capital letters on the left side of each column (AFM, SLS. . .) indicate facies association as given in Fig. 19.

shales sometimes contain limy nodules which are generally several centimeters in diameter, but attain to 80 cm in the eastern part of the Oshika area. Sandstone intercalations within the shale are scarce in the Karakuwa and the Soma areas, but they are sporadically found in the eastern part of the Oshika area.

The shale facies in the Middle Jurassic strata is also well exposed in the Western Subbelt, as will be mentioned later. Because of the occurrence of very thick beds, the wide distribution and the lack of current structures, this shale facies is considered to have been deposited in a stable and quiet offshore environment in the transgressive phase.

1–2 Lower Part of the Upper Jurassic

The strata described here are referred to the Oxfordian, probably ranging up to the Callovian. The Oxfordian strata of the Middle Subbelt are characterized by the conspicuous vertical and lateral facies changes and the predominance of coarser-grained clastic sediments.

Karakuwa Area

The Sakaguchiirizawa Sandstone Member of the Tsunakizaka Formation and the Ishiwaritoge Formation are the units which were formed during early Late Jurassic time. The stratification of the former is shown in Figure 27.

The Sakaguchiirizawa Member consists of bedded and laminated fine- to medium-grained sandstone interbedded with shale (Facies d) and massive or bedded gray, partly black shale (Facies h). Cross-bedding and ripple-drift cross-lamination (Pl. II-1B) in addition to parallel lamination coexist within a single sandstone bed. This fact indicates that the sandstone was deposited in a shallow water environment affected by traction currents. Generally, the sandstone beds of the member are 1 to 2 m thick and become finer grained upward. Sometimes, however, there are upward-coarsening beds as shown in Plate II-1A. The sandstone is not quite coarse-grained, and contains few intraformational shale-clast conglomerate. Therefore, the sandstone is not of fluvial deposition.

The shale of the member is gray on its fresh surface and yellowish gray on its weathered surface, and does not yield marine fossils. Thus, the shale is possibly of non-marine origin.

The depositional environment of the Sakaguchiirizawa Sandstone Member is considered to be an ephemeral lake or lagoon in an alluvial low land.

The Ishiwaritoge Formation consists mainly of massive to very thick-bedded coarse-grained sandstone interbedded with shale (containing plant beds) (Facies c) in the southern part of the area (section no. 2 in Fig. 18), but is dominated by orthoconglomerate in the northern part. In the southern part, more than 10 beds of coarse-grained sandstone alternate very thickly with gray shale beds of probable non-marine origin. The thickness of each bed varies from 5 to 20 m. These alternating beds are referred to the sedimentary cycle of fining-upward sequence described by ALLEN (1964, 1970) and VISHER (1965a).

The individual sandstone beds in this sequence (cycle) are bounded by the contemporaneous erosional basal surface and become finer grained upward. The lowermost part of the sandstone bed has sometimes intraformational conglomerate consisting of shale clasts and the lower half is coarse grained, frequently showing large-scale cross-bedding and parallel lamination. The upper half of the sandstone bed varies from medium- to fine-grained toward the top and grades up into the shale. The scale of cross-bedding in the sandstone also becomes smaller upward. The lower part of the shale bed occupying the upper part of the sequence consists of sandy shale or alternating fine-grained sandstone and shale. Sometimes, plant fossils are found in the shale or the parallel-laminated fine-grained sandstone.

Similar fining-upward sequences of the Cretaceous and Jurassic formations of the Oshika area have already been described by TAKIZAWA (1975, 1976). These sequences were probably formed by lateral migration of a meandering river.

The Ishiwaritoge Formation in the northern part of the Karakuwa area is characterized by the predominance of ill-sorted conglomerate

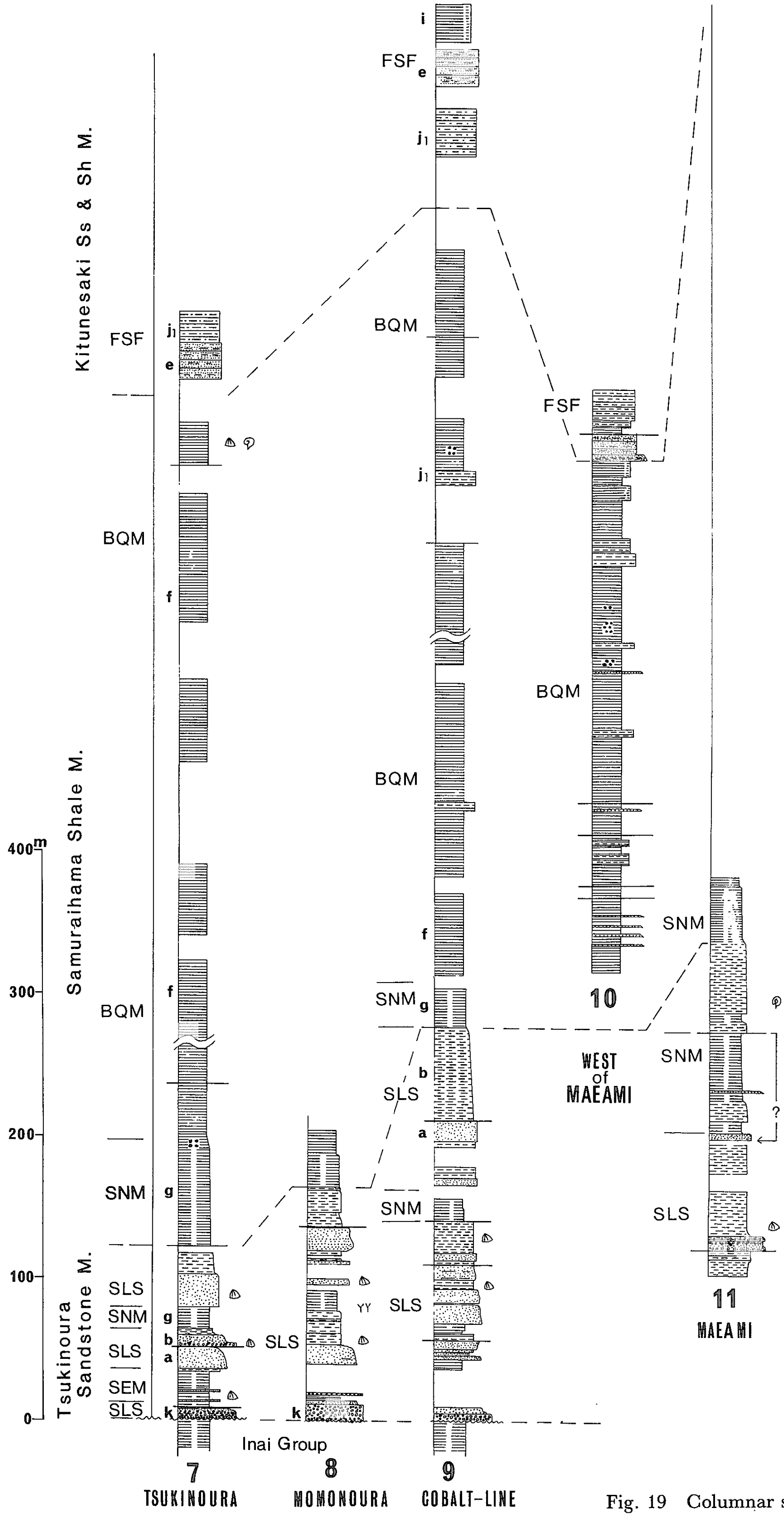
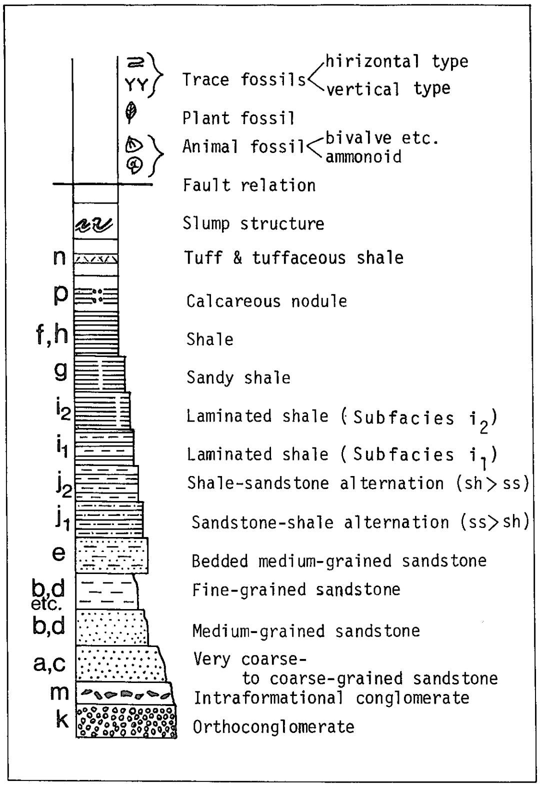


Fig. 19 Columnar sections of the



Legend of figures 18 to 23 and 26

FACIES ASSOCIATIONS

ALLUVIAL

A P F	alluvial fan deposits
A M F	migrating fluvial deposits
A D I	distributary & interdistributary complex

LAKE

A L M	lake & marsh (mostly temporary)

BEACH DIDGE–COASTAL MARSH

A B R	beach ridge deposits

SHALLOW MARINE

S L S	littoral sandy deposits
S N M	neritic sandy mud deposits
S E M	embayment muddy deposits

BASIN FLOOR MUD

B Q M	quiet basin mud deposits
B A M	agitated basin mud deposits

FLYSCH

F S F	delta slope & fan deposits (proximal flysch)
F D F	prodelta deposits (distal flysch)

Legend of figures 18 to 26

Middle Jurassic formations of the Oshika area showing facies sequences.

with subordinate massive sandstone. The fining-upward sequence is therein rather rare. This conglomerate consists mostly of exotic pebbles such as granitic rocks. The conglomerate contains large quantities of contemporaneous erosional shale clasts (or blocks) with a diameter of several dozen centimeters (maximum: 2 m). Scour and fill structures are abundant in the Ishiwaritoge Formation, but shale intercalations are very few (Fig. 27). The northern conglomeratic facies of the Ishiwaritoge Formation is also presumed to be terrestrial deposits, which were affected by a river. Generally, alluvial sediments in which muddy sediments are very poor and cobble to boulder bearing ill-sorted conglomerate is predominant, are considered to have been deposited in a piedmont fan (alluvial fan) environment.

In brief, the lower part of the Upper Jurassic strata in the Karakuwa area is wholly nonmarine sediments which probably accumulated in lake to fluvial flood plain in the southern part or to piedmont fan environments in the northern part.

Oshika Area

The Kitsunesaki Sandstone and Shale and the overlying Makinohama Sandstone Members of the Oginohama Formation belong to the lower part of the Upper Jurassic. The former consists of medium- to thin-bedded sandstone-shale alternation (Facies j), thick- to medium-bedded medium-grained sandstone (Facies e), laminated shale (Facies i) and orthoconglomerate (Facies k). In the Kitsunesaki Member, about 50 amalgamate beds can be observed in all of the thick- to medium-bedded sandstone beds. Repeated graded beddings with more than several units in only one bed are observed in the composite beds and as a whole those form considerably thick sandstone (Fig. 13).

In the southeastern part of the area, the Kitsunesaki Member contains many conglomerate (orthoconglomerate) beds as shown in Figure 21 (section 23) and Plate VII. The conglomerate is composed of pebble- to cobble-sized gravels embedded in coarse-grained sand matrix, and is 1 to 10 m thick. The bottom of the conglomerate has occasionally undulated channel-like surface cutting into the surrounding sandstone-shale alternation and laminated shale. Thus these conglomerate beds are regarded as deposits which filled submarine channels. The sandstone of the member in section 23 in Figure 21 are generally conglomeratic and abundant in composite bedding. Thus, most of the Kitsunesaki Member as a whole is regarded as a proximal turbidites (WALKER, 1967) or fluxoturbidite-type sediments (DZULYNSKI *et al.*, 1959).

The uppermost part of the Kitsunesaki Sandstone and Shale Member is composed mainly of rather ill-sorted coarse- to medium-grained and thick-bedded sandstone. This part changes rapidly into the pebbly coarse- grained sandstone accompanied by cross-bedding of the Makinohama Sandstone Member.

The Makinohama Sandstone Member consists mainly of massive to thick-bedded coarse-grained sandstone interbedded with shale (Facies c), accompanied by massive or bedded gray, partly black shale (Facies h), and well-bedded and laminated fine- to medium-grained sandstone interbedded with shale (Facies d). A typical section of the member is given in Figure 30. A single unit of the coarse-grained sandstone measures 3 to 35 m in thickness with an average of about 9 m. The sandstone alternates with shale showing an upward-fining sedimentary cycle. As the writer has already mentioned (TAKIZAWA, 1976), a standard cycle begins with conglomerate bottomed by contemporaneous erosional surface, through coarse-grained sandstone in its main part, into medium- to fine-grained sandstone and ends with shale. Cross-bedding is by far the most common and decreases in set thickness upward in accordance with the upward-fining of grain size. Shale of the upper part of each cycle varies in color from medium gray through dark gray to black and is frequently accompanied by inky black coaly shale. The plant remains occur in the shale or parallel laminated fine-grained sandstone, but no marine fossils occur in the member.

The sedimentary cycle of the fining-upward

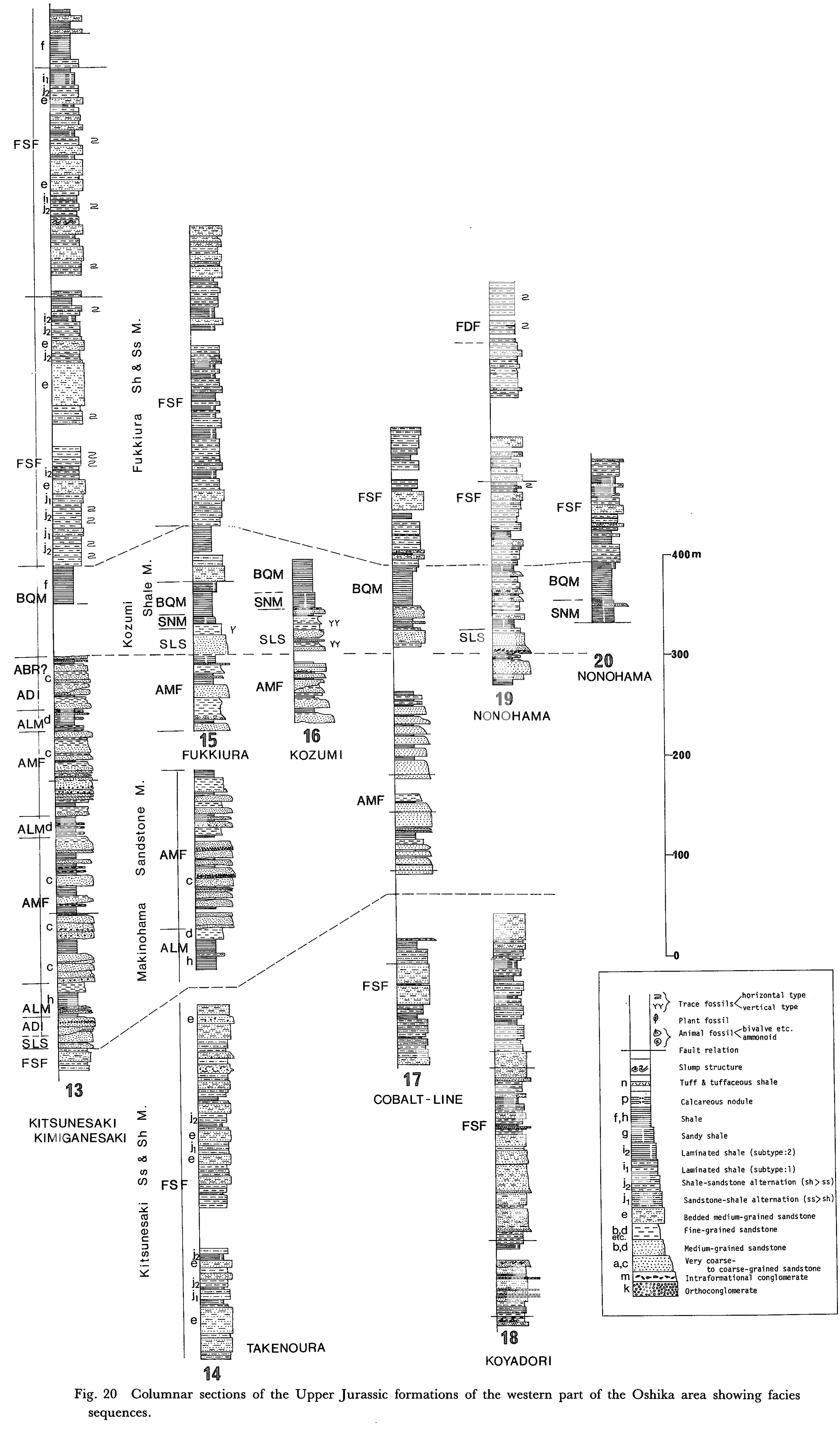


Fig. 20 Columnar sections of the Upper Jurassic formations of the western part of the Oshika area showing facies sequences.

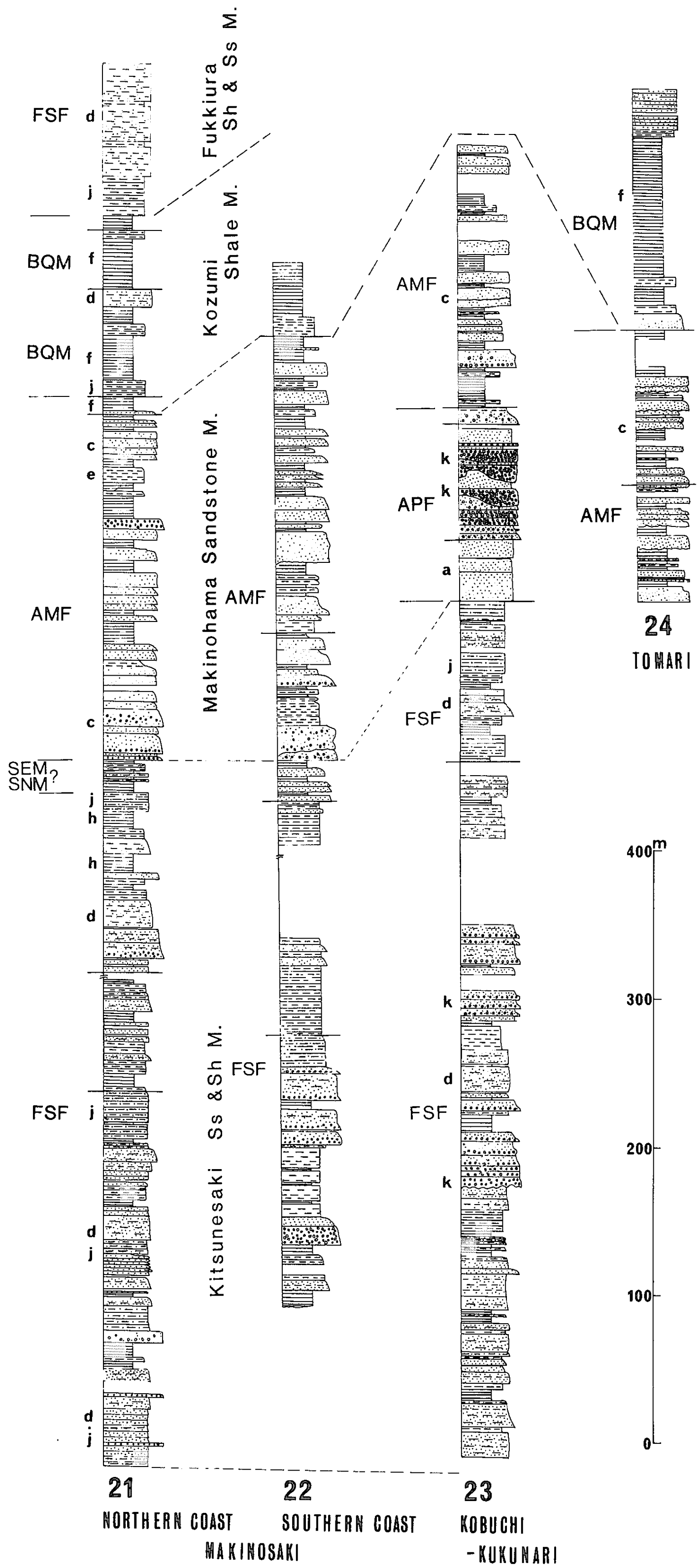


Fig. 21 Columnar sections of the lower half of the Upper Jurassic formations of the eastern part of the Oshika area showing facies sequences.

sequence in the non-marine sediments has been regarded by ALLEN (1964) as being of fluvial deposition due to the lateral shifting of a river. On referring to his idea, the coarse-grained part (sandstone) of the cycle in the Makinohama Member is interpreted as stream-channel deposits, and the fine-grained part (shale) as flood-plain sediments. The cycles dominated by shale probably indicate meandering river sediments in a drainage basin.

In the southeastern part of its outcrop area of the Makinohama Sandstone Member is characterized by the predominance of conglomerate (Pl. I-4) and thick-bedded sandstone. As shown in section 23 in Figure 21, the conglomerate is estimated to be 50 m in thickness and contains a large amount of granite boulders. This conglomerate resembles that of the Ishiwaritoge Formation of the Karakuwa area in the very local distribution, but is poor in contemporaneous erosional structure. The Makinohama Sandstone Member, however, is interpreted as alluvial fan sediments. This evidenced by the scarcity of muddy sediments and lateral facies change into migrating fluvial deposits.

As will be seen from the above, the sedimentary facies of the lower Upper Jurassic formations in the Oshika area is considered to be of the transitional phase from the flysch (proximal turbidite and fluxoturbidite) to the fluvial facies (Pl. I and VII). In the southeastern part of the Oshika area, conglomerate is found abundantly in both the flysch and the fluvial facies. This combined with other available data indicates that the source area of the sediments existed in the proximity of the Jurassic sedimentary basin.

Soma Area

The Yamagami and Tochikubo Formations are referable to the lower Upper Jurassic. The Yamagami Formation consists mainly of massive medium-grained sandstone (Facies b). This sandstone is characterized by comparatively good sorting, and very massive or structureless nature. In the southern part of the area, the sandstone becomes somewhat finer grained intercalated with shale. Several kinds of bivalves such as trigoniids are contained in the Yamagami Formation. Therefore, this formation is believed to have accumulated in a shallow marine environment. In the southern limit of the distribution, on the other hand, it is considered to be a distal part of the shallow marine sand-sheets.

The Tochikubo Formation consists mainly of massive to very thick-bedded coarse-grained sandstone (Facies c) in the lower part and massive medium-grained sandsone (Facies b) in the upper part. These facies are accompanied by massive or bedded gray, partly black, shale (Facies h) and well-bedded and laminated fine- to medium-grained sandstone interbedded with shale (Facies d). Intercalations of coaly or carbonaceous shale are frequently visible. Also some fining-upward sedimentary cycles are recognized in the lower part of the formation. These facts indicate that the lower part of the Tochikubo Formation was deposited in a fluvial environment. Facies d of the Tochikubo Formation is similar to that of the Sakaguchiirizawa Sandstone Member in the Karakuwa area, and is inferred to deposits of a fresh water environment.

The sedimentary environment of the massive medium-grained sandstone of the upper part of the Tochikubo Formation is probably a transitional zone in a coastal environment. This is evidenced by the plant beds or coaly shale seams and also by the conformable relation to the overlying Nakanosawa Formation which consists of shallow marine deposits.

To sum up, the lower part of the Upper Jurassic sequence in the Soma area consists of regressive sedimentary facies changing from shallow marine upward to non-marine deposits, which is similar to the regressive facies recongnized in the Karakuwa and Oshika areas.

1–3 Middle Part of the Upper Jurassic (Upper Oxfrodian—Kimmeridgean)

The Mone Formation of the Karakuwa area, the Kozumi Shale and Fukkiura Shale-Sandstone Members of the upper half of the Oginohama Formation in the Oshika area and the Nakanosawa Formation of the Soma area are assigned to the middle part of the Upper Jurassic, and all of them are marine transgressive sediments.

Karakuwa and Oshika Areas

The Mone Formation and the upper half of the Oginohama Formation have similar lithofacies. Their respective lower parts consist mainly of thick- to medium-bedded black shale (Facies f). The massive medium-grained sandstone (Facies b) underlies the shale facies as a transitional facies. In the Oshika area, this shows cross-bedding and sandstone contains abundant trigoniids (*Myophorella*). Therefore, this sandstone is considered to be of shallow marine deposition.

The bedded shale of the lower part of Mone Formation and the Kozumi Shale Member is very akin to those of the Tsunakizaka Formation and the Samuraihama Shale Member. They are of suspension load origin, which were formed under a calm environment in a stable sedimentary basin. The shale facies gradually changes upward into sandstone-shale alternation (Fig. 20).

The upper part of the Mone Formation has an estimated total thickness of 240 m and the Fukkiura Shale-Sandstone Member more than 600 m. These are characterized by the prevalence of medium- and thin-bedded sandstone-shale alternation. As to the lateral facies change of the flysch sequence, the upper part of the Mone Formation in the Karakuwa area consists of sandstone-dominated facies in the southern area (sections 1–3 in Fig. 18), but is marked by thinly laminated shale (Subfacies i_{1b}) (see Table 11) in the northern area which is only several kilometers away from the south (sections 4–6 in Fig. 18). In the Fukkiura Member in the western part of the Oshika area, too, laminated shale (Subfacies i_{1b}) more or less increases northward (Fig. 20), and bedded sandstone (Facies e) rather decreases northward. Thus, northward fining is noticed in these two areas. This is in harmony with the paleocurrents, as will be mentioned later. On the whole, sandstone is more dominant in the eastern part than in the western part of the Oshika area.

The flysch facies of the Fukkiura Member yields a small amount of bivalves such as *Myophorella* and *Chlamys* and ammonoids. Coquina beds with abraded shell fossils, measuring 15 cm in thickness, are present in the Fukkiura Member in the eastern part of the Oshika area. Also, trace fossils are very abundant in the flysch-type deposits. According to the preliminary identification, *Zoophycos* sp., *Chondrites* sp., *Cosmorhaphe* sp. and others occur abundantly in the Oshika area, and *Zoophycos* sp. and *Phycosiphon* sp. in the Karakuwa area.

Soma Area

The Nakanosawa Formation consists mainly of massive coarse-grained sandstone and limestone. In the Soma area, sandstone-shale rhythmic alternation (flysch-type deposits), which could be observed in the Karakuwa and Oshika areas, is lacking (Fig. 23). In the southern part of the area (the vicinity of Koike), the lower part of the Nakanosawa Formation consists of massive coarse-grained sandstone with occasional cross-bedding (Fig. 35). Some sandstones are medium to fine grained, and are calcareous, dark gray, silty, with burrows which stretch obliquely or vertically to the bedding plane. The volume of coarse-grained sandstone decreases toward the north within the outcrop area of the Nakanosawa Formation, and that of medium-grained sandstone which is frequently limy or silty increases. The medium- or fine-grained sandstone, or silty sandstone of the Nakanosawa Formation yields abundant molluscan fossils (bivalves, gastropods and ammonoids) and a few plant fossils. The shale intercalation occurs rarely.

Judging from the features of the sandstone and the fossils mentioned above, it is suggested that the Nakanosawa Formation accumulated in a typical shallow marine environment. The characteristics of the Nakanosawa Formation indicate that the paleoenvironment in the vicinity of Koike experienced a series of transition history from the stronger current conditions through small scale oscillations to the weak current conditions as suggested by the deposition of the limestone.

The upper part of the Nakanosawa Formation (Koike Limestone Member) is consists mainly of dark gray oolitic and micritic limestone. Oolitic limestone prevails in the lower part of the member. The sedimentological and petrographical studies of this limestone have been reported in detail by KIMURA (1954) and EGUCHI and SHOJI (1965). According to the latter report, this limestone, as a whole, has five sedimentary cycles each of which is bottomed by eroded surface and consists of alternating beds of oosparite (prevailing in the upper part) and biomicrite interbedded with biosparite (prevailing in the upper part). It was clarified that each cycle in this limestone sequence was attributed to the depositional process which began with a bank environment with strong currents and proceeded to a calm reef (lagoon) environment with weak currents (EGUCHI and SHOJI, 1965).

1-4 Uppermost Jurassic

Almost all of the deposits of this category are assigned to Tithonian in age. The Kogoshio Formation of the Karakuwa area, the lower part of the Ayukawa Formation (Kiyosaki Sandstone Member) of the Oshika area and the Tomizawa Formation of the Soma area belong to the deposits of this age. They are characterized by thick beds of very coarse- to coarse-grained sandstone and frequently contain shale which yields abundant plant fossils.

Karakuwa Area

The Kogoshio Formation is subdivided into five stratigraphical units (Kg-1 to Kg-5) of which three units are dominated by sandstone and two others by shale (Fig. 32). Its basal part (Kg-la) is defined by the appearance of whity arkosic coarse-grained sandstone. In the southern part of the area (Oshima), the basal part of the Kogoshio Formation contains contemporaneous limestone pebbles abundantly (Pl. III-1B). The limestone pebbles are composed of oolitic limestone, and biomicritic limestone containing many bivalves and corals. They are generally subrounded and measure from 5 to 25 cm in diameter. The limestone pebbles occupy more than 70 volume percent of this intraformational conglomerate. The conglomerate sometimes includes a small amount of pebbles of granite, siliceous rocks and others which are less than 15 cm in diameter.

Thus, Unit Kg-la was obviously deposited in a shallow marine environment affected by strong currents. Unit Kg-1b consists of very coarse-grained quartzose sandstone and seems to be coastal deposition along a shoreline because the overlying Unit Kg-1c is composed of fluvial sediments as mentioned later. Probably Unit Kg-1b accumulated near a river mouth or a shoreline. Unit Kg-1c shows typical fining-upward cycle and the sandstone therein has frequent cross-stratification. Therefore, this unit is regarded as fluvial deposits. Unit Kg-1d consists of well-sorted medium-grained sandstone, black sandy shale, and channel-like coarse-grained sandstone obliquely cut into the underlying sandy shale. This unit seems to be littoral sediments.

Unit Kg-2 consists of black shale which overlies the coarse-grained sandstone of Unit Kg-1d with a sharp boundary. This shale along the eastern coast of the islet of Oshima yields marine bivalve fossils, and is sometimes well-laminated or interbedded with fine-grained sandstone layers. In the Karakuwa Peninsula, oolitic calcareous fine-grained sandstone is contained in the lowermost part of Unit Kg-2. This peculiar kind of sandstone is referred to a calcite-cemented "sandy oolite" which shows concentric circular structures less than 5 mm across. It is, therefore, noticeable that the lower part of the Kogoshio Formation is regarded as sediments of shallow marine environment containing calcareous material.

Unit Kg-3 consists of thick beds of coarse-grained sandstone with intercalations of shale probably of non-marine origin. Unit Kg-3 is characterized by the occasional occurrence of fining-upward sequence similar to that of Unit Kg-1c. Accordingly, the unit is inferred to be of non-marine origin under the influence of a river.

Unit Kg-4 has a predominant amount of shale of non-marine type with a few sandstone beds showing a fining-upward sequence. The northern facies of Unit Kg-4 consists mainly of well-sorted medium- to fine-grained sandstone

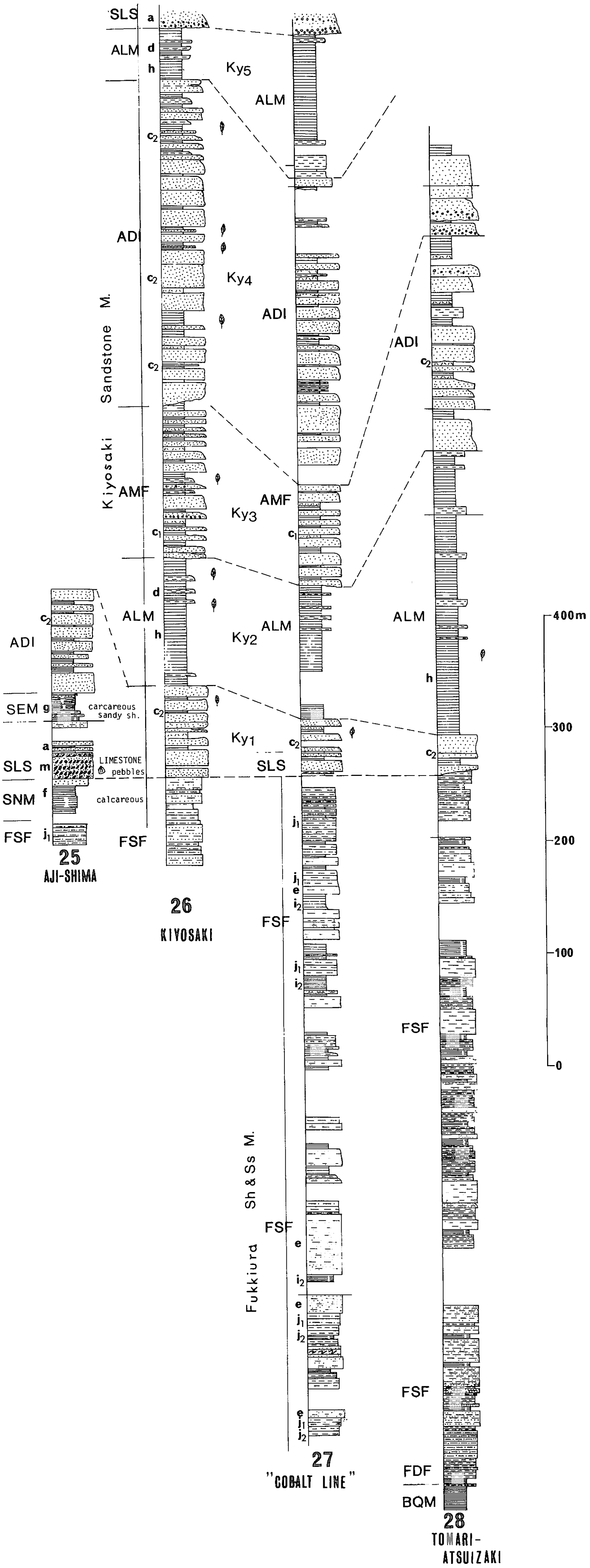


Fig. 22 Columnar sections of the Upper half of the Upper Jurassic formations of the eastern part of the Oshika area showing facies sequences.

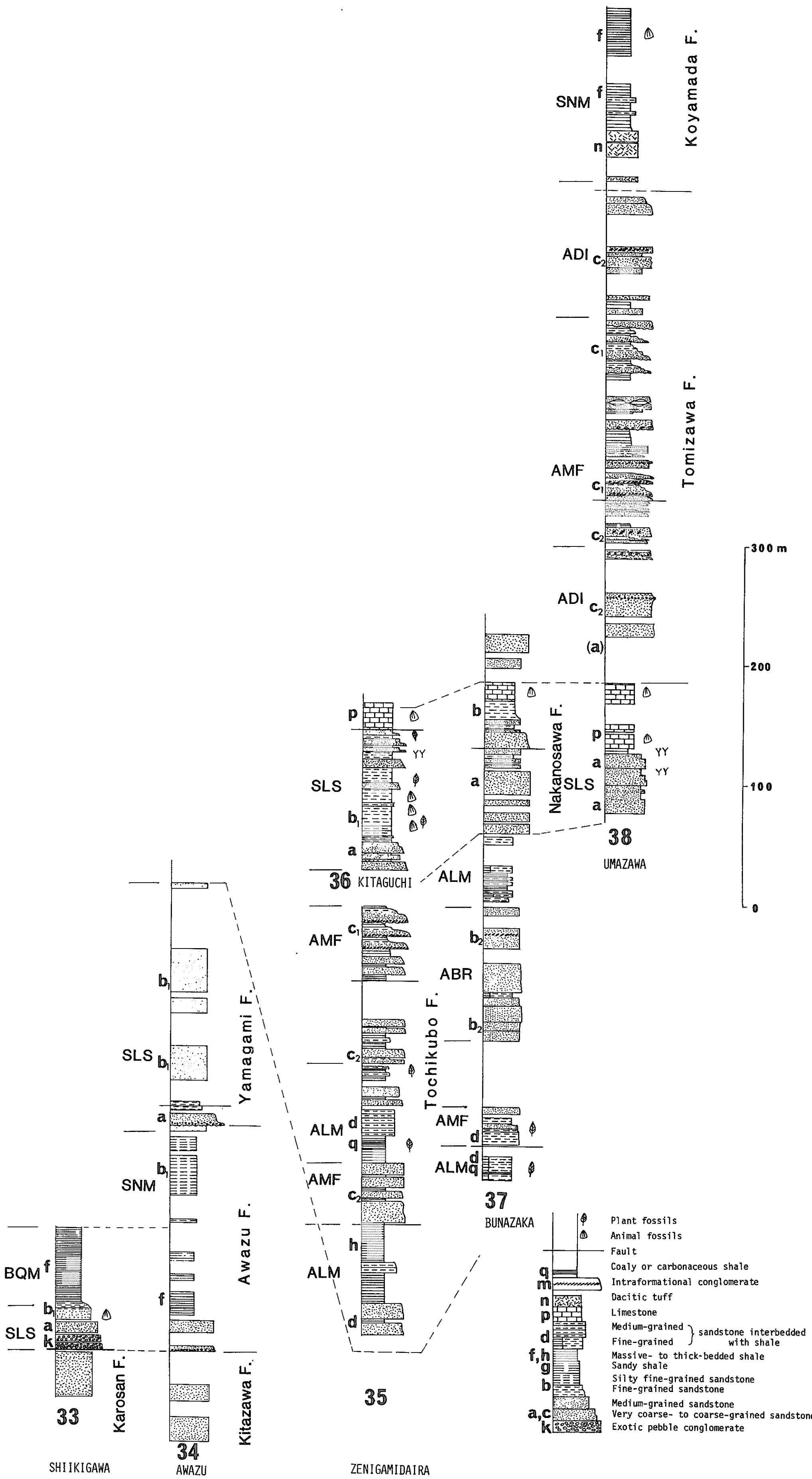


Fig. 23 Columnar sections of the Jurassic formations of the Soma area showing facies sequences.

and sometimes yields marine fossils such as trigoniids. Therefore, this facies is regarded as shallow marine sediments.

In Unit Kg-5, the uppermost part of the Kogoshio Formation, vertical burrows are occasionally found and marine bivalves also occur. Unit Kg-5 gradually changes into the bedded black shale of the Isokusa Formation. Thus, this unit is represented by sediments of marine transgressive phase.

From the above, it can be said that the Kogoshio Formation is characterized by oscillatory sediments consisting of alternating shallow marine and fluvial sediments. The marine sediments are predominant in the northern part of its distribution. Moreover, the geomorphological gradient during the deposition is imagined to have been deeper toward the north.

Oshika and Soma Areas

Both the Kiyosaki Sandstone Member and the Tomizawa Formation are very similar to each other with respect to lithofacies and fossil contents (Figs. 22, 23). The Kiyosaki Member and the Tomizawa Formation resemble the Kogoshio Formation in sandstone petrography. These strata are occupied mostly by very coarse- to coarse-grained arkosic sandstone with gray to partially black and very thick-bedded shale. Also fining-upward sedimentary cycles are frequently recognized and no marine fossils are found. The Kiyosaki Member and the Tomizawa Formation are, therefore, regarded as non-marine deposits chiefly of an alluvial environment.

The lower part (Unit Ky-2) and the upper part (Unit Ky-5) of the Kiyosaki Sandstone Member consist of gray shale accompanied by black shale. Also, bedded and laminated fine- to medium-grained sandstone (Facies d) subordinately occur in both units (Pl. II-1A). Both units yield abundant well-preserved plant fossils. These facts show that Units Ky-2 and Ky-5 were deposited in a non-marine aqueous environment without strong currents, for instance, ephemeral lake or marsh.

1–5 Lowermost Cretaceous

The lowermost Cretaceous formations, which conformably overlie the Upper Jurassic formations, are distributed in three areas of the Middle Subbelt. There is a great difference in sedimentary facies and total thickness among the lowermost Cretaceous formations of the Karakuwa, Soma and Oshika areas. That is to say, the Isokusa Formation (200 m thick) in the Karakuwa area and the Oyamada Formation (150 m thick) in the Soma area consist of thick- to medium-bedded black shale (Facies f) accompanied by massive or bedded sandy shale (Facies g). These shales yield various species of marine bivalves and ammonoids. As there are rare sandstone intercalations, these formations are regarded as sediments of a quiet offshore marine environment.

The Cretaceous formations in the Oshika area (middle and upper parts of the Ayukawa Formation) are about 1200 m in total thickness (Fig. 24). The writer (TAKIZAWA, 1975) described the following vertical facies change of the formation in ascending order.

The Kobitawatashi Sandstone and Shale Member, 400 m thick, consists of the following four lithologic units from the bottom upward; Kb-1, basal conglomerate followed by thick sandstone, which is probably of estuarial or littoral origin; Kb-2, littoral sandstone and shale in thick-bedded alternation, partly including *Thalassinoides*-like burrows; Kb-3, neritic sandy shale including abundant marine bivalves and many ammonites (*Berriasella* sp.) interbedded with fine-grained sandstone; and Kb-4, interbedded assemblages of shale-clast conglomerate, coarse-grained sandstone often showing cross-bedding, and shale containing plant remains. The last unit may have been deposited on a coastal alluvial plain. The paleocurrent directions in this member are approximately to the north. In harmony with this fact, the deeper-water or distal facies of this member is predominantly distributed in the northern part of the studied area.

The Futawatashi Shale Member, 620 m thick, is lithologically tripartite as follows. The main part of the member, showing a muddy flysch appearance, is composed chiefly of laminated shale (Subfacies i_1, i_2, and i_3) and

bedded shale, frequently interlaminated and interbedded with sandstone and coarse siltstone, and is accompanied by frequent slump beds. The lower and upper parts of this member consist of coarser clastic material, as represented by thicker-bedded sandstone with cross-bedding, thus showing a shallower marine environment than does the main part.

Sandstone interbedded with shale in the main part of the member is lithologically of two principal distinctive types. One is graded fine- to very fine-grained sandstone which contains a large amount of mud matrix. The other is ripple cross-laminated very fine-grained sandstone, which has little or no grading and is poor in mud matrix. The latter commonly occurs as a single thin layer topped by current ripple marks. This type of sandstone may have been deposited by bottom traction currents. Most of the sole marks indicate northward (axial) current direction, while the cross-laminations and ripple marks are characterized by east-southeastward current direction. The Domeki Sandstone Member consists mostly of cross-bedded, very coarse-grained sandstone accompanied by conglomerate. The member is 330 m thick in the east and about 600 m thick in the west. The lower half of the member shows a repetition of fining-upward cycle probably of fluvial origin. The upper half dominated by conglomeratic sandstone was perhaps originated from piedmont-type fluvial sedimentation.

2. Facies Sequence of the Western Subblet

2–1 Lower Jurassic (Shizugawa Group)

The Lower Jurassic consists of the Niranohama and Hosoura (Mizunuma) Formations. They are less than 200 m in thickness altogether and become thinner or pinch out toward the west (Fig. 26).

The lower part of the Niranohama Formation in the Mizunuma area comprises fine-grained sandstone, sandy shale, black shale and laminated shale. In the Shizugawa area, sandy shale is predominant. Parallel lamination and cross-lamination as well as ripple-marks are occasionally observed in the fine-grained sandstone. The shale is partially carbonaceous and includes plant fragments. The laminated shale is poorly exposed in the Shizugawa area and well in the Mizunuma area. This shale is well stratified and streaky. On occasion, the laminated shale grades laterally into very fine- to fine-grained sandstone or sandy shale.

According to HAYAMI (1959d, 1961d), embayment or brackish molluscs such as *Eomiodon*, *Isognomon* and *Burmesia* occur abundantly forming a shell bed in the lower part of the Niranohama Formation. In the eastern part of the Mizunuma area, there are a dozen shell beds, 10 to 100 cm thick, containing bivalves and gastropods. Judging from the above facts, the lower part of the Niranohama Formation is regarded as sediments of shallow embayment.

In contrast, the upper part of the Niranohama Formation consists mainly of arkosic medium- to coarse-grained sandstone. It attains a maximum thickness of 100 m in the Mizunuma area. This sandstone is massive and structureless. Cross-bedding is rarely, and a few molluscan fossils (e.g., *Vaugonia*) are found. On the whole, the thickness of the upper part thins out toward the west. From the fossil content and facies, the upper part of the Niranohama Formation is regarded as more or less open embayment sediments in comparison with the lower part.

The Hosoura Formation is widely distributed in the Shizugawa area. Its lower and upper parts consist of sandy shale (Facies g) and monotonous black shale (Facies f), respectively. Well-sorted fine-grained sandstone is intercalated in the sandy shale of the lower part of the formation in which calcareous nodules are included. A few bivalves and ammonites occur in the upper part. The Hosoura Formation is regarded as sediments of transgressive offshore marine environment.

2–2 Middle to Upper Jurassic

The Middle and Upper Jurassic formations in the Western Subbelt are represented by the Hashiura Group which consists of the Bajocian Aratozaki Formation, the Bajocian to Kimmeridgian Arato Formation and the Tithonian Sodenohama Formation in the Shizugawa area. The Aratozaki Formation is composed of transgressive sediments. In the vicinity of Aratozaki, the basal part of this formation comprises fine- to medium-grained sandstone (Facies b_1) measuring about 10 m thick, and the main part consists of coarse-grained sandstone (Facies a) with conglomerate (Fig. 25). The basal fine- to medium-grained sandstone yields shallow marine bivalves including *Trigonia*, *Inoceramus* and others (HAYAMI, 1958, 1961a). The sandstone of the main part of the formation frequently shows cross-bedding and is scarce of muddy matrix. This sandstone has the same sedimentary features as the basal sandstone of the Middle Jurassic formations in the Middle Subbelt. The top surface of the coarse-grained sandstone shows irregular and wave-shaped contemporaneous erosional structures. The muddy fine-grained sandstone and sandy shale overlying this erosional surface abruptly change into the Arato Formation consisting of alternating sandstone and shale. This indicates an abrupt change of environment from shallow marine to more or less deeper marine.

The lower part of the Arato Formation in the northern part of the area (along the Isatomaegawa) consists of sandstone-shale alternation of flysch type (Facies j_1: Pl. VI-2), with graded bedding and "Bouma sequence" as shown in Table 13. This alternating sequence is thin, less than 30 m in total thickness. The lower part of Arato Formation at Akaiwa-zaki in the southeastern part of the area consists mostly of thin-bedded or very thin-bedded shale-sandstone alternation (Subfacie j_2: Pl. VI-3) and laminated shale (Subfacies i_1). Moreover, channel-shaped sandstone bodies cut into thin-bedded shale-sandstone alternation and laminated shale (Pl. VI-1). Trace fossils of horizontal type occur in the laminated shale of the Arato Formation.

The upper part of the Arato Formation consists of bedded black shale (Facies f). This shale is very similar to the shale of the Tsunakizaka and Tsukinoura Formations. The Owada Formation of the Mizunuma area also consists of bedded shale very similar to the shale of the upper part of the Arato Formation. The Arato Formation is regarded as consisting of distal turbidites in its lower part and muddy deposits of a quiet basin floor in its upper part.

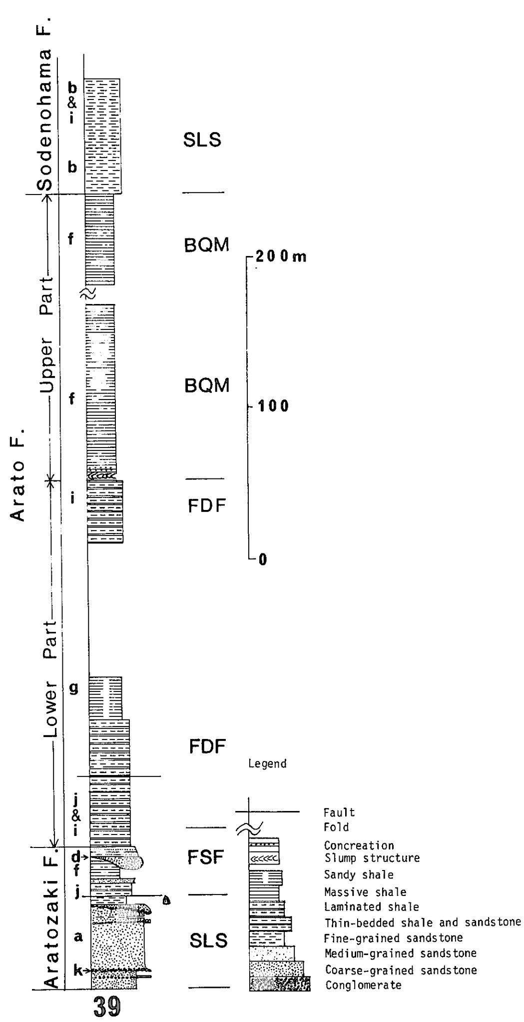


Fig. 25 Columnar sections of the Jurassic formations of the Shizugawa area showing facies sequences.

The Sodenohama Formation of Tithonian age consists of well-sorted fine-grained arenite (Facies b) with few fossils and laminated shale (Facies i_1). There is a gradual westwards increase of shale intercalations. This formation is regarded as sediments deposited in a offshore part of shallow sea.

2-3 Lower Cretaceous

The probable Lower Cretaceous formations are distributed in the Hashiura area as the Jusanhama Group and to the east of the Mizunuma area as the Kanayama Formation in

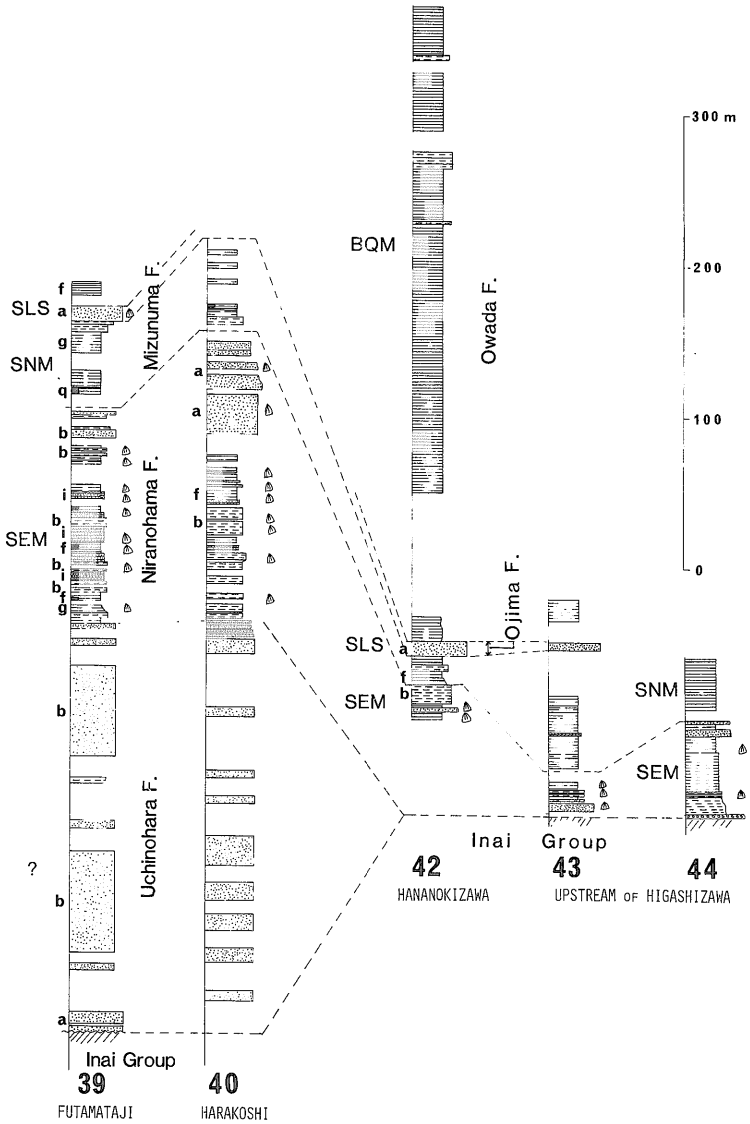


Fig. 26 Columnar sections of the Jurassic formations of the Mizunuma area showing facies sequences.

Table 13 Relationship between sequence type and layer thickness in the lower Arato Formation of the Shizugawa area. For sequence types see Table 12.

Thickness in cm	Number of beds	No-grading, massive	Ta	Tabcd	Tab, abd	Tbc, bcd	Tb, bd	Tc, cd	Td	Others
1–3	20	—	1	—	—	—	—	7	3	9
3–6	15	—	6	—	—	4	1	3	1	
6–10	15	1	—	—	3	5	2	3	1	
10–30	18	1	1	2	5	4	3	2	—	
30–60	1	1	—	—	—	—	—	—	—	
60–100	1	—	—	1	—	—	—	—	—	
Total	70	3	8	3	8	13	6	15	5	9

the Western Subbelt.

The Jusanhama Group consists of massive coarse- to medium-grained sandstone in the lower part, medium- to thick-bedded sandstone-shale alternation in the middle and massive very coarse- to coarse-grained sandstone in the upper. The group yields abundant brackish molluscan fossils. The sandstone in the lower and upper parts of the group is ill sorted and sometimes shows cross-bedding. Therefore, It possibly can be regarded as products of estuarial environment.

The middle part of the group comprises thick- to medium-bedded alternating medium- to fine-grained sandstone and sandy shale with plant fragments, and is characterized by obscure grading. This part seems to show a proximal flysch, but its depositional process is uncertain. Brackish molluscan fossils are found in the sandy shale and fine-grained sandstone of the middle part of the formation (HAYAMI, 1960). It follows from this that the middle part is embayment sediments. Judging from the presence of slump folds as previously reported by BANDO (1959) and the lithofacies, it seems that in the depositional time of Jusanhama Formation slightly steep lateral slopes existed in the sedimentary basin.

The Kanayama Formation consists of very thick-bedded very coarse- to coarse-grained arkosic sandstone, containing exotic pebbles. This formation is considered to be non-marine sediments on the whole, and shows a fining-upward sequence in which cross-bedding is prevalent. Therefore, the Kanayama Formation is regarded as fluvial deposits.

Table 14 Relationships between facies and facies association.

Facies Association \ Lithology		sandstones	shales	sandstone-shale alt.	conglomerates	calcareous rocks
ALLUVIAL FACIES	alluvial fan deposits	c_2			$\underline{k}$, m	
	migrating fluvial deposits	$\underline{c}_1$	h, i_3		m	
	distributary-inter distributary deposits	c_2	h			
LAKE	quiet lake or marsh deposits		h			
	agitated lake deposits	$\underline{d}$	i_3		l	
BEACH RIDGH-COASTAL MARSH (deposits)		b_2, $\underline{c}_2$	h			
SHALLOW MARINE	littoral to neritic sand deposits	$\underline{a}$, $\underline{b}_1$			k	
	embayment muddy deposits	$\underline{b}_1$	$\underline{g}$, $i_{1,3}$			
	neritic muddy deposits		$\underline{g}$			n
BASIN MUD	quiet basin mud deposits	b_1	$\underline{f}$			
	agitated basin mud deposits		$\underline{i}_{1,2,3}$	j_1		
FLYSCH-LIKE	lateral slope deposits	$\underline{e}$	$\underline{i}_2$	j_1	k, l, m	
	delta slope deposits	e	f	$\underline{j}_{1,2}$		
	pro-delta deposits		f, $\underline{i}_1$	j_2		

Underlined lithology : Predominant facies

V. FACIES ASSOCIATION AND SEDIMENTARY ENVIRONMENTS

The foregoing discussion on the facies sequence of the Jurassic formations in the South Kitakami Belt has led to the recognition of various sedimentary environments ranging from alluvial through shallow marine to offshore marine (basin mud, flysch). The six principal facies associations which are distingushed in terms of gross sedimentary environments and their facies combinations are summarized in Table 14. In this chapter the environments and mode of sedimentation of the individual facies associations are described paying attention to both common and special features of these facies discriminated in each stratigraphic unit as well as in every areas.

1. Alluvial (Fluvial) Facies Association

The Jurassic formations of the South Kitakami Belt contain a considerable amount of non-marine deposits represented by fluvial deposits (TAKIZAWA, 1976, 1977). Various kinds of fluvial deposits such as alluvial fan, braided river, meandering river and distributary-interdistributary deposits are exposed in the Middle Subbelt.

1-1 Alluvial Fan Deposits (**APF**)

The alluvial fan deposits belong to the Makinohama Sandstone Member and the Ishiwaritoge Formation in the Middle Subbelt. These are composed of conglomerate containing intraformational shale clasts (Pl. I-4) (frequently of boulder or blocky size), accompanied by massive to very thick-bedded pebbly coarse-grained sandstone and minor pelitic rocks. The conglomerate is comparatively well stratified with scour and fill structures in some places (Fig. 27), but it is massive in others. Both types of conglomerate are poorly sorted in granularity, consisting of pebbles and cobbles with common boulders. The mode of horizontal distribution of the conglomerate is localized, suggesting lateral supply. The fan deposits change horizontally into the migrating fluvial deposits.

BLISSENBACH (1954) and McGOWEN and GROAT (1971) distinguished the following three sub-environments of alluvial fans: i) fanhead (upper fan) or proximal fan, ii) mid-fan (middle fan) and iii) base of fan or distal fan (lower fan). Among these, the proximal fan is usually predominated by boulders and cobbles, and the mid-fan consists of conglomerate interbedded with pebbly cross-bedded sandstone. The distal fan is dominated by cross-bedded sandstone. In addition, sediments due to sheet-flood seem to be predominant in the mid-fan and those due to (braided) stream channel in the distal fan (BLUCK, 1967; STEEL, 1974). The fanhead or the proximal fan deposits are rich in paraconglomerate which is interpreted as mud flow (debris flow) deposits (BLISSENBACH, 1954; BLUCK, 1967; STEEL, 1974). Proximal debris flow deposits contain more angular gravels in some cases (RUST, 1979; BLUCK, 1967). HEWARD (1978) subdivided the mid-fan deposits into the following four types, namely, unstratified conglomerate, stratified conglomerate, pebbly sandstone and cross-bedded sandstone.

Based on the results of the studies of alluvial fans by various authors, the writer considers that the conglomerate facies of the Ishiwaritoge Formation was formed under proximal fan to mid-fan environment. The formation in the vicinity of the Tadakoshi Pass (Fig. 27) consists of stratified conglomerate which grades northward into unstratified, massive conglomerate with an increase in gravel size. In addition, these conglomerates are poorly-sorted, polymodal, and stratified, containing large angular fragments of shale and sandstone and exotic gravels of boulder size (mostly granitic rocks). They have features similar to those of the proximal fan subfacies by McGOWN and GROAT (1971) and HEWARD (1978). In the Ishiwaritoge Formation, coarse-grained sandstone referred to the distal fan deposits is found in the lower part in the western border and only in a small amount in the upper part in the northern part of the outcrop area (Fig. 18).

On the other hand, the conglomerate facies in the southeastern part of the outcrop area of

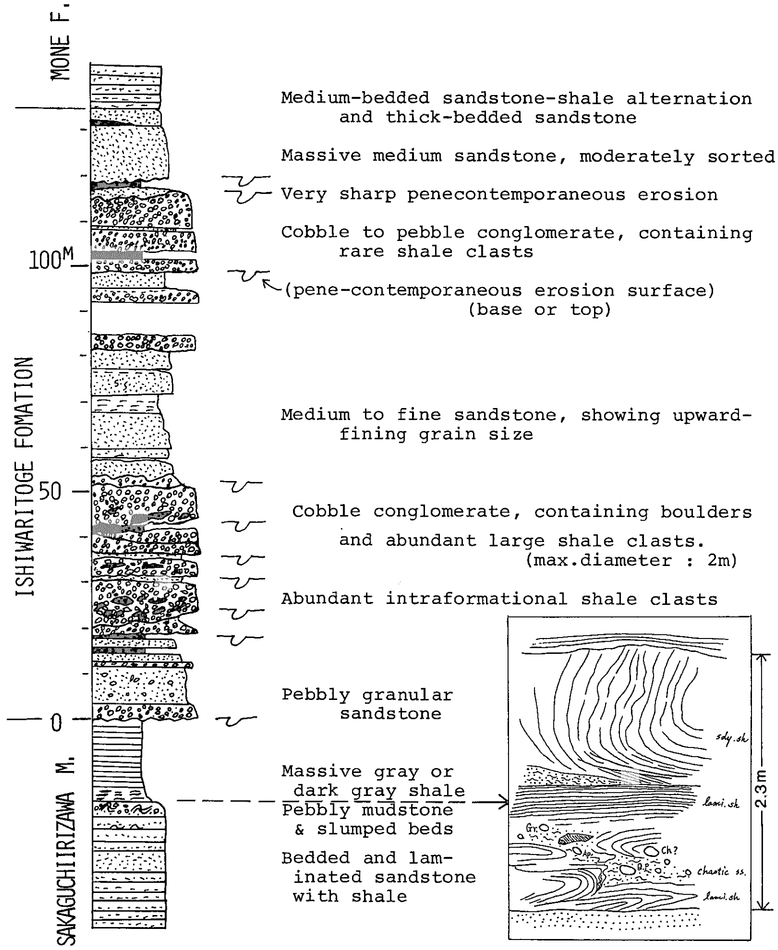


Fig. 27 Detailed measured section of the Ishiwaritoge Formation at Tadakoshi-toge, Karakuwa. This sequence is regarded as alluvial fan deposits (mid-fan).

the Makinohama Sandstone Member (Fig. 21) is divided into the following subfacies in ascending order; massive coarse-grained sandstone, pebbly coarse-grained sandstone, unstratified conglomerate containing boulders (Pl. I-4), stratified conglomerate with sandstone and shale, and pebbly sandstone showing upward decrease in grain size. Its gravels have smaller maximum size and are rather well sorted and smaller in intraformational shale clasts than those of the Ishiwaritoge Formation. The conglomerate facies is probably sediments in the above-defined distal fan to mid-fan.

1–2 Migrating Fluvial Deposits (**AMF**)

Migrating fluvial deposits are extensively developed in all of the Upper Jurassic formations of the three areas in the Middle Subbelt. They are composed of massive to very thick-bedded coarse-grained sandstone interbedded with shale (Facies c), and yield plant fossils in many places. As illustrated in Figure 28, a single unit of the deposits consists of sandstone in the lower half and shale in the upper half, showing a fining-upward sedimentary cycle, 5 m to 35 m thick, averaging about 16 m. An ideal vertical sequence of the sedimentary cycles in the Makinohama Sandstone Member is composed of basal intraformational conglomerate (Fa), lower half sandstone (Fb) which grades upward from coarse- through medim- to fine-grained sandstone, and upper half shale (Fc) with subordinate amount of interbedded fine-

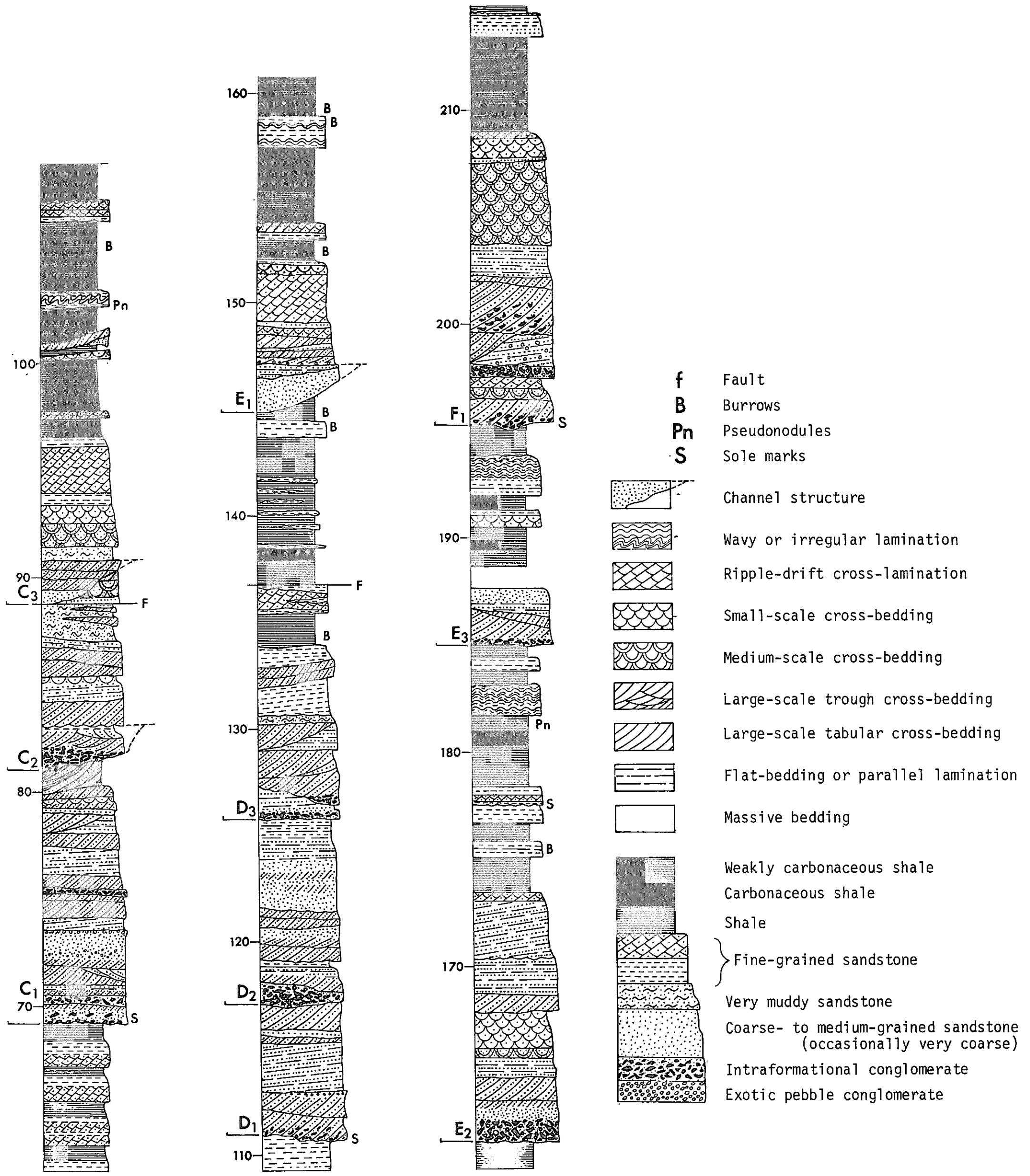


Fig. 28 Detailed measured sections of the Makinohama Sandstone Member (in part), Oshika. This sequence is characterized by fining-upward cycles suggesting fluvial deposition in origin.

grained sandstone and laminated siltstone (Fd) (Fig. 29).

Regarding with the fining-upward cycles of the Makinohama Sandstone Member, the writer (TAKIZAWA, 1976) examined the sandstone's textural properties and flow characters of sedimentary structures, and then discussed the depositional environment and depositional model, making reference to similar sequences in foreign countries (e.g. ALLEN, 1964, 1965a, 1970). The study led to the following conclusions: first, the sandstone of the lower half is referred to point bar deposits in a river and the fine-grained material of the upper half to flood

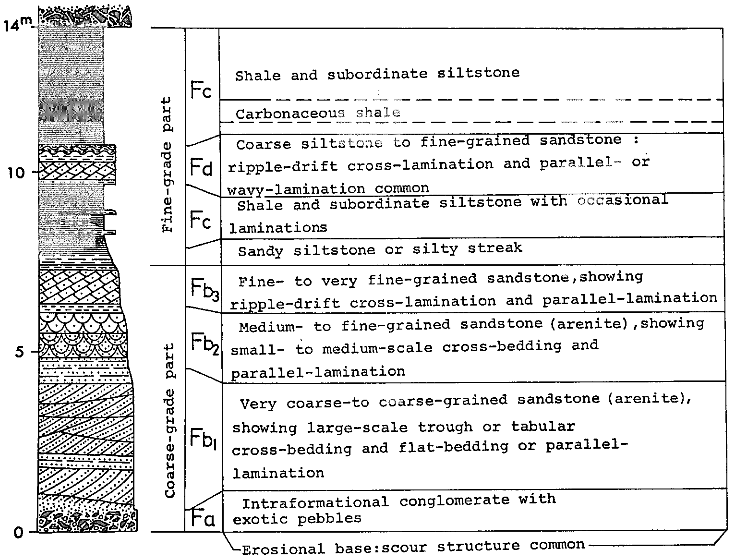


Fig. 29 Ideal sequence of fining-upward cycles in the Upper Jurassic of the Oshika area (after TAKIZAWA, 1976).

plain deposits aside a channel; second, lateral migration of a stream channel played an important role in the genesis of the sedimentary cycles mentioned above. A considerable amount of shale in the sedimentary cycles supports that the cycle is attributed to deposition in a meandering river of alluvial plain.

The above fining-upward cycles that are considered to be of fluvial origin are well developed in the following seven Mesozoic formations of the Middle Subbelt of the South Kitakami Belt, namely, the Ishiwaritoge Formation, the Makinohama Sandstone Member, the Tochikubo Formation (the above three: Oxfordian in age), the Kogoshio Formation and Kiyosaki Sandstone Member, the Tomizawa Formation (the above three: Tithonian in age), and the upper part of the Ayukawa Formation (Lower Cretaceous). These formations are fairly similar one another in principal features such as cycle unit thickness, shale content and sandstone granularity. However, fining upward grade, some of sedimentary structures and sandy intercalations in the shaly part differ among different formations.

The fining-upward cycle is well developed in the Tomizawa Formation (Fig. 23), the Makinohama Sandstone Member (Fig. 28) and the lowermost part of the Kogoshio Formation (Fig. 30). In these units, coarse-grained sandstone is developed in the lower half of each cycle, and medium- to fine-grained sandstone in the upper half, which grades into shale. On the other hand, in the cycles of the Ishiwaritoge Formation (southern facies), the Kiyosaki Sandstone Member, the Tochikubo Formation and the Ayukawa Formation (Domeki Sandstone), the sandstone is mostly coarse- to very coarse-grained, medium- or fine-grained sandstone being as low as 10 to 20 percent in the sandstone.

Furthermore, cross-bedding is very distinct in some places while it is poorly developed in others where most part of the sandstone is massive and structureless. Small-scale cross-bedding or ripple-drift cross-lamination is indistinct on some exposures of fine-grained sandstone and sandstone is apparently structureless although lamination is barely observed by weathering. However, it is not rare that apparently structureless sandstone is revealed to have laminations when polished.

Carbonaceous shale is abundantly contained in the Makinohama Sandstone Member, the Tochikubo Formation and the Tomizawa Formation, but is less abundant in other forma-

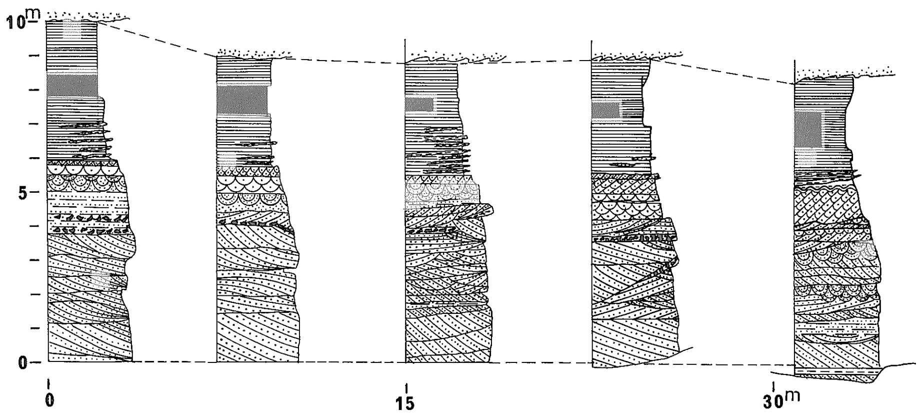


Fig. 30 A fining-upward sequence in the Unit Kg-1 of the lower Kogoshio Formation, Karakuwa. For legend see Figure 28.

tions. A small amount of graded sandstone layers are found in the very thick shaly part of the fining-upward cycles. These sandstone layers are of medium-grained graywacke-like character, and show distinct parallel and cross-lamination. They are less than several dozens of centimeters in thickness and apparently similar to turbidite sandstones of flysch facies. However, they are solitarily developed and are variable laterally in thickness, showing irregularly undulated surfaces at their bottom in many places. One to two, at most several sandstone layers, are sporadically interbedded in a cycle in some places.

Such graded sandstone layers have been reported by various authors (SANDERS, 1968; STANLEY, 1968; HUBERT and HYDE, 1982) for alluvial flood plain deposits. In these cases, the graded layers have a variety of features, such as sedimentary structures similar to those of turbidites, the coexistence of graded bedding and cross-bedding in the main part of a sandstone bed (HUBERT and HYDE 1982), or the intercalation of about 2 m thick sandstone layer containing pebbles in its lowermost part (STANLEY, 1968). However, PICARD and HIGH (1973) maintained that the materials of these graded layers were transported by waning currents due to flashed flood on a lower ground of a flood plain. Such an idea is equally true of the Jurassic graded layers in the South Kitakami Belt.

In the transitional part between the sandy part below and the shale part above in the fining-upward cycle of the South Kitakami Belt, the following three facies are distinguished, namely, massive sandy shale, thinly bedded alternating shale and sandstone (Plate I-3), and laminated sandy siltstone, all of which are considered to be natural levee deposits. A good example of the deposits is shown in Figure 30. Actually, it is well known that such lenticular sandstone layers occur abundantly in recent levee (or stream bank) deposits (PICARD and HIGH, 1973: p. 151–153). These facies grade upward into finer shale facies, where the intercalations of fine sandstone layers, several centimenters thick, tend to thin rapidly laterally.

It should be noted that the lower sandy part of the fining-upward cycle is as much as 20 to 30 m or more in thickness. Its sedimentary cycle will be discussed below in relation to channel pattern. A good example of this is presented in sequences C and D in Figure 28.

Stream channel patterns have been, in general, classified into three types, namely braided, straight, and meandering (LEOPOLD and WOLMAN, 1957; ALLEN, 1965b). Regarding the straight type as a meandering type of very low sinuosity, the basic patterns are grouped into two types, braided and meandering (SELLY, 1970; SHELTON, 1973). Many recent and ancient examples of braided stream sediments have been given by various authors

(DOEGLAS, 1962; BLUCK, 1967; COLEMAN, 1969; WILLIAMS and RUST, 1969; SMITH, 1970; CANT and WALKAR, 1976) and in addition there are a number of reviews. However, braided river sediments do not seem to be easily distinguished from meandering river ones only by the vertical sequence as described by WALKER and CANT (1979). According to the data obtained from the various types of braided river sediments reported in the above references, it seems that muddy sediments due to vertical accretion are, generally, markedly few, and sandy sediments are coarse grained, and poorly sorted in comparison with those of meandering river sediments. Moreover, braided river sediments contain a very small amount of levee sediments, epsilon-type cross-bedding, and ripple-cross lamination. These are also characterized by such sedimentary structures as planar tabular sets of cross-bedding developed in the middle to upper sandy parts of the cycles, and by conspicuous scour structures in the sandstone beds. Braided rivers having the above-mentioned features form wide channels in further upstream reaches of river and on higher slopes (WALKER and CANT, 1979).

In some cycles where muddy sediments are almost lacking as shown in sequences C and D in Figure 28, the major part is composed of coarse-grained sandstone with a small amount of fine-grained sandstone and shale. Up to the upper half of the cycle, tabular cross-bedding is predominant and ripple-cross-lamination is almost lacking. These characters may correspond fairly well to those of braided river sediments as mentioned above. It is, therefore, presumed that the cycles lacking muddy sediments represented by such units as C_1, -D_1 and -D_2 in Figure 28 were formed in environment of intensely braided stream and that the succeeding C_3 and D_3 units were deposits under circumstances suitable for sedimentation of meandering river. Braided river deposits are expected to be found between the alluvial fan deposits to the north and the meandering river deposits to the south in the Ishiwaritoge Formation and also between the two deposits of the Makinohama Sandstone Member. They are represented by the western border facies in the Ishiwaritoge Formation (Fig. 18: section 6) and by the lower part of the Makinohama Sandstone along the Makinosaki section (Fig. 21). In addition, the facies of braided river type is found in the uppermost part of the Ayukawa Formation (Cretaceous) (TAKIZAWA, 1975), and sediments presumably of braided river origin are scarcely found in the Jurassic alluvial facies on the whole.

As briefly reviewed by TAKIZAWA (1976), the fluvial deposits of geologic age, such as the Devonian and Carboniferous deposits (particularly the Lower Old Red Sandstones and the Appalachian System) in the European and American continents (ALLEN, 1964, 1970; ALLEN and FRIEND, 1968; MECKEL, 1970) and the Gondwana System (CASSHYAP, 1970; BARRET, 1965), have been studied in detail. Besides, deposits of this type are found in the wide geochronological range from the Precambrian (SELLY, 1965) to the Cenozoic (CONRAD, 1969; PUIGDEFABREGAS, 1973). In the light of these references, it should be emphasized that the fluvial deposits of the Jurassic of the Kitakami region have coarser-grained sandstone and thicker cycles than those of the Lower Old Red Sandstones and the Gondowana System. However, the fluvial deposits in the Kitakami region appear to be similar to those of the Devonian and Carboniferous of the Appalachian in many respects, such as granularity of sandstone, thickness of cycles, ratio and properties of muddy materials. On the other hand, it is also known that some of the fluvial fining-upward cycles in the Upper Devonian of the Appalachians are very thick, averaging nearly 30 m (WALKER, 1971). This gives an ancient example of energetic fluvial sedimentation.

1-3 Distributary-interdistributary Deposits (ADI)

The deposits consist of massive to thick-bedded coarse-grained sandstone interbedded with shale which contains plant beds (Subfacies c_2) and they do not show upward decrease in grain size. Moreover, they are rather poor in intraformational conglomerate (channel lag). In comparison with Subfacies c_1, the shaly portion is poor in lamina but predominant in carbonaceous shale and plant fragments. The deposits of this type are represented, for example, by the lower part (Ky-1: Pl. II-3A) and the upper part (Ky-4: Pl. II-3B) of the Kiyosaki Sandstone Member of the Ayukawa Formation, the upper part (Kg-4) of the Kogoshio Formation, and the upper part of the Tomizawa Formation.

It is well established in general that rivers are one of the most contributory continental environments to accumulating large quantities of coarse-grained sandstone. However, the deposits comprising Subfacies c_2 are somewhat different from the migrating fluvial deposits vertically adjacent to Subfacies c_2 in any sequence. The almost absence of channel-lag combined with other available data suggests a sedimentary environment with relatively low flow energy. Moreover, from the fact that in the upper half of the Kobitawatashi Member of the Cretaceous strata in the Oshika area, the deposits consisting of Subfacies c_2 rapidly changes northward to shallow marine facies, the writer (TAKIZAWA, 1975) once suggested that the deposits have been originated in a coastal distributary environment.

Distributary channel sediments in many parts of the world are consistent with those of the Kitakami region in the abundance of carbonaceous mud and plant fragments. The forms of the stream channels in a distributary or estuarine environment could be gradient meandering or considerably straight according to their places. Some distributary channels can form complicated stream systems as proposed by WURSTER (1964) and FERM and CAVAROC (1968) or as seen in many recent deltas.

In the distributary of complex flow system, some natural phenomena, such as irregular channel migration and development of chute and chute bar, are liable to prevent the sedimentation from making fining-upward sequences (McGOWEN and GARNER, 1970). FISHER and McGOWEN (1969) pointed out that distributary channels are relatively straight streams and the accumulation of sandstone therein is due to the downward accretion which is facilitated by compactional subsidence. If the deposition is attributed to the downward accretion, the phenomenon of the upward decrease in grain size is not inevitable, because stream channels are liable to abandon and to change suddenly into abandoned channels in which muddy sediments are mainly deposited. Subfacies c_2 is considered to have been generated from such process of deposition in a distributary environment.

From the above evidences and discussions, Subfacies c_2 is inferred to have been formed in distributary channels and interdistributary area. Going into detail, these deposits are referable to the distributary channel-marsh-swamp facies in the fluvial systems proposed by FISHER and McGOWEN (1969).

2. Lake Facies Association

This association, which is inferred to be of non-marine origin from the nature of the associated shale, includes sedimentary deposits formed under a variety of continental environments, such as coastal plain in alluvial lowlands, and limnic depression (marsh or ephemeral lake). With respect to the lithofacies, sandstone is abundant in some places, while shale is predominant in others. Generally, this association is found above the shallow marine sand deposits of regressive phase or both above and below the migrating fluvial deposits. It is regarded as an intermediate association between the two deposits mentioned above. But it is difficult to ascertain the depositional environment of this association in some cases. This facies association is classified into the two facies types of deposits to be described below.

2-1 Agitated Lake Deposits (ALM)

As shown in Figure 31, the deposits consist of bedded and laminated fine- to medium-grained sandstone interbedded with shale (Facies d: Pl. II-1). This deposits occur in the Sakaguchi-irizawa Sandstone Member of the Karakuwa Group, the Kiyosaki Sandstone Member of the Oshika Group and the Tochikubo Formation of the Soma Group. Also, similar deposits are found, for example, in the thick shaly portions

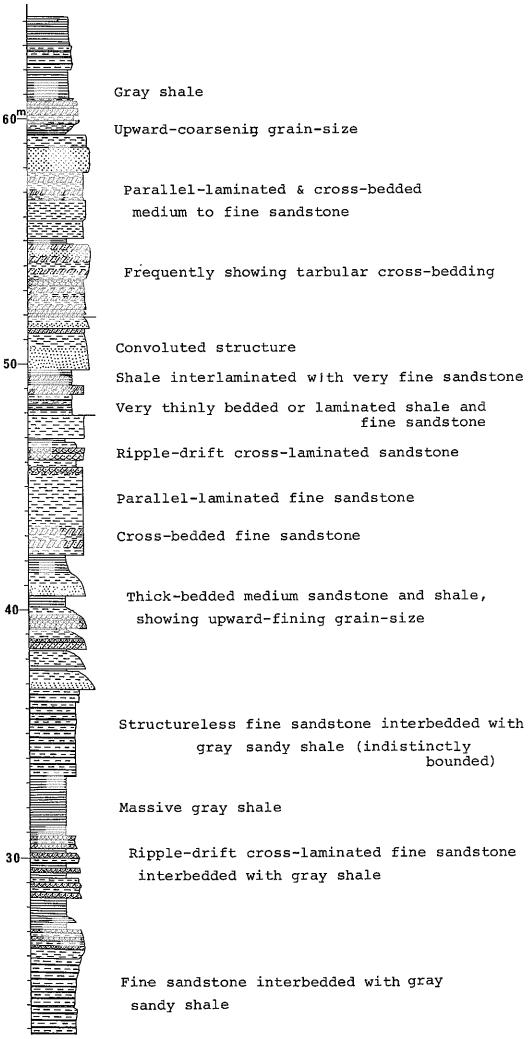


Fig. 31 Detailed measured section of the middle part of the Sakaguchiirizawa Sandstone Member, Karakuwa. The strata above and below consist mainly of Facies h, massive or bedded gray shale of non-marine type. The sequence is probably agitated lake deposits.

of the fining-upward cycle in the Makinohama Sandstone Member. The predominance of cross-stratified sandstone and the frequent intercalations of muddy sediments indicate sedimentations attributed to repetitions of active water-flow action and suspension load. Such non-marine sedimentation due to mixed load occurred probably in a lacustrine (lake) environment as well as in a fluvial environment.

However, Facies d is distinguished from fluvial deposits represented by Facies c_1 by the following charactersistics; no indication of strong water action such as penecontemporaneous erosion structures, intraformational conglomerates (shale clasts) and large-scale cross-bedding. It is rather characterized by small-scale cross-bedding and good stratification marked by the frequent intercalations of thinner finer-grained and better-sorted sandstone beds. In the studied area the shales are massive in some places, but in many others they are thinly bedded or show a varve-like appearance. The above features coincide with those of the lacustrine sediments listed by PICARD (1957). He described the differences between two types of deposits, lacustrine and fluvial, in sediments comprising sandstone and shale. In addition, the sediments of the studied area have a sedimentary sequence very similar to that assigned to lacustrine sediments by HEWARD (1978) and POLLARD *et al.* (1982). These are regarded as the sediments related to a lake delta. Incidentaly, as to recent lake delta sediments, for instance, in the Rhein-delta of Lake Constance, the 2–3 m thick sandstone bed which has been deposited since 1900, can be located down to 30 m below the lake bottom (FORSTNER *et al.*, 1968). This suggests that sandy sediments can be deposited in a comparatively deeper portion of a lake.

On referring to the above references, the Sakaguchiirizawa Sandstone of the Karakuwa Group and a part of the Tochikubo Formation of the Soma Group can be interpreted to be lake sediments which are comparatively rich in sandstone. However, it is not possible to determine whether the above strata are of deltaic origin, because its lateral facies change has not been sufficiently understood yet. It is considered that these strata of the South Kitakami showing cross-bedding were most probably formed under a lake-delta environment. If they were deposited under a non-delta environment, ripple-cross lamination or small-scale cross-bedding should be easily formed in the shallower part of lakes. In any case, the Jurassic of the South Kitakami Belt, as mentioned earlier, contains predominantly of sandy fluvial deposits;

the lake in the area may have been easily influenced by sandy inflow, mostly due to rivers.

The sequence with thicker muddy rocks in the fluvial fining-upward cycles in this area is interbedded with distinctly varve-like, laminated siltstone (10 m in maximum thickness: e.g. Fig. 28) and thinly bedded sandstone in some parts of the thick shale sequence. The siltstone and sandstone can be explained to be sediments accumulated in ephemeral and small lakes on depressions of flood plain.

2–2 Quiet Lake or Marsh Deposits (NLM)

The deposits consist predominantly of non-marine shale represented mainly by massive or bedded gray shale, with some black shale (Facies h). They are interbedded with laminated siltstone or fine-grained sandstone at some localities. These deposits, 30 to 200 m thick, are representatively found in the lower part of the Makinohama Sandstone Member, the Kiyosaki Sandstone Member (Unit Ky 2 and 5) and the Tochikubo Formation.

The sediments of non-marine environment, and the prevailing thick muddy sediments due to suspension load are considered to have accumulated in lake (lacustrine) or alluvial flood plains. The alluvial flood plain deposits are easily mixed with sandy material due to bed load transportation, consisting mainly of mixed load deposits (REINECK and SINGH, 1973: p. 259). Therefore, a lake or marsh environment is exceedingly suitable for the development of thick mudstone (shale).

Except for the agitated lake deposits mentioned earlier, it is known that in lake sediments the grain size distribution generally varies with water depth, that is, finer material increases with depth (TWENHOFEL, 1932; MÜLLER, 1963; MÜLLER and GEES, 1970). On the other hand, ancient lake sediments in continental regions contain a large amount of carbonate rocks such as limestone and dolomite in addition to clayey or silty, clastic material (VISHER, 1965b; PICARD and HIGH, 1972; COLLINSON, 1979). But such non-marine carbonate rocks are not found in the Jurassic of the Kitakami region. In this region, the muddy lake deposits are interbedded sporadically with graded sandstone layers or cross-stratified and parallel laminated sandstone in some places. Graded beds are well known in recent lake deposits (HOUBOLT and JONKER, 1968) as well as in older ones (SANDER, 1968). These graded beds are explained as transport and deposition by turbidity currents flowing down lake bottom. The example of the Kitakami region suggests that some sediments were accumulated by flood currents at the lake bottom.

From the above description, the deposits composed of Facies h are considered to be relatively small scale ephemeral lake deposits on the alluvial flood plain, associated with fluvial deposits.

3. Beach Ridge-Coastal Marsh Association (ABR)

The deposits are composed of massive to very thick-bedded sandstone interbedded with shale. Upward decrease in grain size is indistinct or not observed. Although the deposits are similar to the distributary-interdistributary deposits on the whole, the sandstone is finer grained and better sorted than that of the distributary deposits. Moreover, the amount of the interbedded shale is as much as 10 to 30 percent of this association and the shale is shomewhat carbonaceous in many cases. The sandstone generally shows cross-bedding of planar type and is massive and structureless in some parts. Cross-bed sets range in thickness between 0.2 and 1.5 m and occur in cosets up to 4 to 8 m thick in the case of the Makinohama Sandstone (Pl. II-2).

These deposits are found in a part of the Kogoshio Formation (Kg-1 and Kg-4: Fig. 32), the uppermost part of the Makinohama Sandstone Member, the lowermost part of the Kiyosaki Sandstone Member, and some other formations. The uppermost part of the Tochikubo Formation also may be referred to these deposits. As the shallow marine deposits are in contact with the above formations, these deposits suggest that the deposition took place in coastal areas. Moreover, considering the comparatively well-sorting of sand grains, there is a

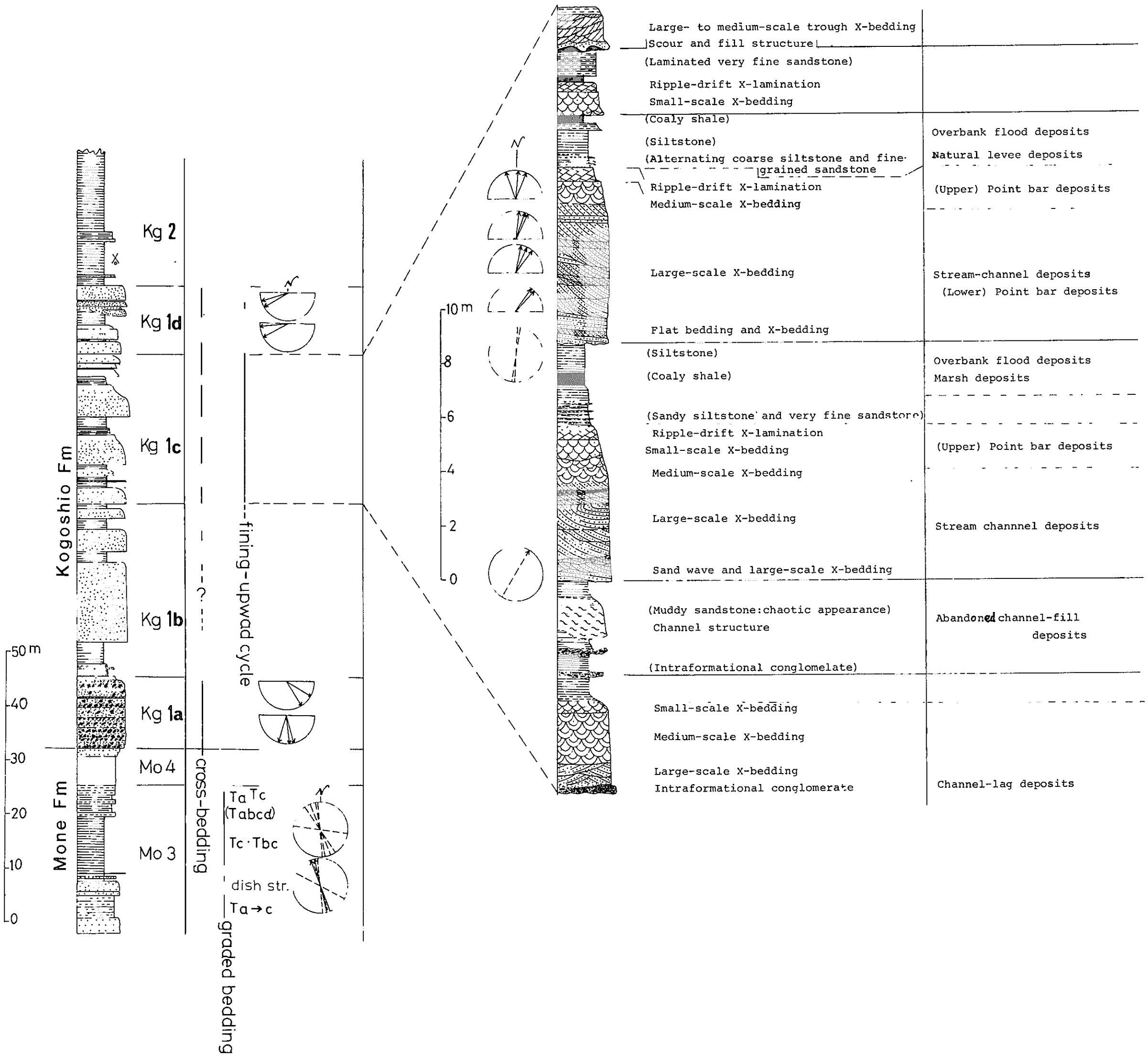


Fig. 32 Sedimentological sectios of Unit Kg-1 of the Kogoshio Formation, at the eastern extremity of the islet of Oshima, Karakuwa. Deposition in mixed environments of shallow marine and non-marine (fluvial sequence) is shown. Arrows in circles and hemicircles indicate paleocurrent directions of cross-bedding and sole marks respectively.

large possibility that the deposits are beach ridge sands such as coastal dunes. Since the intercalated shale is comparatively, carbonaceous, this could have been derived from coastal back marsh. As seen from Figure 33, distributary of estuarine environments with extended beach ridges on the sides were presumably on a coastal plain. The deposits may be comparable with the medium-scale cross-bedded cosets which are underlain by the distributary channel deposits of the Kinderscoutian deltaic sediments (Upper Carboniferous, northern England) reported by McCabe (1977).

4. Shallow Marine Facies Association

Shallow marine facies association is one of the principal deposits characteristic of the Jurassic in the Southern Kitakami Belt. This association is rich in coarse-to fine-grained

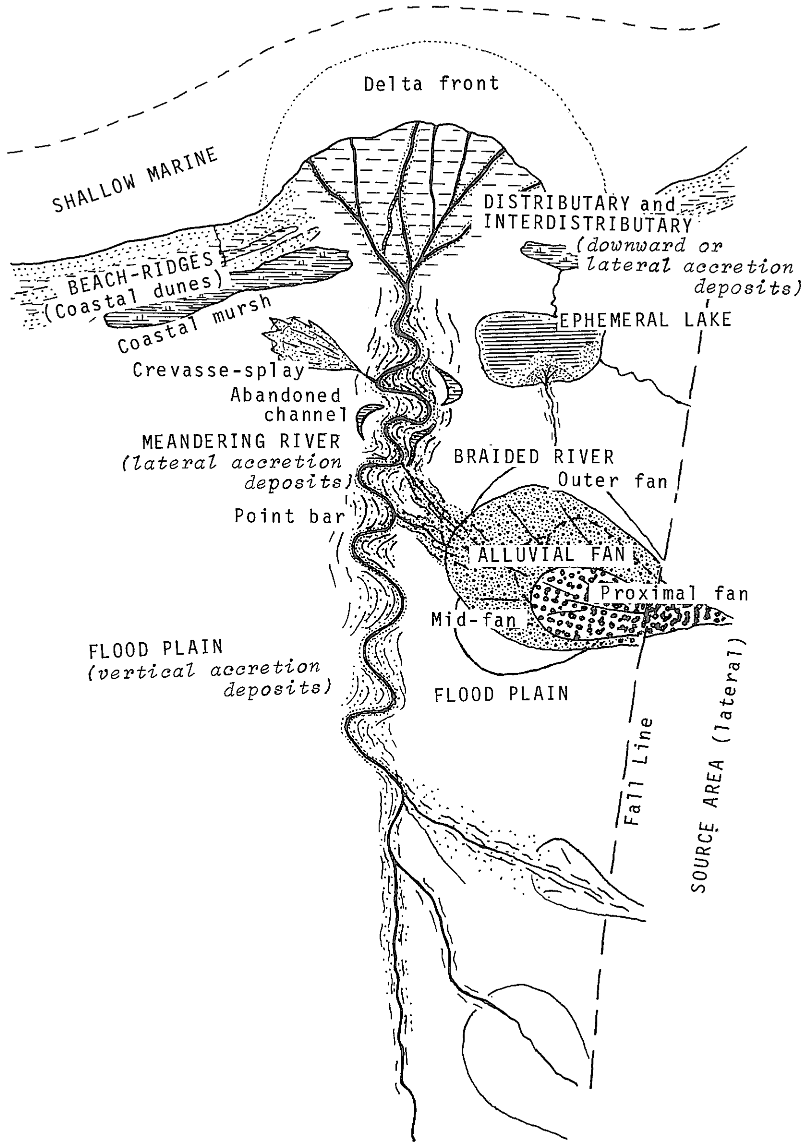


Fig. 33 Diagram showing suggested disposition of various sedimentary environments of the Jurassic non-marine deposits in the South Kitakami Belt. This illustration is based on sedimentological data of the Oshika area.

arkosic sandstone yielding abundant molluscan fossils. However, it is difficult to exactly estimate the depth of deposition in a shallow marine environment. WALKER (1979) has defined the "shallow seas" as the seas of depths of 10 to 200 m. Taking this into consideration, the Jurassic shallow marine sediments are considered to be deposited on the sea floor at most 100 m deep off the shoreline.

Regarding the Jurassic of the South Kitakami Belt, littoral sediments are included in the present association, because the distinction between the littoral (intertidal or beach) and sublittoral sediments is insufficient.

This association is classified into the following several types of the deposits which were formed under various shallow sea conditions.

4-1 Transgressive Shallow Marine Sandy Deposits (SLS)

Transgressive shallow marine sandy deposits are composed mostly of massive to bedded coarse- to fine-grained sandstone (Facies a and b), frequently showing cross-bedding and parallel lamination. The greater part of the sandstone is characterized by arenite. These deposits are also characterized by yielding abundant marine bivalves, especially trigoniids. Shallow marine sand deposits are found in the three stages of Bajocian, Upper Oxfordian and Berriasian in the Middle Subbelt, and also in the four stages of Hettangian, Bajocian, Tithonian and Berriasian in the Western Subbelt. Of these deposits, the Bajocian ones are most extensively exposed in the Jurassic in the South Kitakami Belt. The thickness of these deposits is generally in the order of several tens of meters or less, but in some areas it reaches 200 m or more as in the case of the Tsukinoura Sandstone Member in the Oshika area (Fig. 19).

The transgressive shallow marine sandy deposits bigin with coarse-grained sandstone, and grade through medium- and fine-grained sandstone into sandy shale in ascending order, and in many cases, further upward into thick shale beds of probable offshore basin-floor deposits. Conglomerate is bedded in its basal part in some places. The deposits as a whole grade gradually from nearshore facies into offshore mud, suggesting a transgressive environment changing from shallow-water to deep-water.

It is well known that in shallow seas a large amount of sands can be accumulated on beaches (back shore, foreshore and shoreface), sublittoral sandbar and sandwaves. Moreover, channel- or sheet-like sandstone beds may be formed under the influence of strong river-flood flow or storm.

The details of the sedimentary environment of the Jurassic shallow marine sandstone beds, however, are not understood very well, because the sedimentary structures of these beds are not yet sufficiently clear. It is obscure whether massive and structureless appearances of the Jurassic sandstone beds at many exposures are original or due to disappearances of the stratification structures by strongly weathering or other factors. Actually, in the same sandstone beds, lamination is distinctly displayed at some exposures but not seen or obscure at other localities not far apart. For example, in the sandstone consolidated by calcite cementing, sedimentary structures are very clearly observed at some weathered exposures, but are very obscure at other fresh outcrops. According to REINECK and SINGH (1973), JOHNSON (1977) and WALKER (1979), it is unlikely that the majority of recent and ancient shallow marine sediments are massive and structureless.

The physical processes through which sediments are transported into shallow seas are very diverse complicated, and the processes were classified by SWIFT *et al.* (1971) as follows: 1) intruding ocean currents, 2) tidal currents, 3) meteorological currents (direct wind, wave and storm surge), 4) density currents. WALKER (1979) pointed out that, of these processes, storm and tidal currents are the most important major processes. In this way, the shallow sea sediments of the South Kitakami Belt are studied in the light of the concept of storm-dominated and tide-dominated processes.

In discussing the shallow marine deposits of the Jurassic in the South Kitakami Belt, it is necessary to take paleogeographic conditions into consideration. As will be described later, the Jurassic basin of the South Kitakami probably was formed as an inland sea with an upheaval zone on its eastern side. Therefore, the transportation of sediments by the intruding ocean currents mentioned above probably had no important effect upon the deposition. According to certain reports (e.g. MOGI, 1963), tidal action is generally powerful in inland seas, and thus smooth beaches showing gentle slopes can be easily developed. The beds which, from the conspicuous development of burrows, are inferred to be deposits in an intertidal or littoral zone are found in the lower part of the Kozumi Member (Fig. 34; Pl. III-3A) and the Kobitawatashi Member (Pl. III-3B; TAKIZAWA, 1975) in the Oshika Peninsula and the Kogoshio Formation

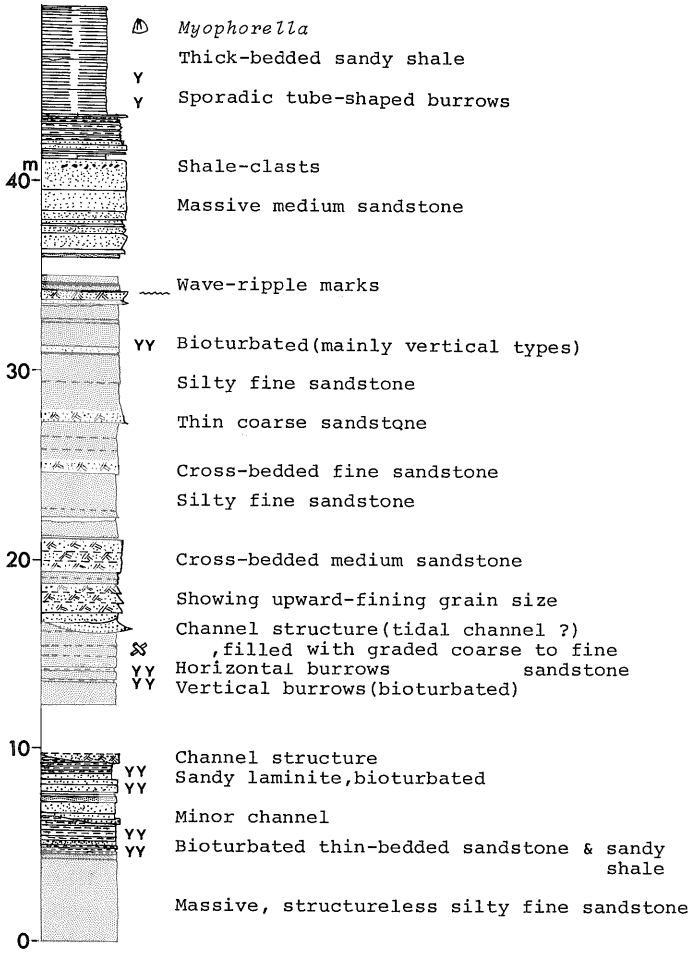


Fig. 34 Detailed measured section of the lowest part of the Kozumi Shale Member, Oshika. This sequence were probably originated from a nearshore shallow marine environment.

(Kg-1d and Kg-5) in the Karakuwa area.

It is well established that in the littoral zone, powerful actions of tidal currents, wind and wave have important effects upon the sedimentary processes of sand. However, as regards the Jurassic strata, it is difficult to reconstruct some concrete bed forms and processes or currents which were contributory to the deposition, because the sedimentary structures and bed forms are not fully clarified at present.

In some parts of the Tsukinoura Sandstone Member and the Aratozaki Formation of Bajocian age where shallow marine sand deposits are best developed, thick coarse-grained sandstone beds are interbedded with sandy shale beds. A portion of these shale beds yield fossils such as *Bakevellia, Kobayashites* and *Eomiodon*, being assigned to the Cyrenoid ("*Corbicula*")-facies of HAYAMI (1962). These fossils suggest a lagoonal environment.

Consequently, the Tsukinoura Sandstone Member and the Aratozaki Formation are mainly of littoral facies, but parts of them are probably of temporary lagoon or embayment origin. During the deposition of the Tsukinoura and the Aratozaki, a part of the shallow sea was probably closed by a barrier bar and then a lagoon was formed. A probable tidal channel traversing sand ridges between the lagoon and the shallow sea was possibly formed and was accompanied by tide-dominated sand deposition as in flood-tidal delta and ebb-tidal delta.

On the other hand, the sandy muds of the Tsukinoura Member and the Aratozaki Formation were accumulated probably toward offshore free from any sublittoral wave action. These sandy muds (sandy shales) together with some finer mud (shales) which were probably deposited further offshore, are interbedded with coarse- to medium-grained sandstones. These sandstone layers, 0.2 m to 3 m in thickness, are classified into three types; lenticular sandstone with tabular cross-bedding (type 1), massive and structureless sandstone with sole marks such as groove and flute casts (type 2), and parallel-laminated thin sandstone (mostly fine-grained; type 3).

Of these various types of sandy intercalations, the sandstone of type 1 is considered to have generated from mega-ripples or small-scale sand waves, and to have been transported probably from a littoral zone to a sublittoral zone by tidal currents. The sendstone is rarely mixed with granular or fine pebbles. The sandstone of type 2 is massive containing comparatively abundant carbonaceous material, and its sole marks indicate approximately northward paleocurrent. This type of sandstone shows graded bedding at some places, but the grading becomes indistinct as the layers increase in thickness on the whole, thus closely resembling fluxoturbidite or proximal turbidite of flysch facies. Actually, a number of examples of such ancient shallow marine deposits interbedded with turbidite-like sandstones have been reported by WALKER (1969, 1970), READING (1970), BARTOLINI *et al.* (1975) and McBRIDE *et al.* (1975). They have maintained that these deposits were formed by river-generated flood currents. As to recent sediments, turbidite-like sediments generated by river-floods are known from the offshore of the mouth of the Kongo River (HEEZEN *et al.*, 1964) and also from that of the river mouth in the western coastal region of France (NESTEROF *et al.*, 1968). Therefore, it is considered that the sandstone of type 2 is of high energy origin and is river-generated flood deposits.

The parallel-laminated thin sandstone (type 3) probably originated from sublittoral sandy material and was transported into muddy environments such as deeper offshore areas by storm currents.

Compared with the Tsukinoura Sandstone Member and the Aratozaki Formation, the other shallow marine deposits of Bajocian age are simple in composition and mode of vertical variation of lithofacies. They grade monotonously from littoral sandstone upward into sublittoral sandy shale.

In the South Kitakami Belt, the transgressive shallow marine sand deposits of Kimmeridgian age consist of sediments better sorted than those of Bajocian, and do not contain conglomerate. The medium- to fine-grained sandstone of the lower part of the Kozumi Member in the Oshika area shows through cross-bedding, comprising alternation of clean matrix-poor sandstone and silty sandstone rather rich in matrix in some places (Fig. 34). The latter may have been formed in littoral depressions with weaker wave action than the former. The absence of muddy rocks in the sand sequence suggests that the environments oscillated between a small-scale wave-formed sandbars on shoreface and interbar troughs. Moreover, the possibility of the presence of a lagoon in the southeastern part of the studied area (Kukunari area) is a problem to be solved in the future.

The shallow marine sand facies of the Nakanosawa Formation in the Soma Group, containing no muddy rocks, is composed mainly of coarse-grained sandstone in the south (Fig. 35), indicating dominant sedimentation in nearshore areas where tidal action was strong. On the other hand, medium- to fine-grained sandstone with calcareous or silty matrix is considerably abundant in some places, especially in the northeast, yielding abundant open-sea bivalves such as pectinids, limids, astartids and trigoniids. The Torinosu bio-facies which comprises the most representative Upper Jurassic neritic bivalve fauna of Japan, shows a bio-facies corresponding to the offshore "shallow mound association" -dominated components (TAMURA, 1961). In the Soma area, the sea was probably not very deep

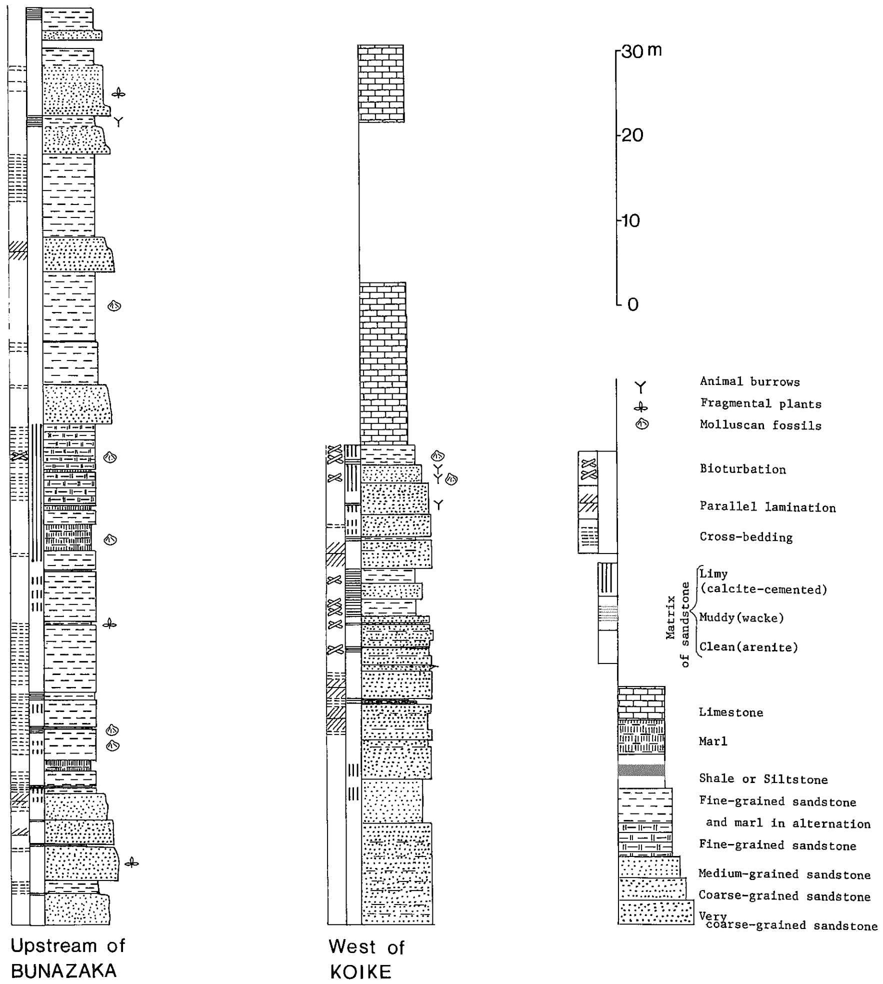


Fig. 35 Detailed measured section of the Nakanosawa Formation, Soma.

with many gentle undulations on the floor. Shallow sand banks presumably extended offshore. However, the bed forms and structures of these sand bodies have not been fully clarified.

4-2 Regressive Shallow Marine Sandy Deposits (SLS)

Some regressive sand bodies occur between the alluvial facies association and the flysch facies association to be described later. These are represented by the lowermost part (Kg-1) of the Kogoshio Formation in the Karakuwa area, the lowermost unit of the Makinohama Member in the Oshika area, and the lowermost part of the Kiyosaki Member in the Oshika area. These are found also in the Cretaceous of the Oshika area (TAKIZAWA, 1975).

As shown in Figure 32, 57 and 58, these deposits consist mainly of coarse-grained sandstone with remarkable cross-bedding, mixed with exotic pebbles at some exposures. They are distinctly different from the underlying flysch facies, and yield marine fossils in the Kogoshio Formation and the Kiyosaki Member. Conspicuous development of tabular cross-bedding is well known in sand waves of offshore (NIO, 1976; FLEMMING, 1978) or tidal flood deltas (HAYES, 1980; MASUDA *et al.*, 1981) as in the regressive shallow marine sandstones with limestone pebbles described here. The lowermost parts of both the Kogoshio Formation and the Kiyosaki Member contain abundant limestone pebbles derived from reef-like limestone, which was probably formed in a more open shallow sea, destroyed by violent storm, and then transported approximately parallel to the shoreline. The deposits in question may have been formed partially by sand waves, judging from the relation to the underlying formation and the paleocurrents. However, paying special attention to the coarse-grained sandstone containing exotic pebbles (mostly granites) and very abundant limestone pebbles, the very restricted distribution of the deposits and the presence of overlying fluvial deposits, it is considered that these deposits of the Kogoshio and the Kiyosaki were formed by tidal flood-delta sedimentation rather than by sand waves. Thus, such deposits probably resulted from pebbly coarser sands which were transported by longshore currents along the beach to form tidal delta through tidal channels in embayments.

The sequence at 3 m to 18 m above the base of the Makinohama Member is regarded mainly as offshore sandbar deposits, judging from well-developed cross-bedding and relatively well sorted sandstone.

4–3 Embayment Muddy Deposits (**SEM**)

Embayment muddy deposits are typically developed in the Lower Jurassic Niranohama Formation in the Western Subbelt. They yield brackish bivalves abundantly, and are composed, in many places, mainly of sandy black shale frequently interlaminated and interbedded with very fine sandstone. The sandstone beds are in the order of several meters thick. Shale is considerably carbonaceous and sporadically contains fine-grained pyrite.

Bays are classified into the two types, steep slope and gentle slope ones, based on their topographic profiles (MOGI, 1963). The Lower Jurassic sediments mentioned above were formed probably in the latter type bay. Also it is said that in bays with smooth profile beaches, sand bars are not developed because of weak wave action (MOGI, 1963).

The sandstone interbeds in this type of deposits are characterized by appreciable parallel lamination with a few ripple marks. The majority of the muddy deposits may have been derived from suspension load, showing sandy lamination formed probably by floods or not-very-strong wave actions.

5. Basin Mud Facies Association

5–1 Quiet Basin Mud Deposits (**BQM**)

These muddy deposits consist of Facies f (thick- to medium-bedded black shale containing marine fossils) and indicate sedimentation on a tranquil and stable basin floor. These deposits are found in the Middle to Upper Jurassic Hashiura Group and the Lower Jurassic Hosoura Formation in the Western Subbelt, and the Bajocian Tsunakizaka, Samuraihama and Awazu Formations and the Upper Oxfordian Kozumi Formation in the Middle Subbelt. They comprise shale beds, and are mostly between 150 m and 500 m in thickness. Fossils are represented by ammonoids, containing some bivalves in some places. Calcareous nodules are ubiquitous in these formations, tending to increase in size eastward.

The deposits generally grade downward to shallow marine sandy beds, interbedded with episodic graded beds (turbidites) in its transitional part. It is considered that suspended material of silt and clay released from rivers into sedimentary basins was diffused and deposited in the basin by various marine currents and formed the deposits in question. The development of the bedding plane suggests some stages of interruption of sedimentation.

5–2 Agitated Basin Mud Deposits (**BAM**)

Agitated basin mud deposits are composed chiefly of laminated shale. Streaky, sandy or silty intercalations and laminations are frequently developed in this shale. These deposits occur in some places thin sequences both above and below the quiet basin mud deposits. In many parts, they are developed showing a lateral change from the quiet basin type. They occur, among others, in the northern facies of the Mone Formation, a part of the Kozumi Member and the lower part of the Arato Formation. The thickest sequence of the deposits of this type occupies the middle part (Cretaceous) of the Ayukawa Formation, where it is mixed with other facies for more than 500 m in thickness.

This laminated shale was derived from deposits formed in basins which were agitated by intermittent actions of currents caused by factors other than ordinary marine currents. These deposits probably were generated from strong suspension load containing relatively coarser material as in the case of the end parts of turbidity currents and storm- or river-generated flood currents. Of the above formations, the laminated shale of both the Mone Formation and the Kozumi Member is inferred to be an end facies of turbidites. This is based on the mode of lateral and vertical facies changes. It was proposed by the writer (TAKIZAWA, 1975) that fine-grained material (smaller than fine sands) in river flood waters was transported by suspension currents of low energy into the basin. The material then diffused and were deposited there by bottom currents of down-slope flow type and formed the middle Ayukawa Formation comprising deposits of distal delta (delta-slope or pro-delta). The lower Arato Formation is considered to be the end facies of turbidites, as will be mentioned later.

The term "agitated basih mud deposits" is derived from De RAAF *et al.* (1965), WALKER (1969, 1970) and READING (1970), which has been applied commonly to delta, shallow marine or lagoon deposits (interbedded also with turbidites) formed under the influence of wave or tidal current. The deposits of the middle part of Ayukawa Formation, among others, are similar to the deposits designated by these authors.

6. Flysch Facies Association (FSF·FDF)

Flysch facies association consists mainly of sandstone and shale in medium- to thin-bedded rhythmic alternation (Subfacies j_1 and j_2), accompanied by thick-bedded medium sandstone (Facies e), and laminated shale (Subfacies i_1 and i_2).

In the Middle Subbelt, the deposits of Flysch Facies Association are most thickly and extensively exposed in the Oginohama Formation of the Oshika Group (2 horizons, Kt and Fk) and in the upper half of the Mone Formation of the Karakuwa Group, both of which belong to the Oxfordian to Kimmeridgian of the Upper Jurassic. They overlie the basin mud facies. It is considered that a slope was formed in the regressive stage of sedimentation of the late Jurassic basin to generate turbidity currents.

In the Western Subbelt, the flysch-type deposits are developed in the lower half of the Arato Formation (Table 13). In the sedimentary basin of the Arato Formation, the flysch facies developed at the early stage of transgression which indicated rapid deepening of the basin.

As shown representatively in Figure 36, various kinds of subfacies are associated with each other in the Upper Jurassic flysch facies in the South Kitakami Belt. The main constituents of these flysch-type deposits are listed below, their representative sedimentary structures being shown in Figure 36.

1. Thin-bedded shale-sandstone alternation (Subfacies j_2)
2. Medium-bedded sandstone-shale alternation (Subfacies j_1)
3. Thick- to medium-bedded medium-grained sandstone (Facies e)
4. Thinly laminated shale (Subfacies i_1)
5. Shale interbedded with thin sandstone layers (Subfacies i_2)
6. Bedded black shale (Facies f)

Among them, 1 to 4 are the main facies, and 5 and 6 are the subordinate facies. Vertically these facies change into and are replaced by each other very rapidly (Figs. 18, 20, 22). Generally, the thickness of the above six facies is found to range from a few meters to about 50 m.

It is, however, recognized in the outcrops that a coarsening- or thickening-upward sequence comprises the following lithofacies in ascending order: bedded shale (Facies f) or laminated shale (Facies i), thin-bedded shale-sandstone alternation (Subfacies j_2), medium-bedded sandstone-shale alternation (Subfacies

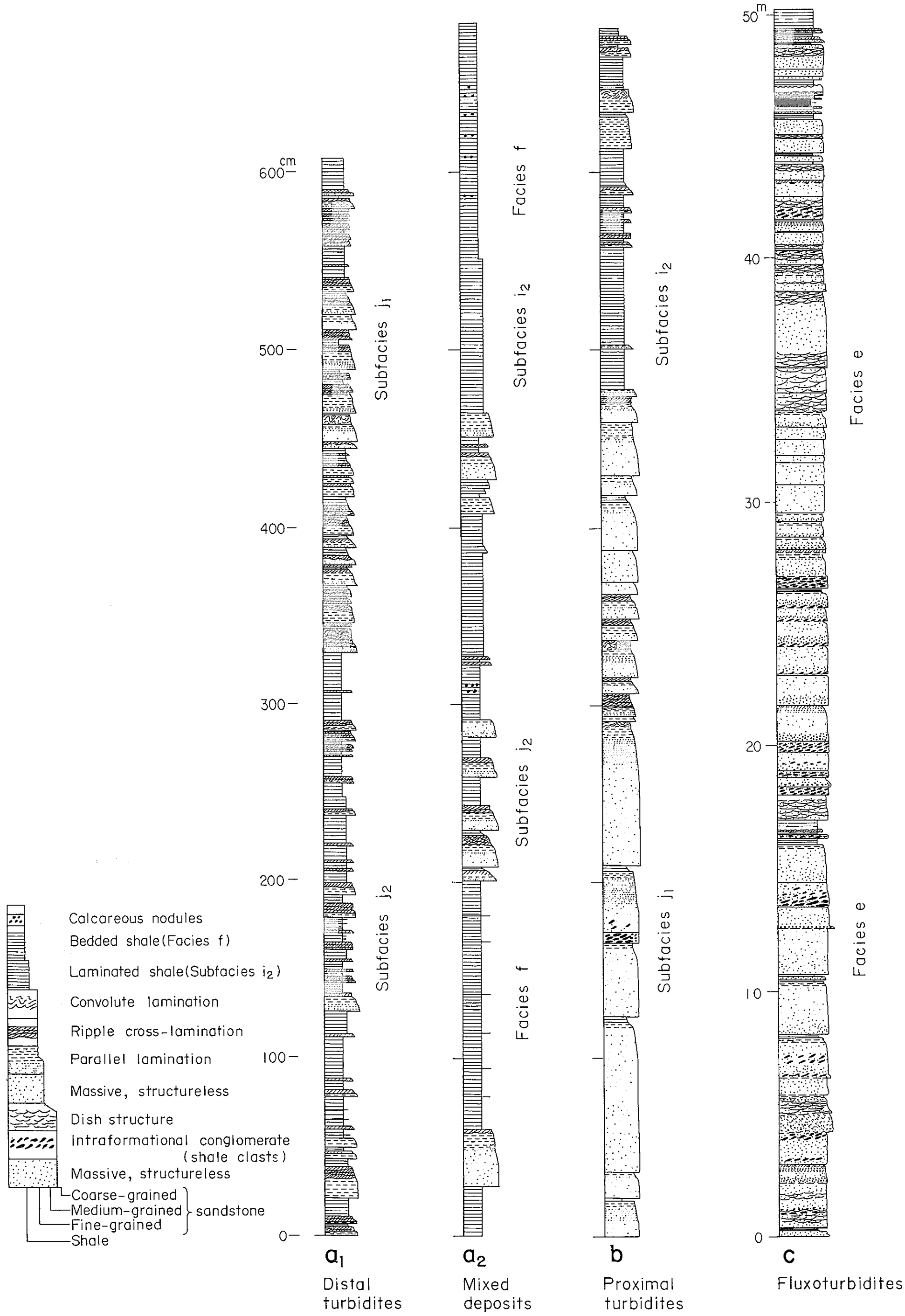


Fig. 36 Sedimentological sections of the Fukkiura Shale and Sandstone Member, Oshika. All of the sections are included in flysch type deposits. The left three sections contain turbidite sandstone beds (Facies j) and the right one fluxoturbidites (Facies e).

j_1) and thick- to medium-bedded medium-grained sandstone (Facies e). In this manner such a sequence shows a definite vertical change from the shale-dominated facies to the sandstone-dominated facies. Thickening-upward sequences are, if anything, found more commonly in the lower part of the Fukkiura Member in the western part of the Oshika area than in the eastern part (Fig. 20) and the lower part of the Mone Formation of the Karakuwa area. A small amount of thinning- or fining-upward sequences are observed in the upper part of the Fukkiura Member in the western part of the Oshika area.

As shown in Table 12 and Figures 37 and 38, sandstone beds of the flysch facies mostly occur as graded beds characteristic of the "Bouma sequence", and they are referable to turbidite, occasionally interbedded with fluxoturbidite of Facies e.

Facies e (thick- to medium-bedded medium-grained sandstones) is characterized by shale-clast conglomerate and dish structure (Fig. 36). It occasionally shows channel structures (Fig. 39). Some of this facies is inferred to have deposited over submarine channels which cut into submarine slopes.

Intraformational mud-pebble conglomerate has been reported from a number of modern

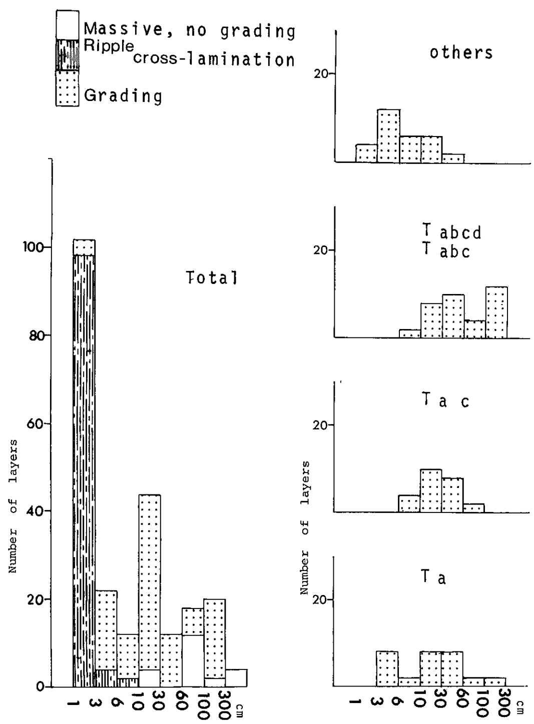


Fig. 37 Frequency distribution of sequence types in the flysch facies association of the Mone Formation, Karakuwa. For sequence types see Table 12.

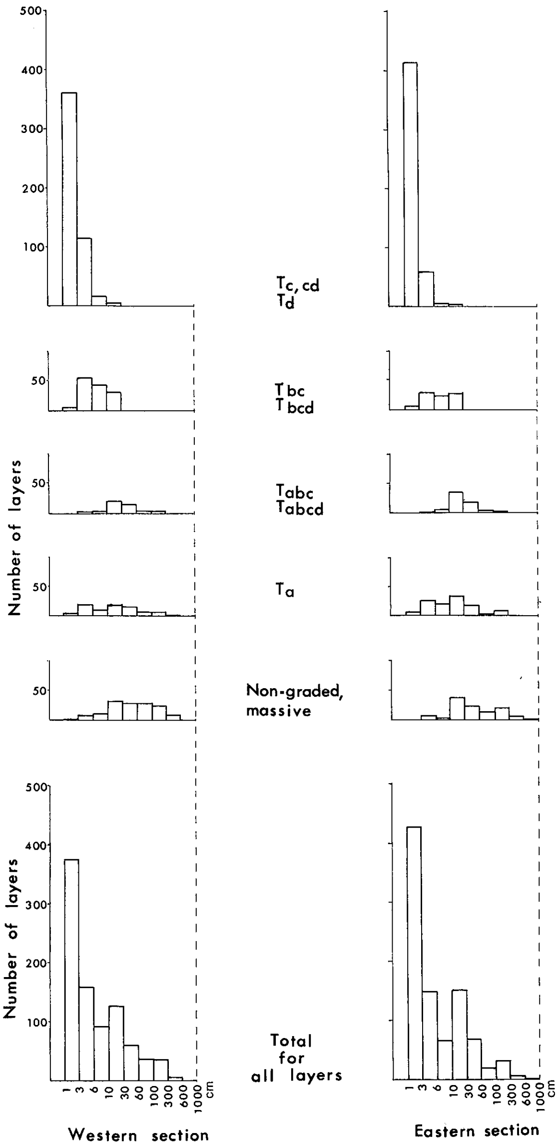


Fig. 38 Frequency distribution of sequence types in the flysch facies association of the Fukkiura shale and Sandstone Member. For sequence types see Table 12.

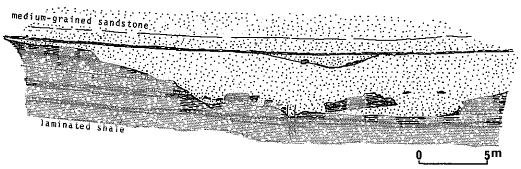


Fig. 39 Submarine channel structure in the Fukkiura Shale and Sandstone Member at Koamikura of the Oshika Peninsula.

and ancient channel deposits (SHEPARD *et al.*, 1969; PICHA and NIEM, 1974; STANLEY and UNRUG, 1972; STANLEY and KELLING, 1978). Furthermore, according to STAUFFER (1967), CHIPPING (1972), CORBETT (1972), STANLEY and KELLING (1978) and HEIN and WALKER (1982), dish structures are characteristically present in slope or channel deposits with in thickly bedded sandstone sequence. This supports the above depositional interpretation of the present facies.

The conspicuous feature in the Upper Jurassic flysch facies of the Middle Subbelt is the juxtaposition of turbidites (Facies j) and laminated shale (Subfacies i_{1a}). This laminated shale is considered to be formed in a relatively shallower water environment such as a subaqueous delta as mentioned later, and a fair amount of the turbidite is also presumed to be formed in not so deep water environment accordingly. For reference, similar deposits to Subfacies i_{1a} have been reported a number of ancient deltaic and shallow marine deposits (De RAAF *et al.*, 1965; WALKER, 1969; READING, 1970; De RAAF *et al.*, 1977).

The laminated shale (Subfacies i_{1b}) is considered to be an end facies of turbidite, and relatively coarser laminated shale to be overbank and levee deposits in the vicinity of submarine channels or interchannel (basin slope) deposits. In the eastern facies of the lower half of the Arato Formation of the Shizugawa area and the northern facies of the Mone Formation of the Karakuwa area, laminated shale of Subfacies i_{1b} is well developed together with a few turbidite sandstone beds. In the former area, as will be described later, inflow of sand from the eastern side of the Middle Subbelt is inferred and resultant deposits can be explained to be distal turbidites. The presence of conspicuous channel structures leads to the presumption of a channel structure inclined westward.

The shale intercalated with thin sandstone layers (Subfacies i_2) frequently occurs adjacent to Facies e (fluxoturbidites) which probably deposited on slopes. The deposition of the thin sandstone interbeds within Subfacies i_2 may have been due to bottom tractional currents (including reworked sediments) as pointed out by HSÜ (1964) and KEITH and FRIEDMAN (1977). Similar deposits in a flysch sequence to Subfacies i_2 have been reported from other ancient submarine slope deposits; Cambrian submarine slope deposits of New York and Vermont (Current-ripple-laminated limestones and sandstones facies) by KEITH and FRIEDMAN (1977), Archaean submarine interchannel deposits of Western Australia (Shale with starved ripples and laminated siltstone) by ERIKSSON (1982), and Precambrian upper basin-slope deposits of North Norway (Current-rippled siltstone facies) by PICKERING (1982).

Lately, submarine slopes and fans have been considered to be the locations of deposition of turbidites in many cases (WALKER and MUTTI, 1973). Also together with a number of studies on recent submarine fans and fan-valley complex (SHEPARD *et al.*, 1969; NORMARK, 1969), the relations of turbidites and associated facies to location of deposition have been discussed (STANLEY and KELLING, 1978). Taking the vertical and horizontal facies relations into consideration, together with the results of the above-mentioned studies, it is necessary to discuss whether the sedimentary locations of the Jurassic flysch facies were major submarine slopes and submarine fans. In connection with the genetic interpretation of the Upper Jurassic turbidites and the depositional pattern of the flysch facies, this problem is discussed in the next chapter.

Brief Remarks on the Trace-fossil Fauna in the Flysch Facies

The formations of flysch facies mentioned above, particularly the Fukkiura Member, the upper half of the Mone Formation and the Arato Formation yield abundant trace fossils.

Table 15 Trace fossils from the Jurassic flysch-type deposits.

Type & Ichnogenus \ Formation	MONE (S)	MONE (N)	OGINOHAMA (S)	OGINOHAMA (N)	ARATO	Rocks
Straight, branched forms						
Chondrites	+		++			laminated shale
Fucusopsis (?)				△		//
Winding, unbranched forms						
Taphrhelminthopsis					+	laminated shale
Neonereites					+	//
Scalarituba (?)					+	//
Meandering forms						
Cosmorhaphe				++		laminated shale
U-shaped trails(type a)		+	+	+	+	//
Spreiten traces						
Zoophycos	+		++			turbidite ss.
Phycosiphon		++			+	laminated shale
U-shaped trails(type b)	+			++		//

△: rare +: common ++: abundant
(S): southern part (N): northern part

The trace fossils are noteworthy indicators of sedimentary environments. The morphological classification of these fossils according to KSIAKIEWICZ's scheme (KSIAKIEWICZ, 1970) is given in Table 15. Compared with the trace fossil assemblage from flysch facies in Europe and other areas, that of the South Kitakami is poor in variety, but the five of the total seven species identified occur very abundantly.

Among these trace fossils, *Zoophycos* cf. *laminatus* occurs in the graded beds of the Mone and Oginohama Formations (Fig. 40), and is especially abundant within divisions Tb (lower parallel lamination) and Tc (ripple-cross-lamination) of the "Bouma sequence", sometimes within division Td (upper parallel lamination). *Chondrites* sp. occurs also in the above formations and has a variable tube width of 1 to 5 mm in diameter. It occurs gregariously from lamina to lamina within thinly laminated shales in the Fukkiura Member of the Oshika area. *Cosmorhaphe* sp. has a narrow tube 1 to 2 mm wide in diameter, and is found only in laminated shale (facies i_1) in the Fukkiura Member of the northwestern part of the Oshika area and the Arato Formation of the Shizugawa area. *Phycosiphon* sp. occurs within micaceous

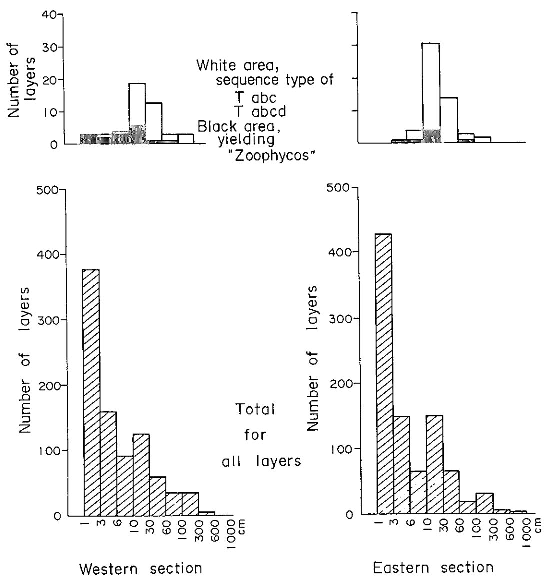


Fig. 40 Relationship between sequence type and frequency of occurrence of trace fossil *Zoophycos* in the Fukkiura Shale and Sandstone Member, Oshika.

laminated shale abundantly from lamina to lamina in the northern facies of the Mone Formation, and the Arato Formation. U-shaped trails of a meandering type which resemble string-like *Helminthopsis*, are very abundant especially within laminated shale of the Fukkiura Member of the eastern part of the Oshika area.

These trace fossils consist of ethologically Pascichnia and Fodinichnia, containing neither Cubichnia nor Domichnia, and all are horizontally in relation to the bedding plane. The trace fossils in question as a whole are assigned to the *Nereites* to *Zoophycos* facies of SEILACHER (1964) or the mesobathyal to epibathyal zone of KSIAZIEWICZ (1977).

However, the flysch facies of the Jurassic in the studied area lacks *Nereites* and *Paleodictyon*, characteristic of the *Nereites* facies. Trace fossils are considerably restricted in variety, occurring nearly always in the "exclusive swarm" in the studied area. Therefore, these trace fossil fauna may reflect considerably peculiar environments or water depth, for instance, not open sea but inland sea.

On the other hand, in relation to the forms of the Jurassic sedimentary basins, the *Nereites* facies of the mesobathyal zone characterized by *Cosmorhaphe* and *Phycosiphon* suggests a basin floor, and the *Zoophycos-Chondrites* "fauna" an intermediate between basin-floor and shallow sea, probably a basin slope. Some further evidence of the trace fossil faunas also supports the hypothesis that the basin was shallow in the southern parts of the Karakuwa and Oshika areas. This is consistent with the lateral facies change, namely, the development of proximal facies in the south.

7. Textural Properties of Sandstones

It is clear from the preceding descriptions that the Jurassic formations of the South Kitakami Belt consist of a wide range of sedimentary facies originated from various sedimentary environments. Different sedimentary environments would result in different mechanism of transportation and thus deposition of clastics with different grain-size compositions. Of many studies on the relation between environment and grain-size composition, the methods of FRIEDMAN (1961) and VISHER (1969), among others, are applied here to the study of the Jurassic formations through grain-size analyses of thin sections.

When the data are plotted on the FRIEDMAN's diagram which relates to environmental distinctions in river-beach domains as shown in Figure 41, the shallow marine sand facies of the studied area almost overlaps the river sand area with skewness and sorting of no meaningful difference. This suggests that the shallow marine sand did not undergo high sorting by waves after its transportation by rivers into the

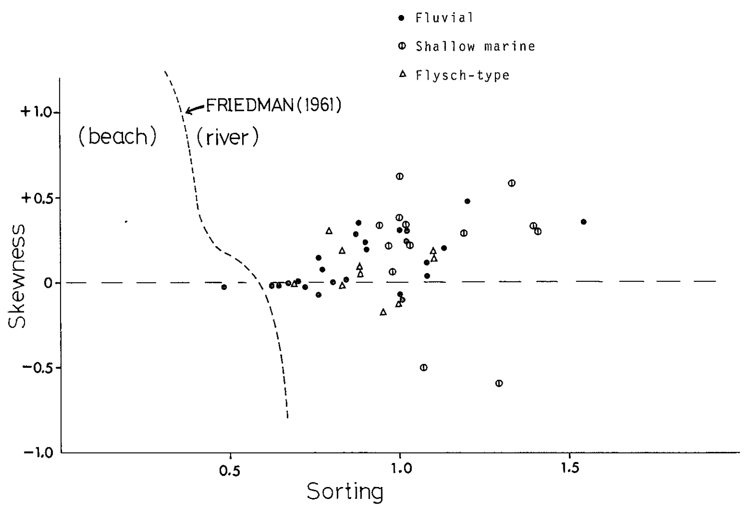


Fig. 41 Plot of skewness and sorting, using phi scale for beach and river sands by FRIEDMAN's scheme (FRIEDMAN, 1961).

shallow sea, that is, it was quickly deposited after a short period of transportation.

The size distribution of the sandstones of different sedimentary facies shown on the VISHER's logarithmic probability graph gives patterns of considerable variety (Fig. 42). The plots of the fluvial deposits are composed mostly of two straight lines, while those of the shallow marine sand deposits are given as a combination of three or more straight lines with frequent "coarse tail". Thus, the graph patterns of the shallow marine deposits seem to show mechanism of transport different from that of the fluvial deposits. It is noted that the turbidite deposits mostly show distribution of a nearly straight line with considerably steep gradient. This means that the mechanism of transportation-deposition was simple and rapid. Although

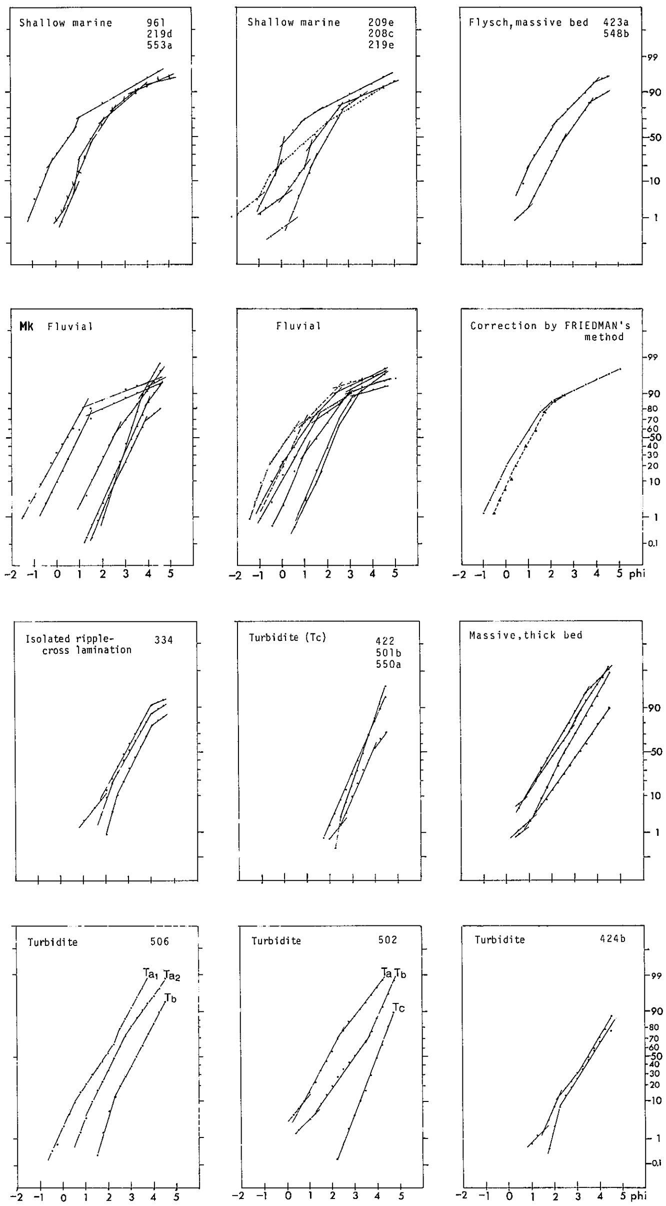


Fig. 42 Cumulative number-frequency curves in grain-size distribution on various kinds of facies of the Jurassic strata.

there could be some doubts as to the validity of the VISHER's method for direct correlation between graph patterns and their respective transport mechanism of suspension—saltation—traction populations, the writer believes that this method can be applied to the present case. Essential difference in plot is not seen between the fluxoturbidites (massive, thick bed) and the turbidites with barely recognisable coarse tail in the former.

It is noted that Subfacies i_2 type sandstone shows a break of the line in the fine-grained part of its cumulative curve. This bed is intercalated in the laminated shale of the flysch association. Although its depositional process is uncertain, this graph pattern is of similar tendency to that of the fluvial fine sandstone and different from division Tc (interval of ripple cross-lamination) of the turbiditic sandstone. This sandstone bed possibly includes element of tractional currents to be further studied. Furthermore, the fluvial sandstone has a tendency for the amount of mica to increase with the fining of grain size as was pointed out by the writer (TAKIZAWA, 1976). This can be explained by LOVEL's opinion (LOVEL, 1969) that hydraulic behavior of micas differs from other clastic grains due to its platy form.

VI. FRAMEWORK COMPOSITION OF COARSE CLASTICS AND PROVENANCE

1. Composition of Conglomerate

The Jurassic formations have a moderate amount of conglomerate composed of pebbles and cobbles. Conglomerate is prevalent particularly in the basal part of the Middle Jurassic and the lower part of the Upper Jurassic (probably Oxfordian). The Jurassic conglomerate is scarce in the Western Subbelt, whereas it is abundant in the Middle Subbelt to the east. In this chapter, reference is made to the Triassic conglomerate as well for the purpose of examination in the Mesozoic geohistory of the South Kitakami Belt.

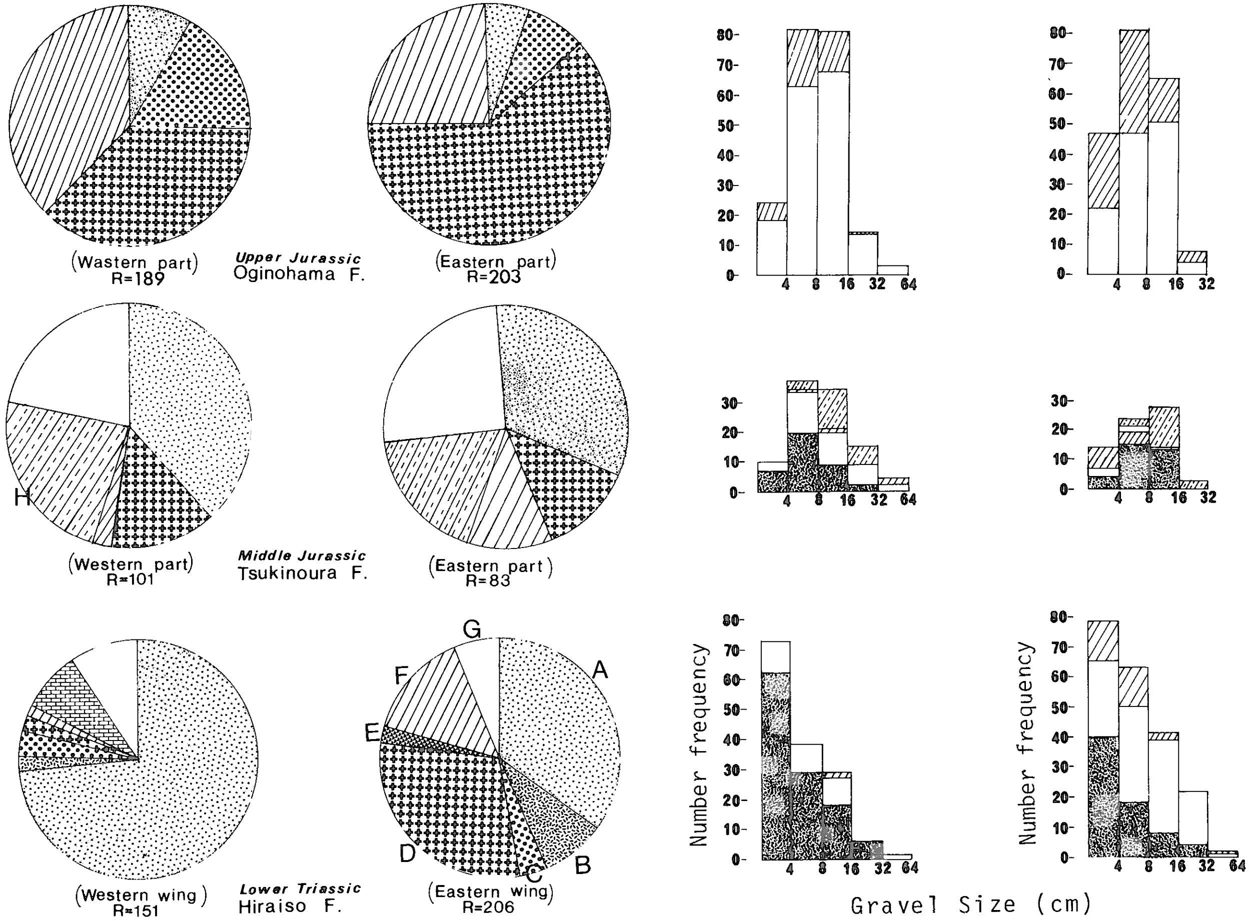
1-1 Triassic Conglomerate

The Hiraiso Formation of the Inai Group contains thick conglomerate at its basal part and locally in its upper part. The conglomerate of the Hiraiso Formation in the east, named the Kojima Conglomerate (ICHIKAWA, 1951), is found near Okatsu to the north of the Oshika Peninsula. This conglomerate crops out repeatedly owing to folds, and has different kinds of gravels in each outcrop. As seen from Figure 43, the conglomerate on the western wing of the Okatsu Antictine contains abundant felsic volcanic rock gravels with large boulders of limestone. In the east, it has gravels of various kinds of rocks such as granitic, metamorphic, volcanic and sedimentary ones, as shown in Table 16.

The conglomerate is poorly sorted, consisting mostly of 5–20 cm size gravels with scattered large boulders (Fig. 42). Gravels of metamorphic rocks, especially of crystalline schist, serpentinite and gabbro are significant in elucidating the provenance, though in small quantities. The limestone gravels of this conglomerate are sometimes rich in fossils including Carboniferous corals such as *Dibunophyllum* sp. and *Siphonodendron* sp. (oral communication by Dr. Makoto KATO) of the Onimaru and Nagaiwa Series. This conglomerate also contains large boulders (up to 85 cm in maximum diameter) of conglomerate which is presumed to have been devired from the Permian Sakamotozawa or Kanokura Formation.

1-2 Middle Jurassic Conglomerate

This conglomerate occurs in the Tsukinoura, Awazu and Aratozaki Formations. It is rich in gravels of dacite, andesite and leucocratic granite accompanied by those of shale and fine sandstone of the Inai Group. Also gravels of siliceous and hypabyssal rocks are found. However, the gravels of the Middle Jurassic conglomerate contain a small variety of rocks compared with the those of Triassic one. The rocks here referred to siliceous rocks include hornfels of siliceous sandstone or chert and vein-quartz. The gravels derived from the Inai Group are generally flat shaped and subangular. They are elongated parallel to the lamination or bedding of the conglomerate. The con-



A, Felsic volcanic rocks; B, Andesite; C, Porphyry; D, Granitic rocks; E, Ultramafic and mafic rocks; F, Sedimentary rocks; H, Sedimentary rocks of Inai Group origins; G, others

R, number of readings

Fig. 43 Compositon and size distribution of the gravels from the Mesozoic strata of the Oshika area.

Table 16 Kinds of pebbles in the Lower Triassic Hiraiso Formation of the Inai Group, South Kitakami (after TAKIZAWA, 1977). Asterisk indicates altered rocks.

Granitic rocks	Metamorphic rocks
Granodiorite	Amphibolite
Trondhjemite	Act-epid-plag-qz hornfels
Leucogranite	Qz-plag-chl-calc hornfels
Diorite*	Qz-K-feld-plag-amph-chl hornfels
Monzonite	Biot-epid-amph-qz-plag hornfels
Quartz diorite*	Garn-qz-calc-epid hornfels
Diorite porphyrite*	Serp-epid-amph-magn-calc schist
Quartz porphyry	Serp-chl-plag-epid-calc schist
Aplite	Serp-epid-pump-calc-cpx schist
Volcanic rocks	Epid-act-musc-calc schist
Andesite*	Sedimentary rocks
Andesitic tuff breccia*	Slate
Rhyolitic(?) pyroclastics	Sandstone
Basaltic rock	Conglomerate
Dacitic tuff	Limestone
Porphyrite*	Chert*
Metagabbro	
Serpentinite	
Qz-epid aggregate	

act: actinolite, epid: epidote, plag: plagioclase, qz: quartz, chl: chlorite, calc: calcite, amph: amphibole, biot: biotite, garn: garnet, serp: serpentine, musc: muscovite, magn: magnetite, cpx: clinopyroxene, pump: pumpellyite, K-feld: Potash feldspar.

glomerate of the Awazu Formation in the Soma area includes much more gravels of metamorphic rocks such as psammitic or siliceous schist than in other areas, though in small quantities.

1-3 Upper Jurassic Conglomerate

This conglomerate is several tens of meters thick and is found in the Ishiwaritoge Formation of the Karakuwa area and the Oginohama Formation in the Oshika area, showing a maximum thickness among the Mesozoic conglomerates of the South Kitakami Belt. In the Soma area, conglomerate is only scattered in coarse sandstone or occurs as very thin layers unlike the above two cases. In the Kogoshio, Ayukawa and Tomizawa Formations, gravels are frequently scattered in the coarse sandstone and are occasionally even crowded to form thin conglomerate beds.

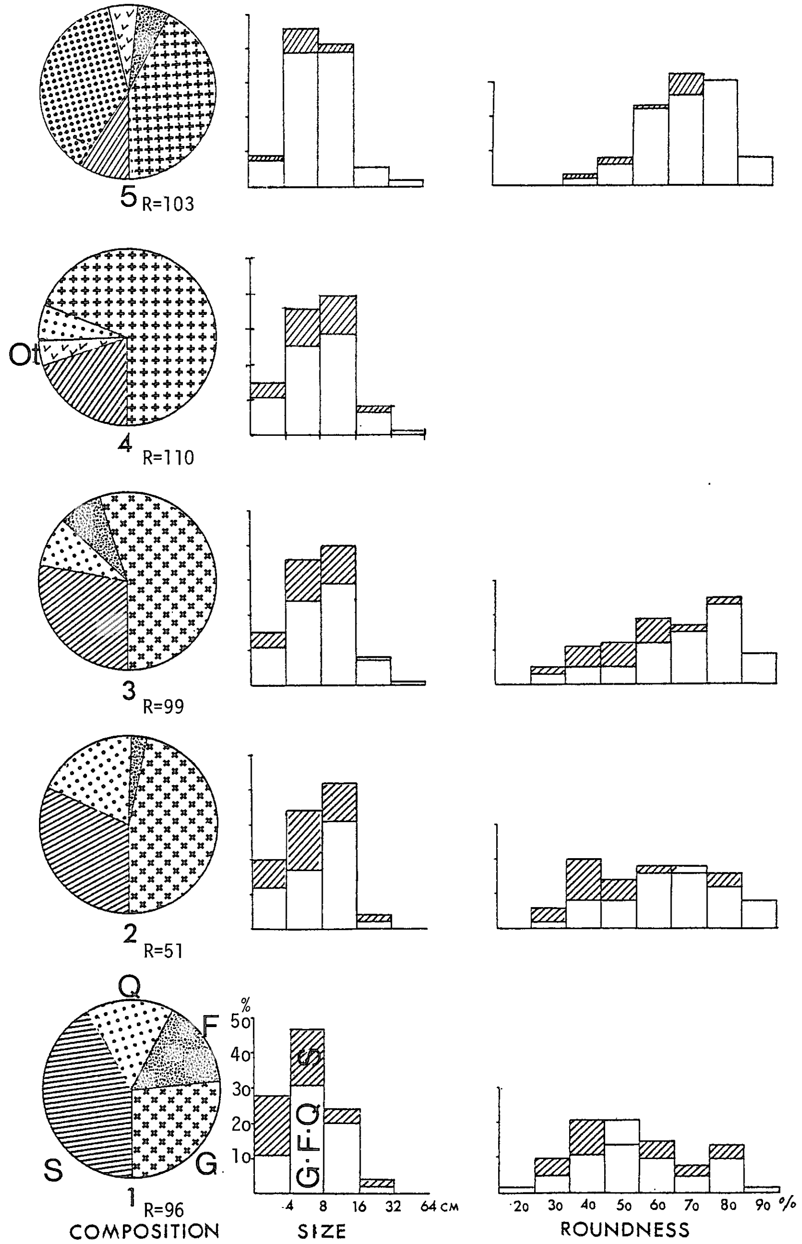
The kinds of gravels of the Oginohama Formation are shown in Table 17 and Figures 43 and 44. Unlike those of the Triassic and Middle Jurassic, the Upper Jurassic conglomerate consists mostly of gravels of granitic rocks with 10 percent or less volcanic rocks. There are a large amount of mylonitic rock and gneiss-like granite. They are characterized by strong foliation, granulation, wavy extinction of quartz, kink folds or warping of plagioclase, crenulation of biotite, and corroded or rolling phenocrysts. Quartz porphyry also includes deformed phenocrysts and very large potash feldspar.

In the conglomerate of the Oginohama Formation, pebbles of sedimentary rocks include hornfels metamorphosed from sandstone, shale and siliceous sedimentary rocks such as quartzose sandstone and chert. This quartzose sandstone has 95 percent or more of quartz in total volume. The medium-to coarse-grained quartz grains therein are surrounded by fine-grained matrix quartz. Thus, this sandstone does not show an equigranular texture typical of orthoquartzite. This sandstone includes a small amount of rock fragments of mica schist, recrystallized chert (?) and dust-ring bearing

Table 17 Kinds of pebbles in the Shirahama Conglomerate of the Makinohama Sandstone Member, Oshika.

Granitic rocks	
Granite, adamellite	frequent mylonite
Granophyre	
Granite porphyry	
Aplite	
Hornfels	
Quartz porphyry	
phenocryst: plagio	variable amount
K-feld	
quartz	
Quartz schist (-hornfels)	
Quartzite	
Metaorthoquartzite	
Metachert	
Volcanic (including pyroclastic)	
Dacitic rock (?)	
Sandstone	

quartz arenite. Foliation can be noted in many pebbles of siliceous rocks with relatively flat quartz grains. This suggests that the siliceous rocks were originally either typical orthoquartzite which had come to show a bimodal grain-size texture through granulation of quartz grains during the transformation into schistoze metamorphic rock or were bimodal quartz arenite showing two modes of coarse and fine grains. As other kinds of associated gravels are composed mostly of tectonites, the hypothesis of typical orthoquartzite origin is more probable.



G, Granitic rocks ; F, Volcanic rocks ; Q, Quartz porphyry
S, Sedimentary and metamorphic rocks ; Ot, Others ; R, number of readings

Fig. 44 Compositon, size distribution and roundness of the pebbles from the Oginohama Formation of the Oshika are.

Most of the metamorphic rocks are of pelitic rocks and show schistosity. No green rocks or limy rocks are found.

In the conglomerate of the Oginohama Formation, the gravel size and the amount of granitic rocks generally tend to increase upward, while the reverse is the case with the amount of hypabyssal, metamorphic and sedimentary rocks (Fig. 44).

The conglomerate of the Ishiwaritoge Formation is very similar to that of the Oginohama Formation in gravel composition, grain size, total thickness and stratification. Gravels of granitic rocks constitute most of the conglomerate and the gravel size increases northward with a maximum of over 50 cm. According to KANO (1959), the granitic rocks are mostly leucocratic adamellite, granite and gneissose two-mica adamellite. They are protoclastic-cataclastic or mylonitic and of shallow-depth type including porphyritic adamellite, trondhjemite, aplite, granite porphyry and graphic granite. The gravels other than granitic rocks are minor compared with the case of the Oginohama Formation. They are sandstone, slate, laminated shale, quartzose rocks and metamorphic rocks.

As to the uppermost Jurassic Kogoshio Formation and Tomizawa Formation, the coarse sandstone beds contain gravels which are similar in rock type to those of the Oginohama and Ishiwaritoge conglomerates and moreover, contain a considerably large amount of dacitic volcanic rocks in some parts. Quantitatively, quartzose rocks such as meta-quartz arenite and vein quartz are abundant. From the Tomizawa Formation of the Soma area, OKAMI *et al.* (1976) reported the frequent occurrence of orthoquartzite pebbles.

1–4 Lower Cretaceous Conglomerate

The conglomerate confirmed to be of Cretaceous age crops out in the Domeki Sandstone Member of the Oshika area. Major gravels of the conglomerate are of felsic volcanic and granitic rocks with minor amount of quartzose rocks. Among these, the volcanic rocks characteristically consist of dacite and rhyolite as major components and a small amount of andesite. The dacitic pyroclastics are very glassy with a clear welded structure, comprising a small amount of pumice (maximum diameter 20 cm) in some cases. These volcanic rock gravels frequently occur as boulders of 30–40 cm (75 cm at a maximum) in diameter. Some of them are sub-angular. The gravels of dacitic pyroclastic rocks including welded tuff suddenly appear in the uppermost Jurassic strata represented by the uppermost Kogoshio, lower Ayukawa and Tomizawa Formations.

2. Composition of Sandstone

The mineral composition of the Jurassic sandstone together with that of the Triassic Inai Group, is given in Figure 45. The composition of Paleozoic sandstone of the South Kitakami Mountain is also shown for reference after MIKAMI (1969, 1971).

The Jurassic sandstone is mostly feldspathic arenite or wacke, corresponding to arkose of the classic classification. The mineral compositions of Upper Jurassic sandstones among the Jurassic outcrop areas of the South Kitakami Belt are quite similar to each other. A few regional differences in sandstone composition are recognized among the Middle Jurassic sandstones which show the largest amount of rock fragments in Oshika, less in Shizugawa and the least in Karakuwa and Soma.

In the Jurassic sandstone, many quartz grains exhibit wavy extinction. As to feldspar, generally the amount of potash feldspar which contains abundantly microcline or perthite is equal to or more than that of plagioclase. The potash feldspar is considerably coarse grained and sometimes form the largest group in grain size. Quartz, potash feldspar and plagioclase are believed to have derived mostly from granitic rocks.

Rock fragments contain felsic volcanic rocks, andesitic rocks, chert and quartzose metamorphic rocks, being in a small quantity. Colored minerals are generally very small with the exception of a rather large biotite in the Oginohama Formation. They are biotite, tourmaline, zircon, amphibole, sphene and garnet, with chlorite as a secondary mineral in some cases.

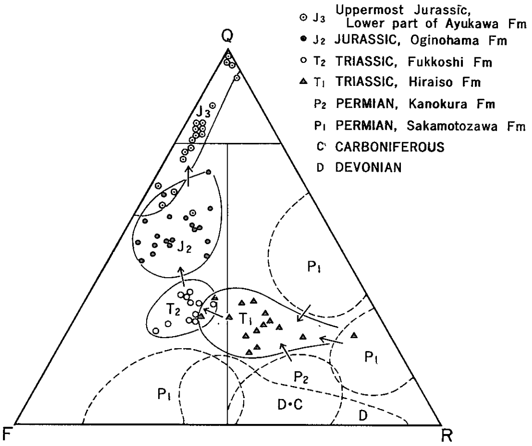


Fig. 45 Sandstone composition of the Jurassic and Triassic strata of the South Kitakami Belt (modified from TAKIZAWA, 1977). Samples from the Oshika area. Data on Paleozoic sandstones of the Ofunato area from MIKAMI (1969, 1971). Q, quartz; F, feldspar; R, rock fragments and other minerals.

The quantity of rock fragments decreases upward in the Jurassic. The Soma area is an exception where the uppermost Jurassic Tomizawa Formation contains a rather large amount of rock fragments of felsic volcanic rocks.

It should be noted that quartz arenite is common in the respective lower parts of the Kogoshio, Ayukawa and Tomizawa Formations. Generally, this quartz arenite contains quartz occuping at least 95 percent of total detrital minerals. The quartz grains are mostly coarse-grained and subangular to angular and seem to have been reworked very little. This quartz arenite is generally similar in composition to the orthoquartzite of the continental Precambrian, but is different from the latter in the angular grain-form. OKAMI (1969) made detailed sedimentary petrological study of the Jurassic quartzose sandstone of the Soma area.

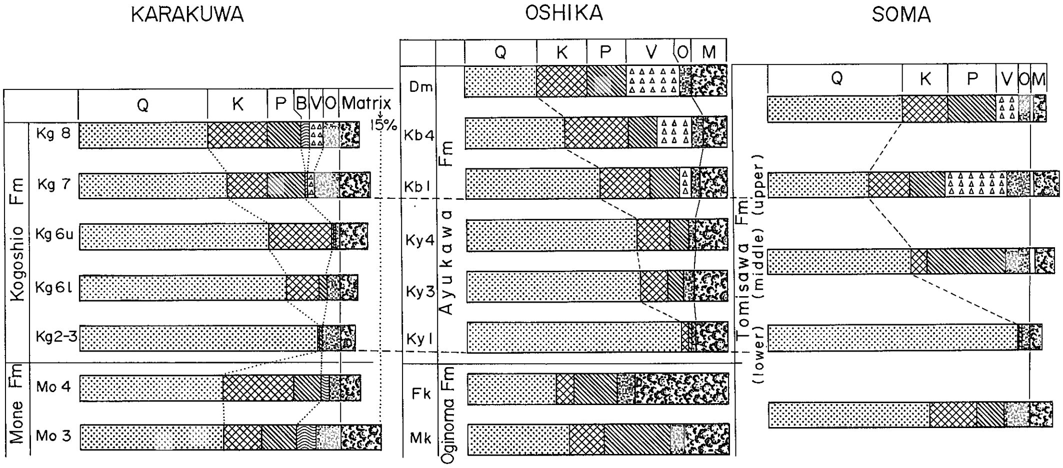
The quartz arenite mentioned above gradually changes into typical feldspathic arenite stratigraphically upwards with the increasing of feldspar content in the above three formations. In this case, the potash feldspar is very coarse-grained and is considered to have been more stable than the plagioclase against weathering. The feldspar in the sandstone below and above the quartz arenite is almost exclusively potash feldspar. The sandstone above the quartz arenite is very coarse-grained often with granular or conglomeratic sandstone. In fact, it is the most coarse grained among the Jurassic sandstones of the South Kitakami.

As seen in Figure 46, the stratigraphical changes of sandstone composition throughout the whole Middle Subbelt indicate that the sources of the Jurassic sandstone were similar or of the same kind of rocks. The Jurassic sandstones differ greatly from the Triassic and Paleozoic ones mentioned as follows.

The Triassic (Inai Group) sandstone is arkosic but rich in rock fragments compared with the Jurassic sandstone. The rock fragments of the Triassic sandstone are, as in the case of the Triassic conglomerate, of various kinds of rocks. The sandstone of the Lower Triassic Hiraiso Formation which contains felsic volcanic rocks, various kinds of crystalline schist, hornfels of muddy rocks, limestone, and unstable basic to ultrabasic plutonic rocks (garbbro, pyroxenite and serpentinite), thus being referred to immature lithic sandstone (mostly arenite). The sandstone of the Middle Triassic Fukkoshi Formation is poorer in unstable minerals and rock fragments and richer in quartz and feldspar than that of the Hiraiso Formation. Thus the sandstone of the Fukkoshi is assigned to feldspathic arenite or wacke. The Triassic sandstone contains a considerable amount of various colored minerals, especially epidote.

Concerning the Paleozoic sandstone, MIKAMI (1969, 1971) noted that quartz is very few at least in the Devonian and Carboniferous sandstones. They are mostly lithic sandstone composed chiefly of volcanic rock fragments. There are two types of the Permian sandstone, one being rich and the other poor in feldspar, while both have abundant volcanic rock fragments, thus being of lithic type in many cases. The Permian sandstone is almost lacking in plutonic and metamorphic rock fragments.

The vertical changes in mineral compositions of the Paleozoic and Mesozoic sandstones of the South Kitakami Belt are summarized as



Q, Quartz ; K, K-feldsper ; P, Plagioclase ; V, Felsic volcanic rocks
O, Others ; M, Matrix

Fig. 46 Vertical changes in sandstone composition of the Upper Jurassic and Lower Cretaceous of three areas of the Middle Subbelt.

follows. The paleozoic lithic sandstone consists mostly of volcanic rock fragments, and the Mesozoic one decreases upward gradually in rock fragments and increases in quartz and feldspar. Finally, the sandstone becomes subarkose-quartzose sandstone in the uppermost Jurassic. This suggests that the source of the sandstone changed with time from exogenetic to endogenetic rocks.

3. Provenance of the Jurassic Deposits

As noted above, the Jurassic conglomerate contains abundantly gravels of granitic rocks and other rocks such as hornfels, sedimentary rocks and felsic volcanic rocks. Most of the Jurassic sandstone consists chiefly of quartz, potash feldspar and plagioclase with minor amount of rock fragments. This shows that the greater portion of the source area of the Jurassic deposits was occupied by granitic rocks.

These granitic rocks and the accompanying hypabyssal rocks and hornfels have various types of well-developed schistose or mylonitic structures. The strongly schistose or mylonitic structures are interpreted as one of the characterics of the granitic rocks rich in "tectonite". This indicates the high possibility of the source rocks belonging to a sort of "paleostructural belt" which was formed as a result of intense tectonic movement and was composed of various tectonites. The fact that the Triassic conglomerate involves many gravels of crystalline schists and ultrabasic rocks sustains also this idea. The felsic volcanic rocks do not show the effect of thermal metamorphism and thus they probably were not intruded by granitic rocks.

It is summarized that the lower portion of the source area of the Jurassic deposits consisted of granitic rocks with strongly schistose or mylonitic structures accompanied by hornfels of sedimentary rock origin and the upper portion of felsic volcanic rocks overlying the granitic rocks. Most of the upper portion had successively been eroded away during Jurassic time.

It is inferred from the intercalation of tuff in the uppermost Jurassic that felsic volcanic activity took place immediately before the Cretaceous, and resulted in the terrestrial pyroclastic flows covering the source area.

VII. DEPOSTITIONAL PATTERNS OF THE UPPER JURASSIC

In the South Kitakami Belt, many cross-bedding and various sole marks are found in the Jurassic strata. These structures provide a clue to the transport direction of coarse-grained clastics in the time of deposition.

However, paleocurrent measurements were not made on some of the imbricated structures in conglomerate beds, because these structures were subjected to the rotation of the gravels involved during the folding (see Chapter II). The total paleocurrent readings taken from the Jurassic strata are about 700, and those of the Cretaceous stata are about 250. Correction for the effect of folding or tilting on the measured values was made in terms of every measured plunge value.

Depositional patterns of the Jurassic strata

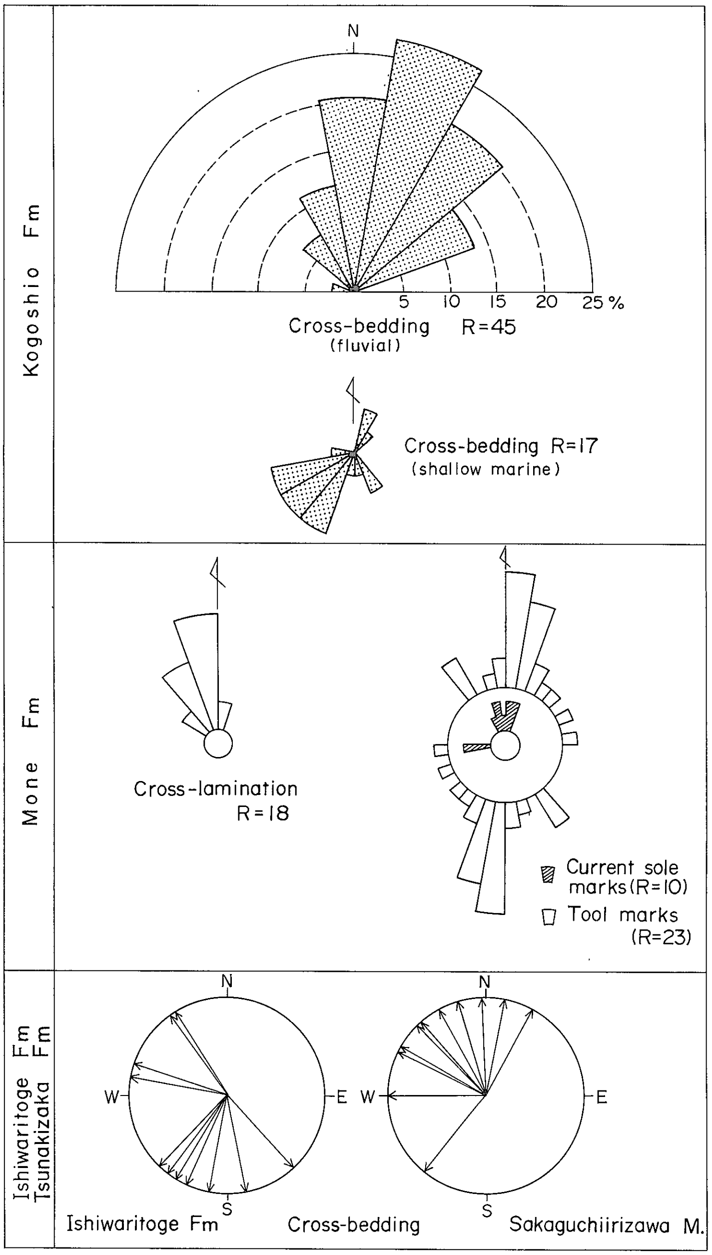


Fig. 47 Paleocurrent data from the Jurassic formations of the Karakuwa area.

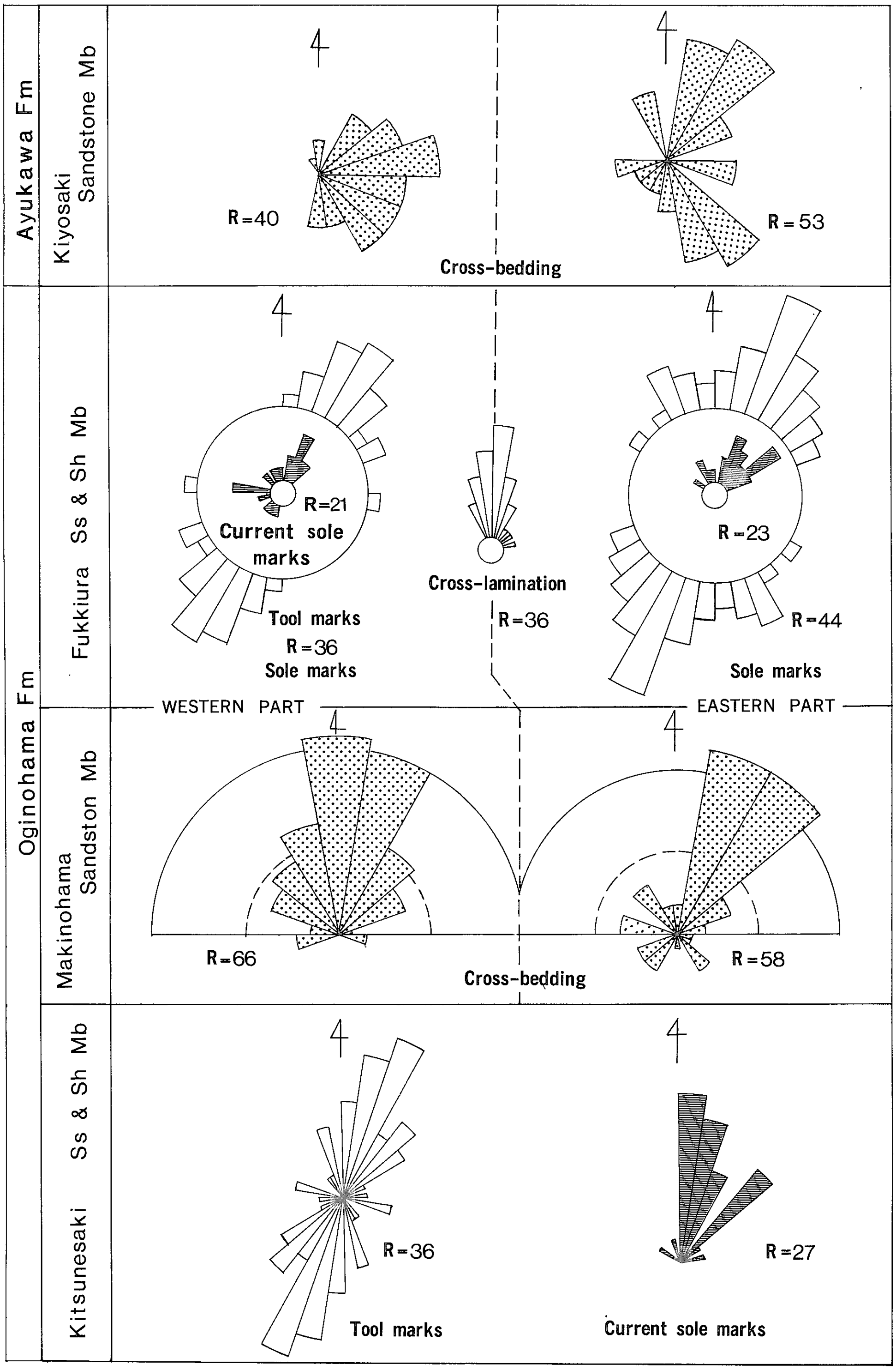


Fig. 48a Paleocurrent data from the Jurassic formations of the Oshika area (Oginohama Formation and lower part of the Ayukawa Formation). R: number of readings

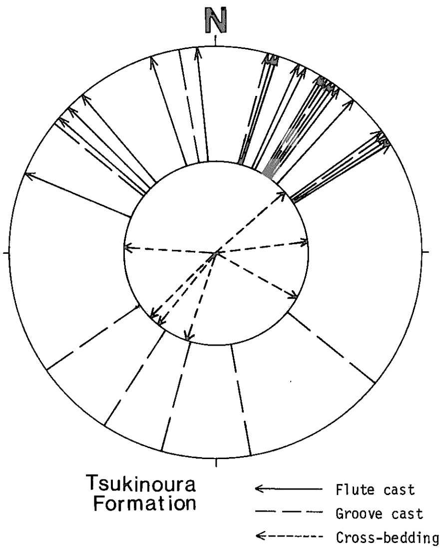


Fig. 48b Paleocurrent data from the Jurassic formations of the Oshika area (Tsukinoura Formation).

are discussed on the basis of the lateral and vertical changes of facies and facies association and the composition and characters of clastics in conjunction with the paleocurrent directions.

1. Paleocurrents

1-1 Karakuwa Area

Figure 47 shows paleocurrent data obtained from the study of the Jurassic of the Karakuwa area. It is clear from the figure that most of the cross-bedding, cross-laminations and sole marks indicate northward paleocurrents, except in the Ishiwaritoge Formation. It is also noted that there are several lines of evidence for some subordinate paleocurrents which flowed approximately to the west at every horizons. Although not shown in Figure 47, cross-bedding (only five readings) at the base of the Kosaba Formation shows southwestward or westward paleocurrents.

In brief, the main currents were roughly toward the north-northeast in the non-marine deposits and flysch type deposits especially of the upper half of the Jurassic strata and they were greatly contributory to the transport of clastics. On the other hand, there were episodic lateral transport currents flowing to the south or to the west when the Ishiwaritoge Formation and the Sakaguchiirizawa Member were deposited.

1-2 Oshika Area

The Jurassic formations in the Oshika area have both cross-bedding in their non-marine deposits and sole marks and cross-lamination in their flysch-type deposits (Fig. 48). These sedimentary structures indicate that the paleocurrents flowed predominantly north-northeastward as in the case of the Karakuwa area. No conclusive evidence of subordinate (lateral) currents is presented in the flysch-type deposits, but only a few current structures indicate northwestward or eastward flows.

The cross-bedding of the Kiyosaki Sandstone Member consisting mostly of alluvial deposits indicates rather variable current directions which can be generalized to be toward the east. In this member of the northern part of the Oshika area, the different two current directions to the northeast and to the southeast are repeatedly shown in a 650 m thick sequence. In the southern part, the islet of Aji-shima, however, the current directions are approximately eastward and they differ very much from those of the underlying Fukkiura Member. The paleocurrents to the east in the lower part of the Kiyosaki Member and the drastic and abrupt facies change from the underlying formation are of significance in inferring the location of the source area.

Reference is made to Figure 49 cited from TAKIZAWA (1975) which shows the paleocurrents of the middle part (Cretaceous) of the Ayukawa Formation of the Oshika area. The figure indicates predominant currents flowing to the north with subordinate currents flowing to the southeast or to the east in some parts. The middle part of the Ayukawa Formation is probably attributed to deltaic deposition in a sedimentary basin with a northward plunging gradient. Analytical study of the slump folds shows the existence of an eastward inclining lateral slope on the west side of the sedimentary basin. The Cretaceous subordinate eastward currents may be related to the similar current pattern of the underlying Kiyosaki Sandstone Member mentioned above.

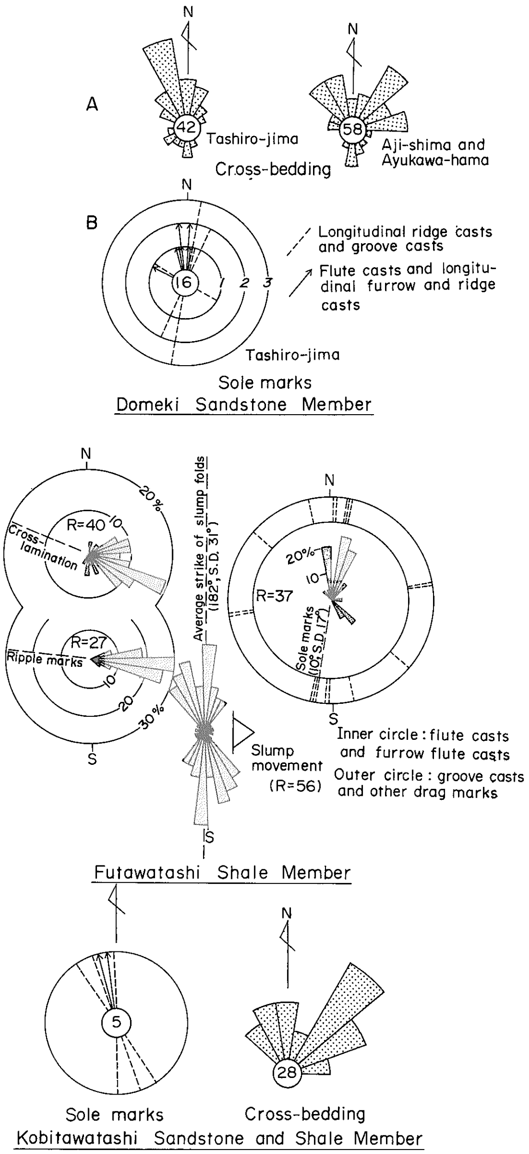


Fig. 49 Paleocurrent data from the Cretaceous formations of the Oshika area (after TAKIZAWA, 1975).

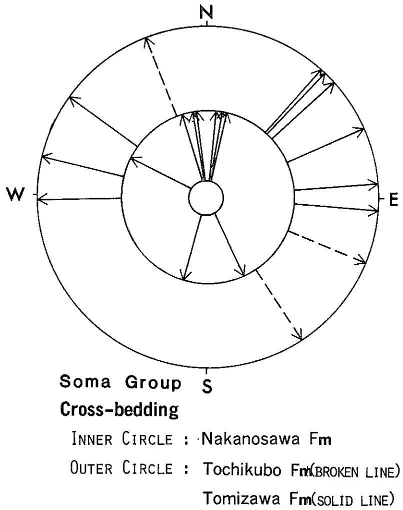


Fig. 50 Paleocurrent data from cross-bedding for the Soma Jurassic strata.

1-3 Soma Area

In the Soma area, a small number of paleocurrent measurements were made by means of the cross-bedding of the alluvial and shallow marine associations (Fig. 50). The current direction seems to be northward in the main, though very variable. On the other hand, a few currents flowing southward are observed only in the shallow marine association of the Nakanosawa Formation, but there is almost no possibility of the source of supply on the north. The variable current directions also seem to have been related to the geometry and other conditions of the sedimentary basin.

1-4 Shizugawa Area

Of the formations in the Western Subbelt, paleocurrent information was gathered only about the Shizugawa area and no study was made of the Mizunuma area.

The cross-bedding in the coarse sandstone beds of the Aratozaki Formation shows eastward currents, while the turbiditic sandstone of the Arato Formation shows westerly or southwesterly current directions (Fig. 51). The fluxoturbiditic sandstone beds accompanied by channel structures have groove cast indicating a southwestward current direction. it follows from these facts that in Middle Jurassic time the coarse material of the flysch facies of the Shizugawa area was derived from the area which is now occupied by the Eastern Subbelt.

1-5 Directions of Submarine Channels and Slump Folds

In the Jurassic formations, particularly in the flysch facies, small-scale channel structures and slump folds are found. Their directions are important in reconstructing the geometry of the sedimentary basins. It is, however, not easy to

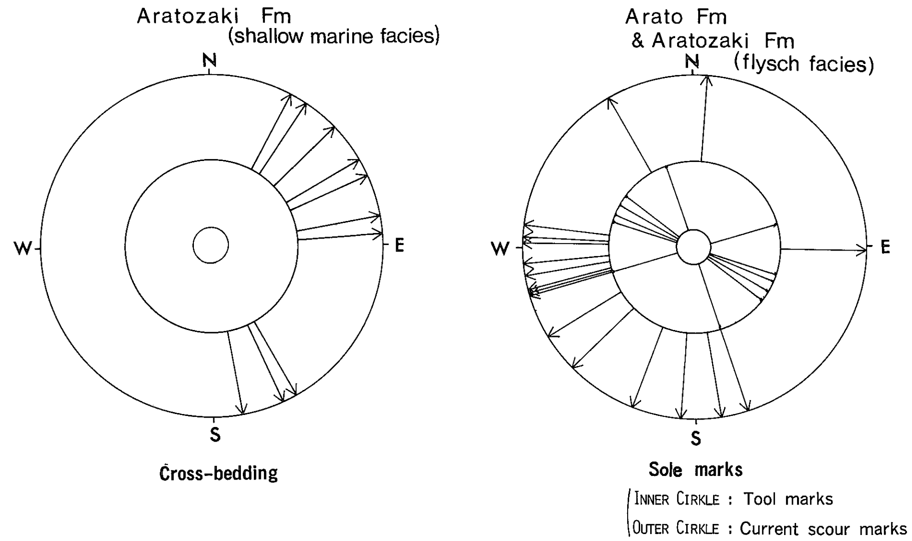


Fig. 51 Paleocurrent data from the Jurassic formations of the Shizukawa area.

find out their directions in many cases. For this purpose, channel walls and slump folds being assumed to be hemi-cylindrical and their elongated directions are plotted on stereo graphic nets.

The examples of the Kitsunesaki Member of the Oshika area are shown in Figure 52. With slump overfolds assumed to have moved in the direction of their turnover, those of Plate VII-1 show slump movement to the west. Slump overfolds in the pebbly mudstone extend in the north to south direction with apparent movement to the west. Submarine channel structures which are filled with pebbly sandstone and conglomerate several meters thick found in the southeastern part of the outcrop area of the Kitsunesaki Member extend in the southeast to northwest direction.

The coarse-grained clastics with a large amount of conglomerate of the Kitsunesaki Member are locally distributed in the southeastern part of the Oshika area (Fig. 59; Pl. VII). Considering this, together with the slump folds and channel structures of the member, the writer arrived at the conclusion that the sedimentary basin of that time had a submarine slope dipping to the west on its east or southeast side and the channel- filling conglomeratic sediments had their source, from which pebbly coarse material was transported directly into the basin, probably to the east.

In the Fukkiura Member, a few channel structures and abundant slump structures are also found. The direction of the channel structures is not determined. The slump structures are mostly of small scale and mostly occur in beds of less than 1 m thick within the shale-dominated facies. The directions of the slump folding axes indicate that the slump movement was from the south or the southwest. These directions are different from those of the Kitsunesaki Member.

The Arato Formation of the Shizugawa area also has channel structures and slump folds. As shown in Plate VI, the channel structures cut into laminated shale and thin-bedded alternation in the southeastern part of the area and into medium-to thin-bedded alternation in the northern part. At Akaiwasaki in the southeastern part of the area, channel-filling sandstone has an estimated thickness of over 30 m and the general direction of the channel is approximately northeast. At Nakazai in the northern part of the area, many small-scale channels are observed. The channel-filling sandstone is at the most 5 m thick and the directions of the channels are inferred to be north-south or northeast-southwest.

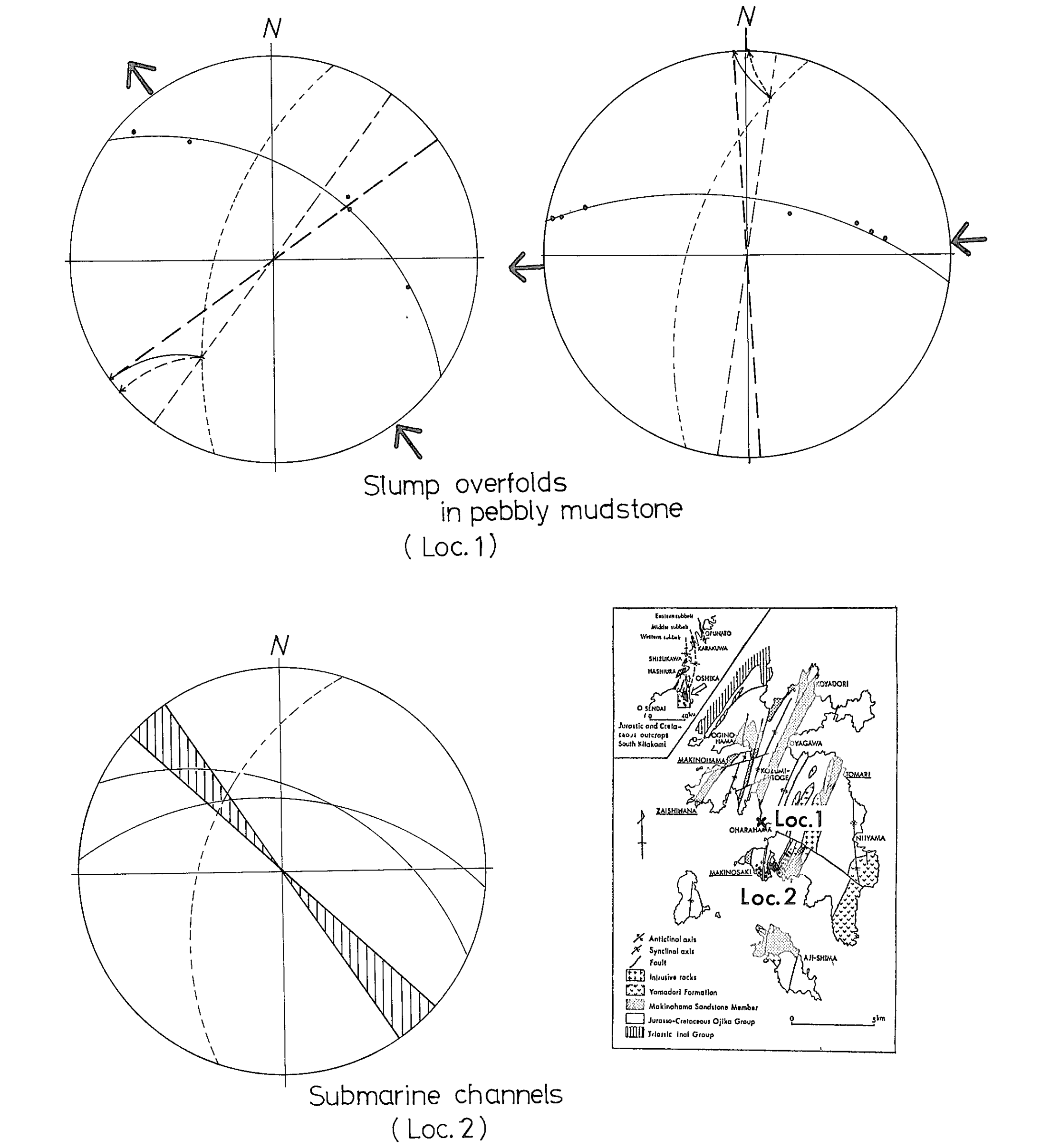


Fig. 52 Directions of slump movement (arrows) and submarine channel structure in the Kitsunesaki Sandstone and Shale Member, in addition to the process of tilt correction on a stereographic net.

In the Arato Formation a considerably large number of small-scale slump folds are found in the laminated shale, and those of large scale are developed at the boundary between laminated shale and the overlying bedded black shale. The average direction of the slump movement is estimated to be nearly from the north to the south. The observed examples are from N10°W to S10°E, N4°E to S4°W and partly from the northeast to the southwest. These observations support the hypothesis that the Jurassic sedimentary basin of the Shizugawa area had a basin slope dipping to the southwest. The paleocurrent directions (Fig. 51) are approximately consistent with the direction of this slope and are of slope down type.

2. Depositional Reconstruction of the Upper Jurassic Clastic Sequences

As mentioned before, the Upper Jurassic domain of the South Kitakami Belt is divided into the Middle and Western Subbelts which have remarkably common characteristics in their lithofacies. The Upper Jurassic of the Middle Subbelt shows strongly oscillatory sedimentary facies with alternating marine and non-marine strata. It has, in a typical case, changes of facies association in ascending order as follows; shallow marine - offshore basin mud - flysch type - shallow marine - alluvial (distributary) - (lake or marsh) - alluvial (fluvial) facies associations. Such a vertical sequence is often repeated two or three times. In this section, considering the sedimentary facies and environments combined with the paleocurrent data, some examinations are made here for what kind of depositional patterns prevailed in the Upper Jurassic sedimentary basin.

2-1 Interrelationships of the facies associations

Upper Jurassic in the Karakuwa Area

The summarized vertical and horizontal facies changes of the Upper Jurassic formations deduced from Figure 18 are given in Figure 53. Opposite lateral arrangement of facies in the sedimentation of the Ishiwaritoge and Mone Formations suggests large difference and opposite direction of their sources.

Regarding the Ishiwaritoge Formation, the coarse clastics were supplied from the north and formed an alluvial fan in the northern part of the sedimentary basin and a low-flat flood plain

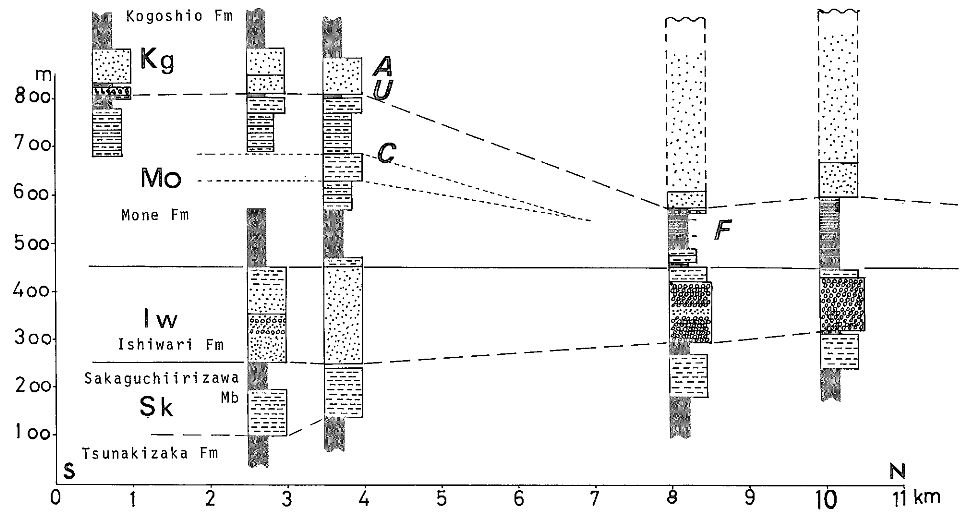


Fig. 53 Diagram showing facies interelationship of the Upper Jurassic sequence of the Karakuwa area. A, alluvial; U, undathem; C, clinothem; F, fondothem.

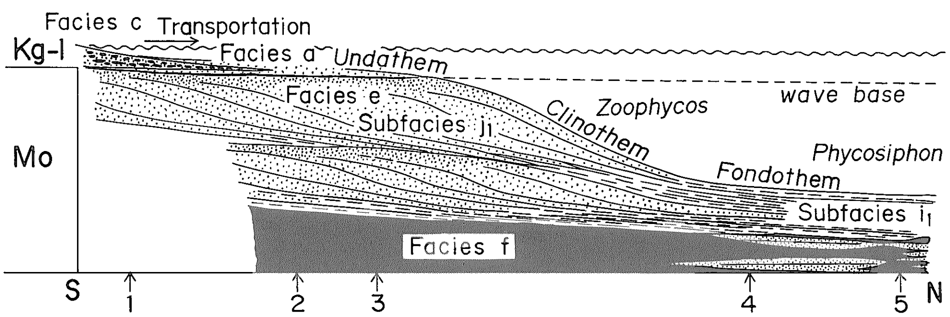


Fig. 54 Diagrammatic cross section showing facies distribution in the Upper Jurassic sequence of the Karakuwa area.

incised by stream rivers in the south. With the Mone and Kogoshio Formations, the clastics were supplied solely from the south with a proximal facies in the south of the basin and a distal facies in the north.

The southern facies of the Mone Formation is a proximal flysch facies rich in turbidite and fluxoturbidite sandstone, while the northern facies is of distal flysch with predominant laminated shale. The Mone Formation becomes extremely thin to the north and the contained ichnofauna also comes to show a deeper basin environment to the north. Between the shallow sea and the offshore basin bottom, a basin slope was formed with mud, turbidite and fluxoturbidite deposited thereon. Northward progradation of the slope was a phenomenon common in the basin. The turbidity currents were of too small scale to transport much sandy material into the northern part of the sedimentary basin and thus only a distal facies which consists mainly of laminated shale was deposited in the northern part. Considering shallow marine sand beds with abundant in-

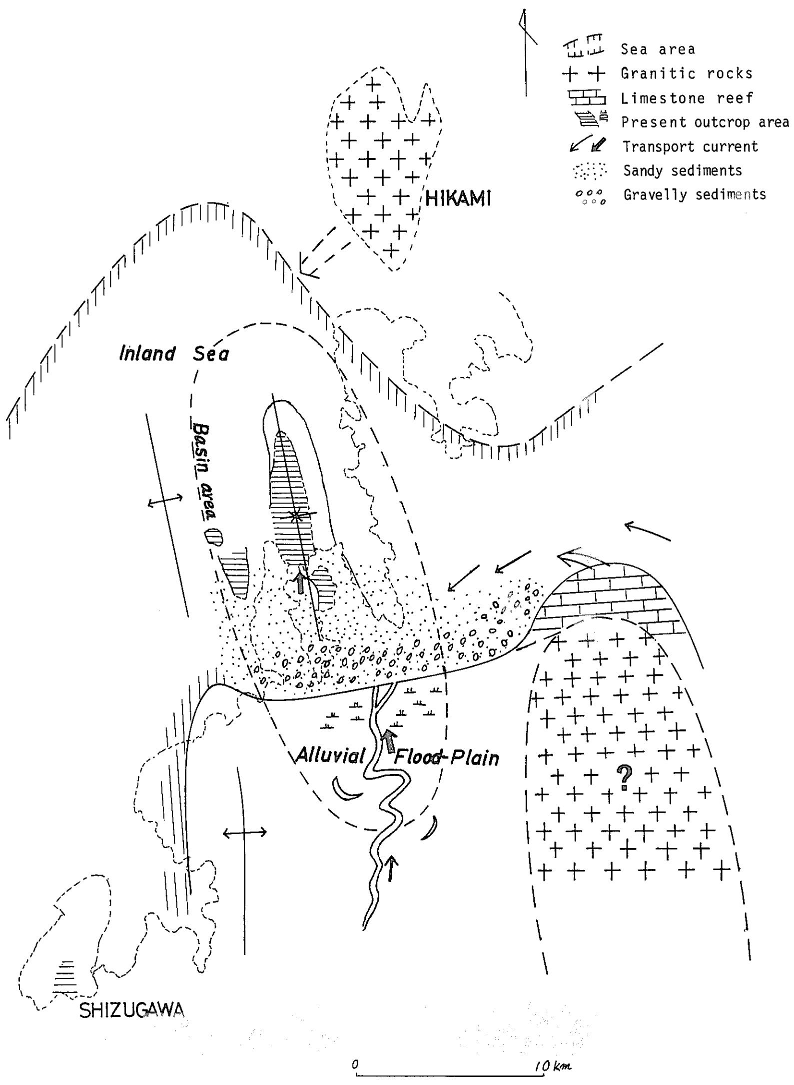


Fig. 55 Depositional reconstruction of the Upper Jurassic sequence of the Karakuwa area.

traformational limestone pebbles directly overlying the Mone Formation, the diagrammatic sedimentary profile during the deposition is shown in Figure 54. This profile on the Upper Jurassic sedimentation is referable to the RICH's sedimentation model (RICH, 1951). Further discussion is given of the sedimentation model, placing great emphasis on the deltaic sedimentation.

The Kogoshio Formation is rich in alluvial deposits in the south, while in the north it is rich in marine deposits with well-sorted and finer-grained sandstone and shallow marine facies. Its coarse-grained clastics were transported by rivers mostly from the south.

From the above observations, the paleogeographical representation of the sedimentation of the Mone and Kogoshio Formations is given in Figure 55. The Mone Formation shows a steeper gradient of sedimentary basin, whereas the Kogoshio Formation indicates that the basin became shallower through a regression or active filling by clastics and thus resulted in a gentler gradient.

Upper Jurassic in the Oshika Area

The Upper Jurassic strata contain two flysch facies associations and two alluvial facies associations, each facies association measuring several hundred meters in thickness. The Upper Jurassic sedimentary facies of the Oshika area changes much less laterally within a given distance than that of the Karakuwa area. This, together with the wider distribution of the Upper Jurassic strata is interpreted as evidence of the sedimentary basin having been larger in this area than in the Karakuwa area.

However, the clastics of both the flysch and the alluvial deposits of the two areas were supplied from the south with a more distal facies to the north. This suggests that the basic sedimentary process of the two areas was similar, regardless of the different size of the sedimentary basin. Similarity between the two areas is also observed in the local development of pebbly alluvial deposits, say, fan deposits, in the southeastern part of the area where the Makinohama Sandstone Member is distributed (Fig. 59). This member is considered to be roughly coeval with the Ishiwaritoge Formation. The Kitsunesaki Sandstone and Shale Member is composed of massive and structureless medium-grained sandstone, graded sandstone interbedded with shale and laminated shale. Most of these rocks are regarded as sediment-gravity flow deposits on the basin slope. On the contrary, large-scale cross-bedding is frequently observed in most of the sandstones of the Makinohama Member, which were deposited from bed load. A pebbly facies (proximal flysch) is found in the Kitsunesaki Member as submarine channel-filling deposits or upper slope deposits. In short, the source of the lateral supply for the Upper Jurassic is considered to have been different from the main source of the longitudinal supply.

2-2 Morphologic aspects of the basin slopes

As seen from the above, the Upper Jurassic formations in the Karakuwa and Oshika areas show a quite similar mode of sedimentation. The most probable paleogeographical and sedimentary relations between the two areas are schematized in Figure 56. Deposition of the Jurassic flysch-type deposits is thought to have been closely related with the basin slope, and also with the geometry of the sedimentary basin and the deposition of the overlying non-marine sequence.

In géneral, flysch-type deposits are mostly considered as turbidites and a recently prevailing hypothesis has provided a submarine-fan to their sedimentary environment (WALKER, 1975, 1978; WALKER and MUTTI, 1973). Here, the writer proposes submarine slope formed not tectonically as the sedimentary environment for several subfacies of the flysch-type deposits of the Jurassic formations.

In various parts of the world, the factors which contributed to the formation of the slopes are usually believed to be "tectonic" as attributable to increasing gradient caused by contrasting tectonic movements of uplifting background and sinking basin (STANLEY and UNRUG, 1972).

Concerning the deposition of the flysch association of the Oginohama Formation, it is

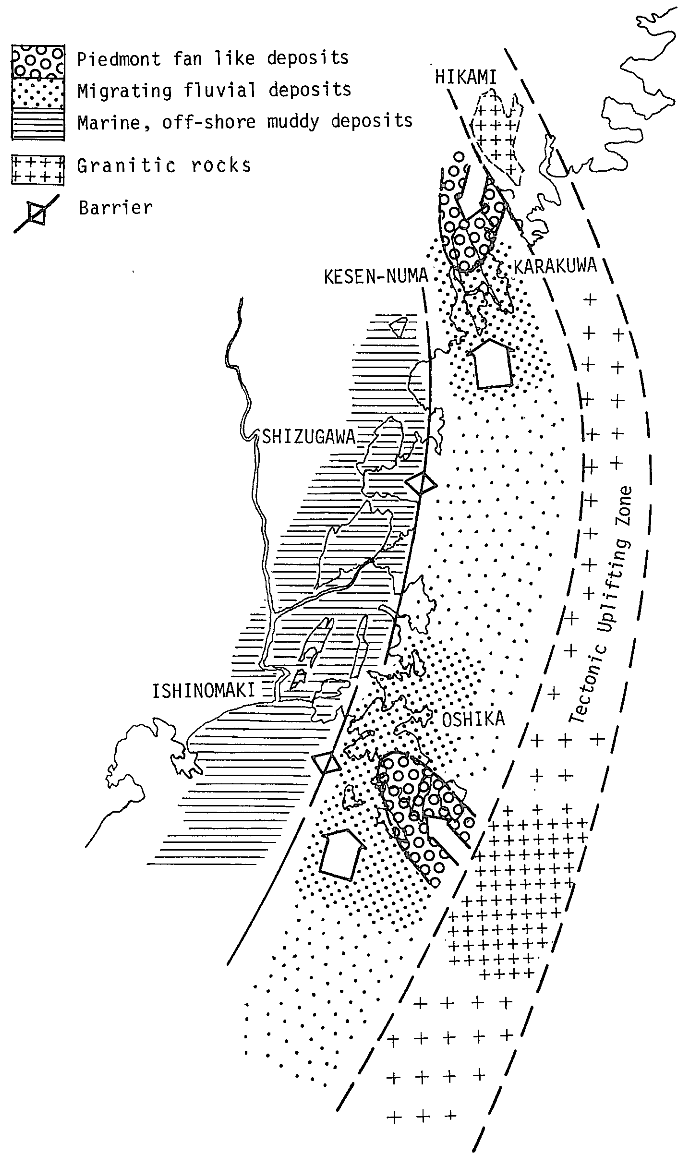


Fig. 56 Paleogeographical map showing depositional patterns of the Upper Jurassic non-marine sequence in both the Karakuwa and the Oshika areas. Arrows indicate the direction of main transportation of clastics.

evident that there were two basin slopes, one north-dipping slope with an east-west strike on the south side of the sedimentary basin (main slope) and another west-dipping one with a north-south strike on the east side. The latter is a "lateral slope" of temporary existence and is presumed to be a slope of tectonic origin related to the uplifting of lateral background. A similar situation is found in the relation between the Ishiwaritoge Formation and the Hikamiyama granitic body in the Karakuwa area.

As to the main slope, though there was no indication of pronounced slope during Middle Jurassic time, the slope was formed rapidly in the southern part of the basin in the early Late Jurassic. Since sandy material was supplied mainly from the south-southwest, this slope may have been formed through the northward "fore-accretion" of deposits in the form of foreset in response to increasing supply of clastics from the south. Thus, the main slope is considered to have been formed not tectonically but entirely endogenetically by sedimentation itself. This case is referable to the RICH's sedimentation model (RICH, 1951), which puts great emphasis on the depositional formation of the slope (clinoform). In connection with the origin of "graywackes", SHIKI (1968) maintained that graded beds could be deposited even in the clino environment with some modification of this model. He also suggested that the three critical environments (unda, clino and fondo environments) in a sedimentary basin can be formed under the following conditions: i) birth of a relatively deep basin, ii) a great amount of sediment supply exceeding subsidence, iii) growth of clinothem due to prograding deposition. It is considered that the Upper Jurassic sedimentary basin was acceptable to these conditions.

The environmental reconstruction for the Jurassic clastic sequences of the South Kitakami Belt suggests depositional environments to be different from a modern continental slope-fan-shelf complex, because of the features of deposits attributed to inland sea origin. Modern large continental slopes or their ancient analogous submarine slopes (and fans) have been presumed by many authors to be depositional places of turbidite or flysch-type deposits as reviewed by STANLEY and UNRUG (1972) and STANLEY and KELLING (1978). Compared with these examples the slope in the Upper Jurassic basin of the South Kitakami Belt probably was much smaller-scale basin slopes facing on small and relatively shallow, land-encircled "troughs".

This kind of slope formed through certain sedimentary process probably played an important role in deposition of the flysch facies of the Oginohama Formation and the Mone Formation. During the Late Jurassic that the two formations were deposited in the Middle Subbelt, filling-up and shallowing of the basin were progressing. Figures 54 show a diagrammatic illustration of this process.

2-3 Deltaic Sedimentation in Late Jurassic, South Kitakami

It is probable that the sedimentary body consisting of flysch association and the overlying alluvial deposits represented by fluvial deposits are of deltaic sedimentation.

As is well known, deltaic sequences are characterized by the coarsening upward nature during a regression (De RAAF *et al.*, 1965; SELLY, 1970; OKADA, 1971b; TANAKA and TERAOKA, 1973). In order to confirm deltaic sedimentation, gradual shallowing of sedimentary environments and occurrence in order, whether horizontal or vertical, of deposits attributable to prodeltaic shelf, prodeltaic slope (delta slope), delta front and on-delta subenvironments from the sea landward must be recognized (TAYLOR, 1963; De RAAF *et al.*, 1965; GREENSMITH, 1966).

The Upper Jurassic flysch-type deposits of the South Kitakami Belt are scarcely similar in lithofacies to deltaic sequences of the above examples, that is, subaqueous deltaic sediments (especially on deltaic slope and distal delta-front sediments) known in many other parts of the world consist mostly of muddy sediments such as laminated muds and streaky muddy beds (RAAF *et al.*, 1965; GREENSMITH, 1966; KANES, 1970; OKADA, 1971b). However, it may have important significance that streaky laminated shales (Subfacies i_1 and i_2) are abundant and juxtaposed with turbiditic sandstone (Pl. V-1, 2) in the Upper Jurassic flysch-type deposits which are presumed to be of regressive sequence.

Here, it should be considered whether flysch-type sediments would be able to occur on a delta slope. From the viewpoint of the deltaic sedimentation, detailed sedimentological reexaminations on the successive sequences of flysch to non-marine deposits in the Upper Jurassic of the South Kitakami Belt are given as follows.

Figure 57 gives a columnar section of the boundery strata between the Kitsunesaki and Makinohama Members. In other words, this section shows vertical facies change of the boundary strata between the flysch-type deposits and the non-marine aluvial deposits. The former are regarded as deposits on the basin slope as mentioned earlier. The pebbly sandstone bed in the lowest part of the Makinohama Member is massive and structureless with flute casts and bounce casts at its sole. This sandstone is regarded as a fluxoturbidite which suggests transport and deposition by high density currents probably of river-flood origin. It is overlain compositely by coarse-grained sandstone with large-scale cross-bedding of 50 cm in set-thickness. Therefore, the boundary between the above two members indicates a transition from the "last turbidite (fluxoturbidite)" to the "initial shallow marine deposits" generated by traction current, and is attributable nearly to the wave-base defined by RICH (1951). This indicates a considerably abrupt shallowing of the sedimentary environment. The above-mentioned pebbly sandstone bed is presumed to be deposits at the top of the slope.

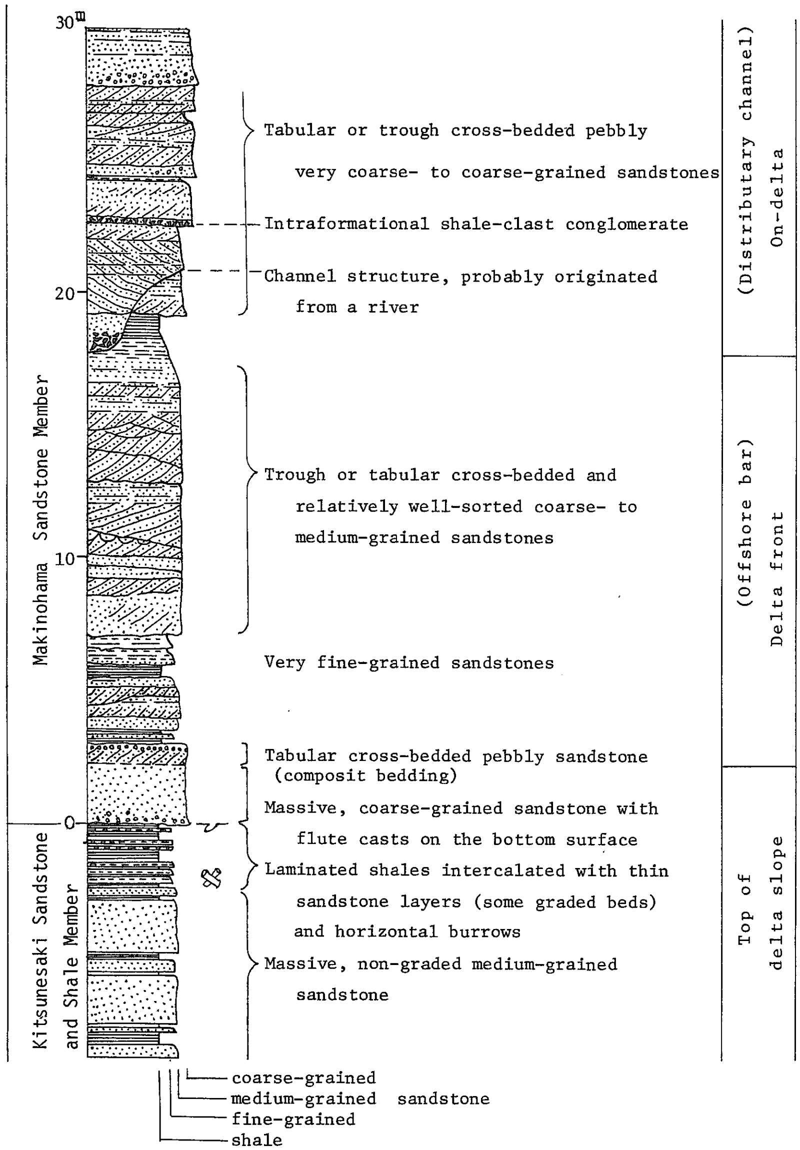


Fig. 57 Columnar section of the boundary strata between the Kitsunesaki and the Makinosaki Members, showing a transition from offshore marine through shallow marine to non-marine environments.

In this transitional sequence, there is not found thick shale or sandy shale which is considered to be characteristic of the offshore part of shallow marine environment of the basin. This shows no existence of a wide shelf sea during the deposition. Moreover, this transitional sequence can be explained by that the shallow sea part of the basin was almost filled with sands originating in enormous influx from rivers into the shallow sea. Moreover, abundant supply of sands from rivers must have produced a sand-dominated delta in the basin. The delta is thought to have prograded directly into the basin plain where monotonous bedded black shale as seen in the upper part of the Tsukinoura Formation was laid down.

At a horizon 18 m above the base of the Makinohama Member, a channel structure filled with pebbly and cross-bedded coarse sandstone is observed. This indicates the influence of a river channel (distributary). Six to fifteen meters above the base there are cross-bedded sandstone beds which are believed to have been formed by well-sorted sands of nearshore depositon (probably sandbar deposits) accompanied by the sandy shale of very shallow sea origin below and above.

From the above examinations the lower part of the Makinosaki Member is correlative to delta-front (subaqueous delta top) deposits fronting to delta slope. The main slope argued earlier is interpreted to have been a delta slope, and the flysch-type deposits of the Kitsunesaki Member are considered to be delta slope deposits. The upper boundery of the delta slope is sharply demarcated by the lowest pebbly sandstone of the Makinosaki Member. The delta slope played an important part inproducing the flysch-type deposits roughly referable to turbidites and related rocks. The on-delta (delta platform) beds in this deltaic sequence are represented by the distributary and the fluvial deposits of the Makinosaki Member.

Thus, the successive strata from the uppermost of the Tsukinoura Formation (probably bottomset deposits) through the Kitsunesaki Member (delta slope deposits) to the lower part of the Makinohama Member (delta-front deposits), roughly indicate a shallowing- and coarsening-upward sequence, and can be explained by the successive northward advance of a delta slope into a moderately deep basin. It should be emphasized that this delta is attributed to the development not on a shelf such as the modern continental shelf but at a basin floor within an inland sea basin. A relatively steep delta slope is assumed to have existed in the basin, compared with the case of the mud-dominated deltas mentioned earlier.

The analogous exampes of the flysch sequence deposited in a delta slope environment have been reported in the Eocene Matilija Sandstone of California (LINK, 1975), the Late Cretaceous to Paleocene Difunta Group of Mexico (McBRIDE *et al.*, 1975) and the Carboniferous Kinderscoutian deltaic sequence of North England (COLLINSON, 1970; McCAVE, 1978). The Matilija Sandstone has thicker regressive shallow marine deposits than the others including the Kitakami Jurassic, and is poorer in or devoid of fluvial deposits as on-delta deposits. The Kinderscoutian sequence is richer in delta slope mudstone (Grindslow Shale) than the others. On the other hand, the Kitakami Jurassic is conspicuously characterized by the frequently repeated occurrence of thick-bedded sandstone (fluxoturbidites) throughout the sequence.

The Tithonian regressive sequences from the Fukkiura Member to the Kiyosaki Member (Fig. 58) and from the Mone Formation to the Kogoshio Formation (Fig. 32) are very similar to the transition from the Kitsunesaki Member to the Makinohama Formation with some local variation. As a result, the Tithonian sequences of the former are referable to the deltaic motif like the latter. The abrupt changes of facies in these transitions can not occur in a condition of gentle gradient from shoreline to offshore. Probably, they are attributed to a sudden change of gradient at the shallow sea bottom of the basin. The horizon of these facies changes is considered to correspond to the position of the wave-base generated by wave actions. Such a horizon is recognized at both bases of the Kogoshio Formation and the Kiyosaki

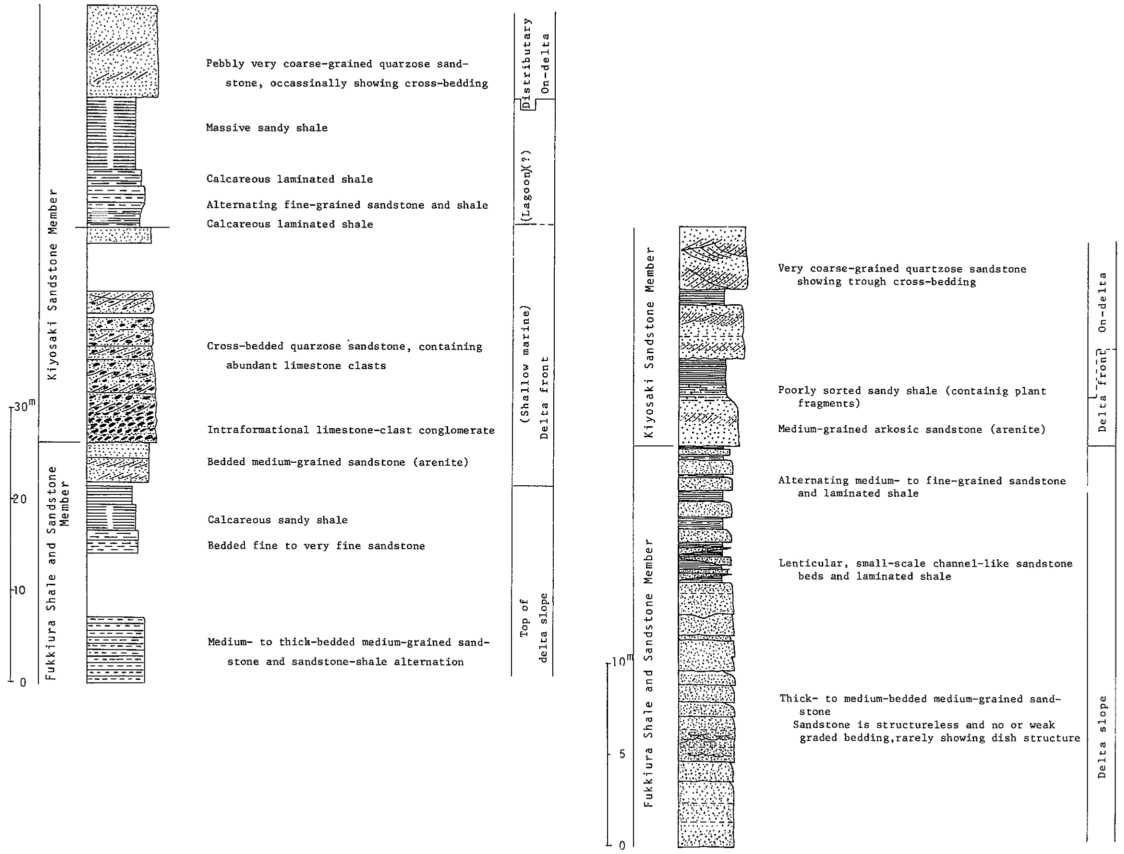


Fig. 58 Columnar section of the boundary strata between the Fukkiura and the Kiyosaki Members, showing a transition from delta slope to on-delta.

Member. The cross-bedded, coarse-grained sandstone (arenite) with a large amount of intraformational limestone pebbles exists in both basal parts. These sandstone beds directly cover rhythmic alternating beds of sandstone (wacke) and shale with thick-bedded sandstone (fluxoturbidite). The above basal sandstones of the Kogoshio and the Kiyosaki probably were deposited mainly in a delta-front environment (subaqueous delta top) in like manner with the case of the lowest part of the Makinohama Member mentioned earlier. The upper part of the Mone Formation and the Fukkiura Member which consist mainly of flysch-type deposits are believed to have been laid down on a delta slope. In addition, the bedded and laminated shale of the lower part of the Mone Formation and the Kozumi Member is referable to prodelta (bottomset) beds and on-delta beds are represented by the lower parts of the Kogoshio (Kg-1c) and the Kiyosaki (Ky-1).

Flysch-type deposits under the conditions of the above-mentioned sedimentary process indicate that the sediments which were transported by rivers probably could easily reach the considerably deep portion of the sedimentary basin during floods. In connection with this, it should be noted that large drifted wood fragments (Pl. VIII-1) are often found in the sandstone beds of the Kitsunesaki and Fukkiura Members. They are considered to have been transported by flooded rivers onto the sea bottom.

OTSUKA *et al.* (1973) reported that abundant fresh green grasses and woods twined around the submarine cable were picked up from the sea bottom about 800 m deep in the Bay of Sagami-nada. They also described that the

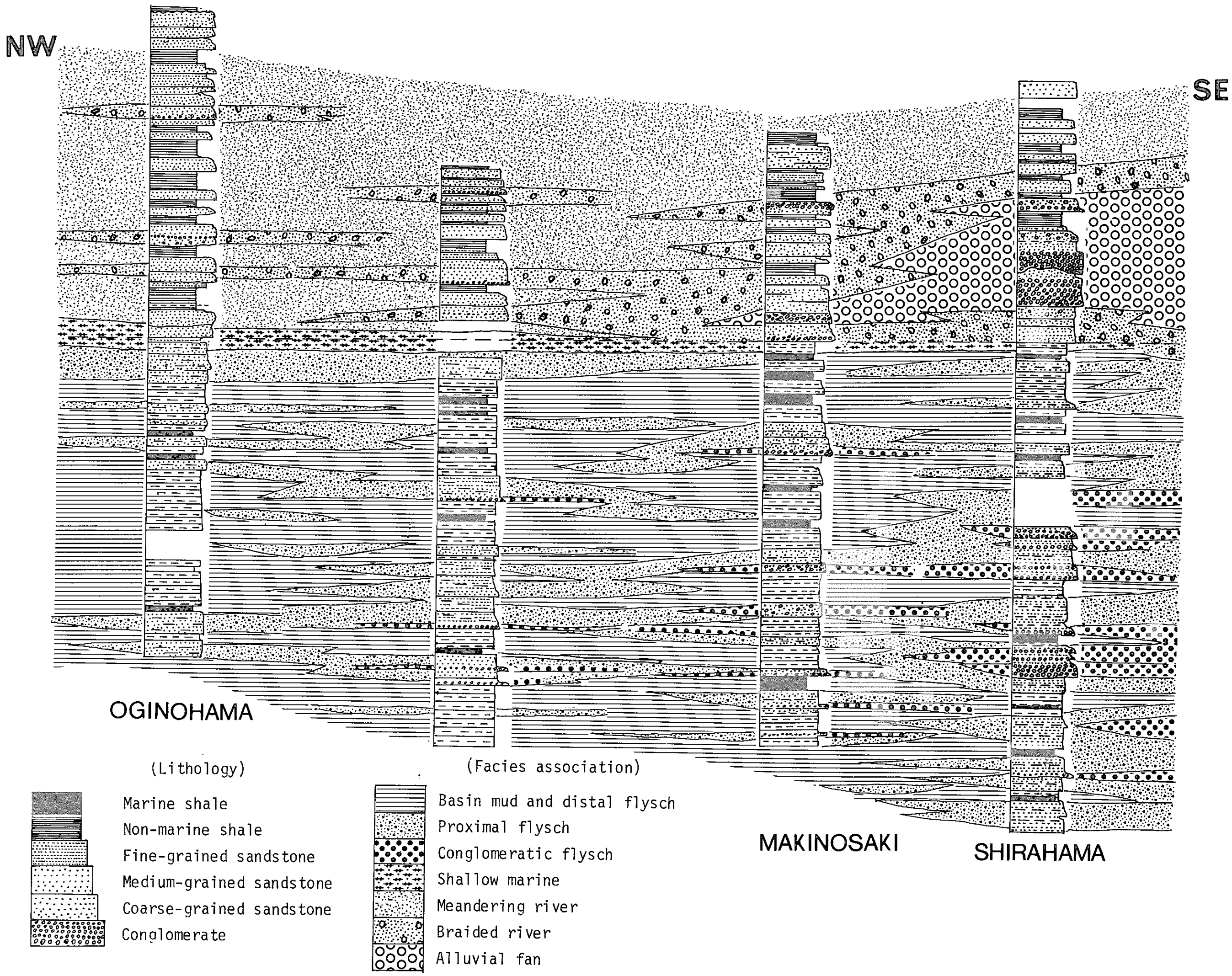


Fig. 59 Composite section through the lower half of the Oginohama Formation.

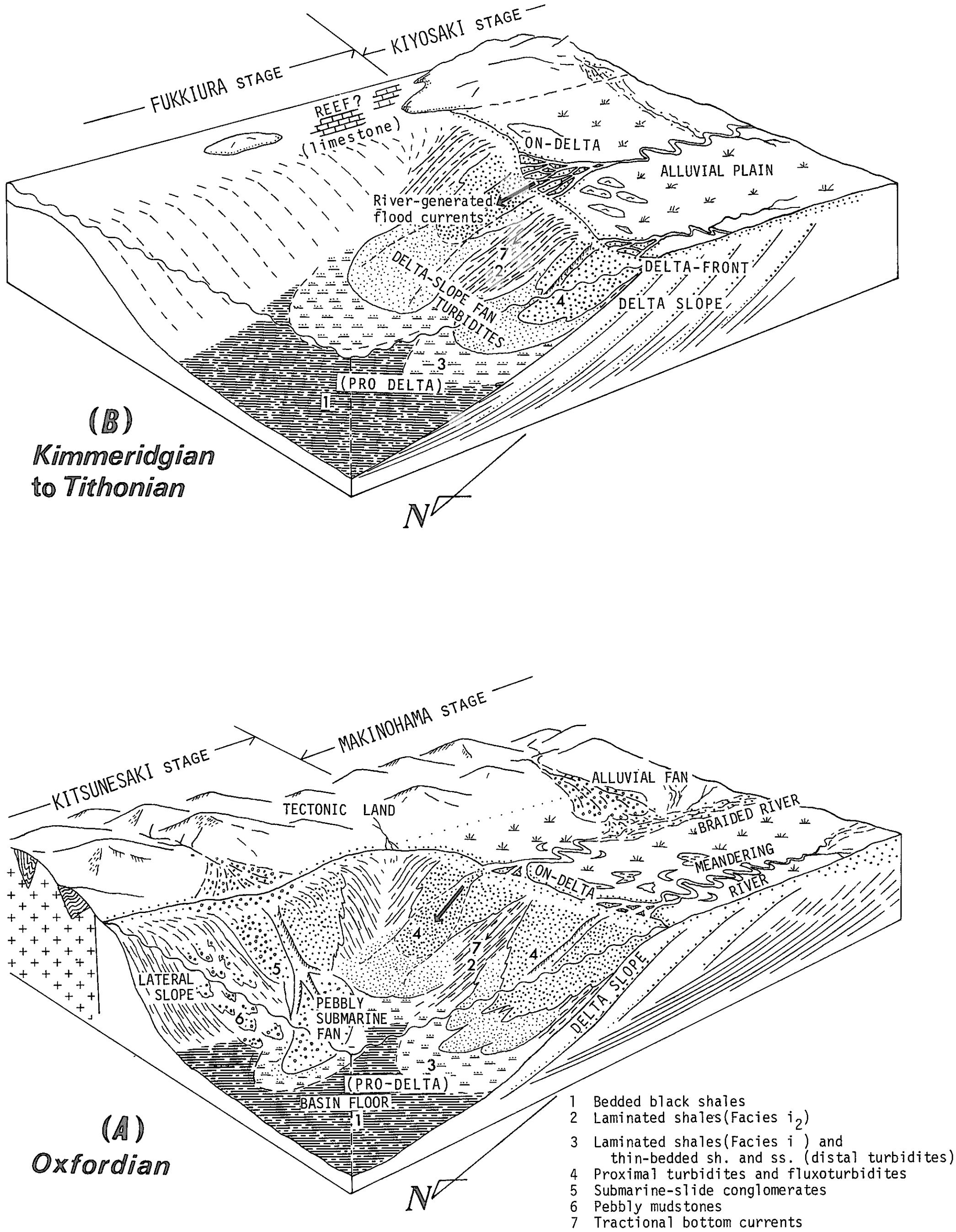


Fig. 60 Depositional reconstruction of the Upper Jurassic sequence of the Oshika area. Diagram A shows the deposition of the lower half of the Oginohama Formation (Oxfordian time), and diagram B the deposition of the Upper half of the Oginohama Formation and the lowermost part of the Ayukawa Formation (Kimmeridgian to Tithonian time).

cable break was caused by submarine slumping or turbidity current due to collapse of sediment which was deposited from river-generated flood currents. Actually, the cable break occurred a few hours after passing of the peak of the river flood at the mouth due to a very heavy rain in July, 1972. This shows the large energy for the river-generated density currents and the possibility for the currents to reach the deeper portions of the sea bottom. It is noted that graded sand covered by a bed with abundant plant debris was obtained from the box core samples at the sea bottom about 500 to 1100 m deep in the La Jolla submarine fan-valley (SHEPARD *et al.*, 1969). Also the generation of turbidity currents from river floods has been postulated by HEEZEN *et al.* (1964) to explain the correlation of cable breaks and floods at the mouth of the Congo River. As to the ancient examples, COLLINSON (1969) and WALKER (1971) thought that the turbidites forming flysch facies were produced by sliding down of turbidity currents which transformed from highly concentrated mud water generated by river flooding. These references indicate without doubt some of the deep water sediments to have deposited from large flood currents from rivers.

From the above, it is evident that there is an intimate analogy between the flysch type deposits of the Upper Jurassic and the above examples of turbidite-like deposits. It is therefore proposed that most of the turbidity currents were not the result of slumping or sliding of unstable masses of sediments, but were generated directly by the influx of water highly laden with sediment from a river into the basin. An abundance of streaky, laminated shale (Subfacies i_{1a} alternated with turbidite sandstone in the Jurassic of the South Kitakami (Pl. V-1, 2) may have been deposited in deltaic environment. This laminated shale was probably generated from seasonal and periodically smaller flood-currents or storms in a shallower marine environment. Thus, a depositional model of the Upper Jurassic is assumed as in Figure 60. This model presented here is concerned with deltaic deposition as well. The Upper Jurassic alluvial deposits were formed on low flat land which was covered by sea water before. It seems probable that such a river system easily formed a strongly meandering and laterally migrating river which branched off into many distributaries at the mouth. Moreover, a possibility is that at high discharge flows emanating from the distributaries of the on-delta as high-concentration sediment gravity flows proceeded onto the delta slope. Delta progradation, initiation and eventual abandonment of distributary channels, and switching of the main delta lobes may have contributed to the complex facies relationships now seen in the Upper Jurassic of the South Kitakami. In this way, the sedimentary model of a delta-river migration system is applicable to explaining the frequent vertical facies changes of the flysch facies associations of the Upper Jurassic.

VIII. DEPOSITIONAL HISTORY AND PALEOGEOGRAPHIC EVOLUTION

The most important characteristic of the Jurassic basin in the South Kitakami Belt is defferentiation of the sedimentary basin with time (YAMASHITA, 1957). During Triassic time as in Late Permian, the sedimentary basin was a simple one broadly covering the South Kitakami Belt with little horizontal changes of the facies. During Jurassic time, however, the sedimentary basin differentiated into two north-south trending troughs which are now occupied by the Western and the Middle Subbelts. They are greatly different in amount of subsidence and sedimentary facies from each other.

The Jurassic strata in the Middle Subbelt show great vertical facies changes as represented by two major sedimentary cycles of transgression and regression as well as great lateral ones. Laying stress on the difference of lithofacies between the Western and Middle Subbelts, It should be considered that the depositional history of the Jurassic with the Cretaceous of the South Kitakami Belt is divided into four stages as shown in Figures 61 and 62.

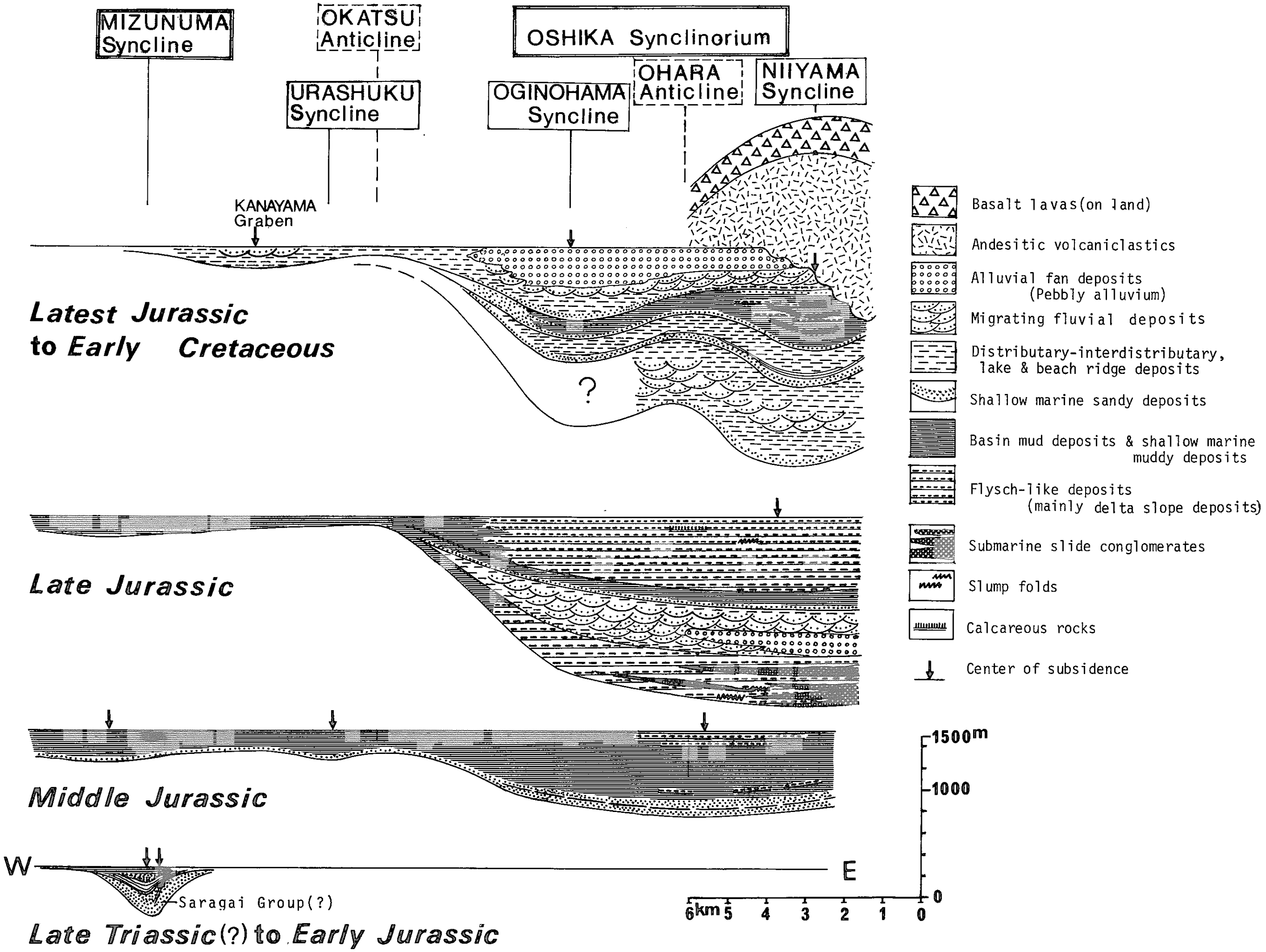


Fig. 61 Schematic cross sections showing vertical changes in the facies association of the Jurassic sedimentary basins in the Mizunuma and Oshika areas.

1. Early Jurassic

A narrow embayment elongated in a nearly north-south direction was formed in the Western Subbelt including the Shizugawa, Hashiura and Mizunuma areas to receive mainly fine sand and sandy mud rich in organic matters. This bay was comparatively shallow, and probably nearly closed to be a lagoon with great breeding of brackish bivalves and gastropods to form shell beds. Since the Sinemurian, this bay may have opened at Shizugawa and its environs (HAYAMI, 1961a). The coarser clastics deposited mainly along the eastern margin of this bay with thinning-out to the west. Thus, the mouth was affected by the open sea water and increased its width and depth. This event has been designated as the Hosoura transgression by SATO (1962). This conclusion is supported by ammonoid-bearing finer muddy rocks of the Hosoura Formation. However, at Mizunuma in the south no ammonoids are known. The provenance of sediments at this time has not been made clear about its position, but it is proved to have not existed at least to the west.

2. Middle Jurassic

In the final stage of the Early Jurassic, regression and erosion occurred and the South Kitakami Belt was followed by a considerably large transgression in Bajocian time. This transgression covered both Western and Middle Subbelts with considerable rapidity and became the largest during the Middle Jurassic. Lithofacies was nearly the same through both subbelts. It was composed of shallow marine sand and quiet basin mud with a common biofacies of ammonoids and bivalves which show that the area was of nearly uniform environment. The Karakuwa and Soma areas were covered by a shallower sea and the intermediate zone between both subbelts was probably a site of deposition without barrier. However, just after this transgression, the Shizugawa area had a slope plunging to the west or to the south with more rapid deepening of the basin than in other areas, and produced sediment-gravity flows. During this transgression, both subbelts had uniform quiet basin mud facies till Callovian time. Amount of depression was the greatest in the central part of the Middle Subbelt, that is, in the Oshika area.

The coarser clastics of this age in the Middle Subbelt were littoral sandy deposits with a maximum thickness of 200 m or more (Oshika and Karakuwa) in the basal part (Bajocian). Conglomerate is the thickest with large gravels (cobbles) in the Oshika area, but is not found in the Mizunuma area to the west. It leads to the conclusion that the source area was to the east of the Middle Jurassic basin. The source area was composed mainly of granitic rocks and felsic and andesitic volcanic rocks. In addition, the Triassic Inai Group was exposed nearshore and became the source rocks for the early Middle Jurassic deposits in the neighbourhood of Oshika. The main source rocks in the Karakuwa area were granitoids. Judging from the coaser and thicker sediments in the northeastern part of the Karakuwa area, the main source suggests to have been to the northeastern side. In the Soma area, the source area was composed mainly of adamelitic granite with a small amount of metamorphic rocks.

In the Shizugawa area of the Western Subbelt, a lateral change of the basal coarser facies (Aratozaki Formation) of the Middle Jurassic is seen from conglomerate-bearing coarse-grained sandstone in the east to medium-grained sandstone in the west. Judging from the main paleocurrent pattern showing sediment transport toward the southwest or west, it is concluded that the sediments were transported from the source area to the east across the Middle Subbelt. The flysch facies in the overlying Arato formation was produced by rapid deepening of the shallow marine basin in the early transgressive phase. It is entirely different from the flysch facies in the Middle Subbelt with the overlying non-marine deposits which were formed under regressive conditions. The estimated major direction of the paleocurrents and channel structures of this formation is southwest as mentioned earlier. The coarse beds are of the same age as those of the Tsukinoura and Kosaba Formations in the Middle Subbelt and possibly came from that subbelt. During the deposition of the lower Arato Formation, shallow marine sands accumulated in the Middle Subbelt and then constantly flowed from there into the sedimentary basin of the Shizugawa area in the Western Subbelt to form turbidites. In the Western Subbelt, the sedimentary basin plunged deeply to the south in contrast to the Middle Subbelt.

During the Mid-Jurassic, no clear differentiation of sedimentary basin into the Western and Middle Subbelts took place.

3. Late Jurassic

This stage is noteworthy in the Mesozoic depositonal history of the South Kitakami Belt, as there was significant differentiation of sedimentary facies and amount of subsidence between both the subbelts.

In the Western Subbelt, during the period since the former stage to the Kimmeridgian, monotonous quiet basin mud continued to deposit with intercalation of a small amount of fine sandy deposits. In the Middle Subbelt, the beginning of this stage was marked by the appearance of sandstone-dominated strata (Sakaguchiirizawa and Kitsunesaki Members, and Yamagami Formation) to be tentatively assigned to the latest Callovian or earliest Oxfordian. Inflow of sandy sediments increased sharply associated with the shallowing of its sedimentary environment, and coarsening-upward sequences were produced. This process is evidenced by the vertical changes from the quiet basin mud to proximal flysch-like deposits of northerly prograding deltaic sedimentation in the Oshika area, proximal lake deposits in the Karakuwa area and shallow marine sandy deposits in the Soma area, and further to fluvial deposits even with conglomeratic alluvial fan deposits in the Karakuwa and Oshika areas. Thickness of these deposits is several times as much as that of the Western Subbelt to result in great differential subsidence with a barrier between the two subbelts.

Distribution of different sedimentary facies and supply of coarse clastics during the Late Jurassic are summarized in Figure 56. The Soma area, though not given in this figure, has a fluvio-lake facies possibly with partly shallow marine facies, instead of lacking a conglomeratic alluvial facies.

In late Oxfordian time, a transgression restarted in the Middle Subbelt and littoral sand, sublittoral sandy mud and quiet basin mud deposited in ascending order. But the Soma area is scarce in muddy deposits. The transgression of this stage was of smaller scale than that of Bajocian and characterized by the yielding of *Perisphinctes*, a representative ammonoid of Late Jurassic.

In Kimmeridgian time, this marine basin of the Middle Subbelt (Karakuwa and Oshika) started to receive the inflow of sandy material mainly through turbidity currents possibly affected by the rising of the source area. This inflow in the subbelt was originated from longitudinal currents from the south, almost without lateral supply such as what occurred in "early Oxfordian time". The flysch-type deposits thus were probably formed on the delta slopes and at the foot of the slopes under the condition of deltaic sedimentation. They show the effects of flood flows of a river and probable storm-generated currents, and were presumably not formed at the deep sea bottom in general. The deposits increase distal facies toward the north.

During this period in the soma area a shallow sea environment continued with stronger effects of open-sea water. On an offshore submarine bank, limestone deposited with good lateral continuity (Kimura, 1954). It is believed that the land on the east side of the basin had already submerged in a sea at that time. In the Karakuwa and Oshika areas, limestone which deposited almost simultaneously is found abundantly as intraformational breccias above the flysch deposits noted above. This limestone is believed to have formed near the margin of the basin because of the existence of calcareous (oolitic) sandstone in the two areas.

Briefly, the sedimentation of the Upper Jurassic (Oxfordian-Kimmeridgian) indicates complete differentiation of the Jurassic basin into the Western and Middle Subbelts. The sedimentation took place in each subbelt independently with little interrelationship. The Middle Subbelt is characterized by the predominance of coarser-grained material with frequent oscillation of sedimentation.

4. Latest Jurassic to Earliest Cretaceous

Tithonian strata are not found in the Mizunuma area of the Western Subbelt. This shows some possibility that deposition in this time did not occur in this area. However, in the Shizugawa area of the same subbelt fine sand and mud which are of distal shallow marine origin were deposited during Tithonian time. These sediments laid down on what seem to be wavecut terrace where the underlying beds were eroded away, as exemplified by the Sodenohama Formation.

In the Middle Subbelt, the flysch or shallow sea facies of the previous stage was replaced by non-marine, very coarse-grained and angular quartzose sands. The source of these sands seems to be heavily weathered granitic rocks. It is possible that the depositional site of these sands was a nearshore or a low land such as a declining uprise zone on the east side of the basin during the Kimmeridgian transgression. This might be related with the formation of the reef-like limestones mentioned earlier. This latest Jurassic sandstone gradually increases its content of feldspar upwards and it becomes typical arkose sandstone deposited mostly in a fluvial environment. Its supply was mostly from the south, and there is a more proximal facies in the south of the Middle Subbelt.

In the earliest Cretaceous (Neocomian), the Middle Subbelt suffered the third transgression with thick deposition of neritic mud. Only the Oshika area had northward inflow of a large amount of sandy material into the Neocomian sea, and coastal non-marine deposits and agitated subaqueous delta formed in the south (TAKIZAWA, 1975). Subsidence also occurred in the eastern half of the subbelt, and here, it is presumed to be the result of new tectonic downwarping. The direction of the supply of clastics was from the south to the north with the basin plunging northward.

In the Western Subbelt, only the Hashiura area experienced a Neocomian marine invasion as evidenced by the Jusanhama Group. This group is composed mainly of arkose sandstone of shallow sea facies probably of nearly the same age as that of the Ayukawa Formation of the Oshika area. There is possibly some interrelation between both strata.

During the latest Titonian to Neocomian time, there was acid volcanism in the source area and it resulted in the supply of a great amount of coarser detritus surpassing granitic material.

As seen from the above, during this stage (latest Jurassic and earliest Cretaceous) the basin geometry and sedimentation in the Middle Subbelt were basically similar to those of the Late Jurassic. They were probably continued from the previous stage. In the Western Subbelt, there were abundant supply of coarse clastics and marked oscillation of sedimentation compared with the quiet conditions of the previous stages.

This Jurassic to Cretaceous sedimentary basin underwent weak crustal deformation followed by andesitic and basaltic volcanism in probable Hauterivian time.

Concerning the study of paleogeography and sedimentation of the Jurassic, uplifted land as the lateral sources is assumed to have existed on the east of the basin through the sedimentation of the Upper Jurassic in the Oshika area, and a similar idea is adapted to the Traissic Inai Group (TAKIZAWA, 1977). This idea was also held by KANO (1958) and MURATA (1976) and is nearly consistent with the "Ofunato Islands" which have been assumed by KIMURA *et al.* (1975).

The magnetic anomaly zone off the Sanriku Coast shown in Figure 1 is noted in relation to the above "eastern paleo-land". The magnetic zone extends in a N–S trend with a breadth of 20 km and a length of more than 80 km between the islet of Kinkasan and Mt. Hikamiyama. The origin of this anomaly zone has been assumed by OGAWA and TSU(1976) as a high- to medium-grade magnetic body such as granitic rocks sitting at a very shallow position under the sea bottom. There are three high anomaly subzones and the western of them is connected also with the Cretaceous volcanic rocks at the headland of the Oshika Peninsula and with the Kanaegaura volcanic formation of the Karakuwa area to the north. These remarkable linear arrangements show a tectonic-zonal character. It should be noted that the Hikami granitic body of Paleozoic or Precambrian age exists on the northern extension of the above anomaly zone. The source of the Ishiwaritoge Conglomerate is considered to have been the Hikami granitic body (KANO, 1959).

The gravels of the schistose metamorphic rocks and granitic rocks in the Jurassic conglomerate must have been derived from a source area located in the magnetic anomaly zone. This assumption can be strongly supported by the existence of the Hikami granitic body. This source area in the Jurassic time which existed in the area near Hikami to Kinkasan is called here the "Hikami-Kinkasan paleo-tectonic land" under the assumption that this zone was a tectonic land of pre-Cretaceous time (TAKIZAWA, 1977).

The magnetic anomaly zone disappears abruptly at the outside of Sendai Bay, but it reappears off the city of Soma as a result of about 20 km of horizontal dislocation toward the northwest. The Jurassic strata of the Soma area are the southern marginal facies in the Jurassic sequences of the South Kitakami Belt, and also are most likely to have deposited in a closed basin with land or submarine upheaval to the east. However, the basin also had a stage of open sea with active currents as inferred from the limestones and coarse arenites of the Nakanosawa Formation of Kimmeridgean to early Tithonian age.

Depositional history of the Jurassic basin discussed above, together with the "paleo-tectonic land" which probably existed to the east, provides useful information concerning the paleogeography of the South Kitakami Belt during the Jurassic Period. The Jurassic paleogeography are shown in Figure 62.

The Jurassic inland sea of the South Kitakami Belt was most probably connected with the inland sea which existed in the inner, Japan Sea side of the Japanese Islands ("Tedori Sea") through the northern side of the Abukuma Mountains. This is based on the following two reasons. Firstly the Jurassic deposits are generally of offshore or distal facies in the Western Subbelt compared with those of the Middle Subbelt. This indicates the existence of a sea possibly spreading toward the west. Secondly the Middle Jurassic of the South Kitakami Belt contains the same ammonoids and inoceramids of boreal type as in the Tedori Group in the Hida Mountains. They are represented by *Kepplerites* sp. (KOBAYASHI, 1947), *Inoceramus* cf. *lucifer* and *I. morri* and are similar to those from eastern Siberia (HAYAMI, 1961d). The Late Jurassic and Early Cretaceous faunas have a considerable number of species common to the Torinosu fauna of the Outer Zone of Southwest Japan (TAMURA, 1961). Thus, it is concluded that the Jurassic formations of the South Kitakami Belt are of intermediate type between those of the Inner and Outer Zones of Southwest Japan with character common to both.

IX. CONCLUSIONS

1) The Jurassic formations of the South Kitakami Belt are regarded as epicontinental deposits laid down in an inland sea basin accompanied by non-marine alluvial deposits. In Kimmeridgian or early Tithonian time, the Jurassic basin was under the influence of an open sea at least temporally. This is shown by the presence of coral-bearing calcareous rocks and the occurrence of the "Torinosu-type fauna".

2) The basin was distinctly differentiated into two minor basins which are now occupied by the Western and Middle Subbelts, at latest Middle Jurassic or earliest Late Jurassic time. After the differentiation, a great difference in sedimentary facies and environments occurred between both subbelts, and the center of deposition migrated into the east. Especially in the Oshika area, the amount of subsidence was the greatest in the Jurassic basin and the resultant strata are several times as thick as the corresponding sequence in the Western Subbelt.

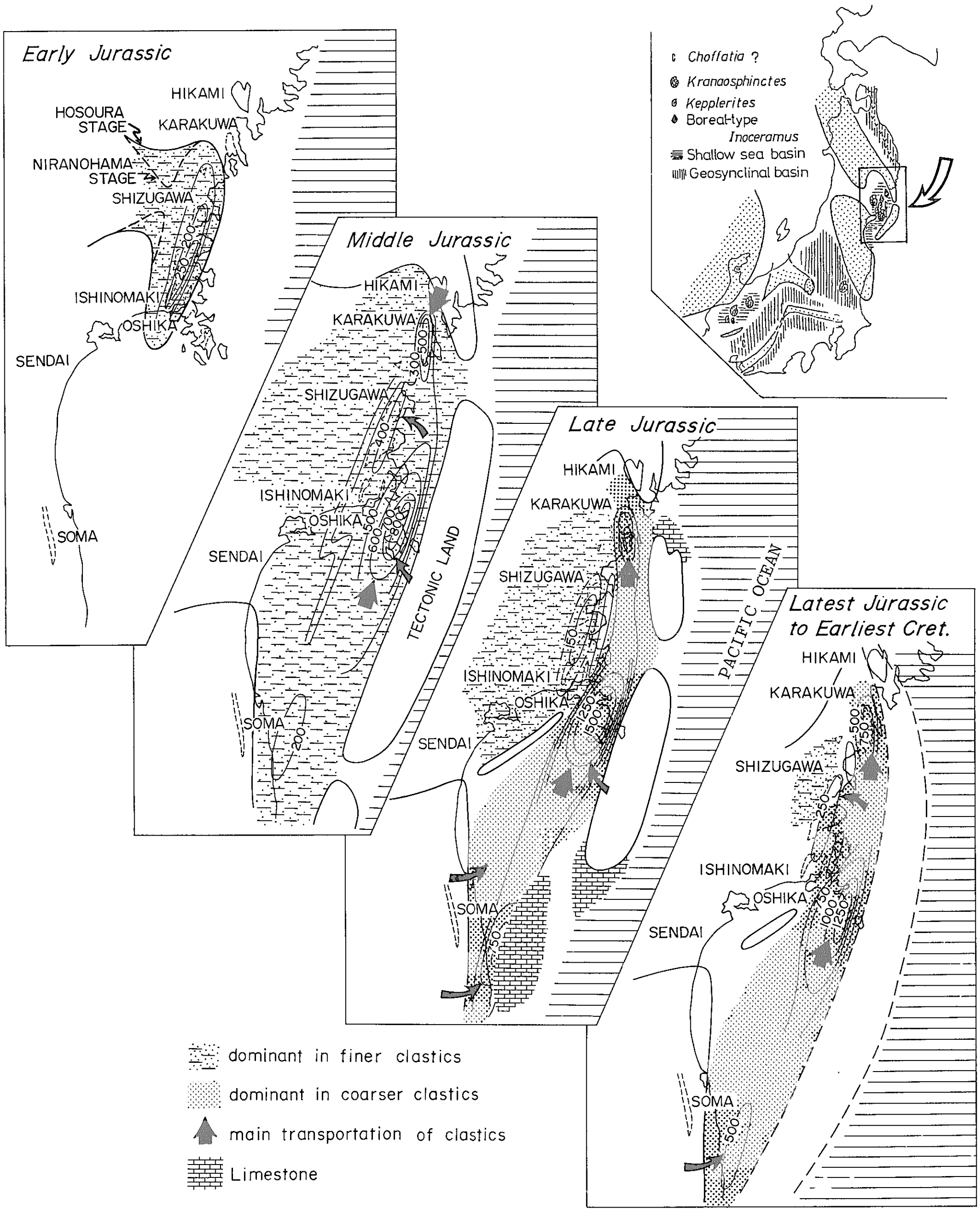


Fig. 62 Maps showing suggested paleogeography of the South Kitakami Belt during Jurassic time. The thickness of deposits is shown by isopach lines for each stage. Inset is a paleogeographic map of Northeast Japan during middle to late Jurassic time (modified from TAKIZAWA, (1977).

3) In Late Jurassic time, a great amount of coarse clastics which are composed chiefly of arkosic sandstone and conglomerate deposited in the Middle Subbelt. At least a part of the coarse clastics were supplied from the "tectonic land" to the east of the Jurassic basin. The position of the above land is considered to correspond with the narrow N-S zone of land-type magnetic anomaly to the east of the Kitakami Mountains.

4) The following facies associations are recognized in the Jurassic strata: shallow

marine, offshore basin mud, flysch, alluvial and lake associations in ascending order. The repeated sequences of their associations form three major cycles of transgression to regression in the Middle Subbelt, whereas the last two associations, that is, non-marine deposits, are not present in the Western Subbelt. Consequently, it is presumed that the Jurassic inland sea opened toward the west during at least Middle to Late Jurassic time and was connected with the inner sea of the Japanese Islands ("Tedori sea") and also with the outer sea of the Islands ("Torinosu sea").

5) Flysch facies association represented by turbidites contains a fair amount of laminated shales and fluxoturbidites. As regards depositional environment of the flysch facies, there is almost no sedimentary record of a major slope facies as indicating continental slope into a deep sea basin. This is interpreted as having been due to rapid deposition on a local deltaic slope. The occasional occurrence of plant fragments within the turbidites and fluxoturbidites shows that parts of the flysch sediments are probably attributed to river flood-generated turbidity current deposition.

6) Based upon the rapid changes from flysch through shallow marine (partially lacking) into alluvial facies association, the predominance of the northward paleocurrents and also other combined data, the accumulation of the flysch-alluvial sequence in the Jurassic of the Middle Subbelt is assumed to have resulted from a northerly prograding deltaic deposition. Most of the flysch facies association is regarded as deposits on a delta slope. Consequently, it is possible to recognize the following four constructional phases of a delta: on-delta (fluvial and distributary), delta-front (regressive shallow marine), delta slope (flysch) and pro-delta (distal turbidites and basin mud association).

References

ALLEN, J. R. L. (1964) Studies in fluviatile sedimentation; six cyclothems from Lower Old Red Sandstone, Anglo-Welsh Basin. *Sedimentology*, vol. 3, p. 163-198.

——— (1965a) Fining-upwards cycles in alluvial successions. *Liverpool Manchester Geol. Jour.*, vol. 4, p. 229-246.

——— (1965b) A review of the origin and characteristics of recent alluvial sediments. *Sedimentology*, vol. 5, p. 89-191.

——— (1970) Studies in fluviatile sedimentation: A comparison of fining-upwards cyclothems, with special reference to coarse-member composition and interpretation. *Jour. Sediment. Petrol.*, vol. 40, p. 298-323.

——— and FRIEND, P. F. (1968) Deposition of the Catskill facies, Appalachian region: With notes on some other Old Red Sandstone basin. *In* KLEIN, G. de V. (ed.): Late Paleozoic and Mesozoic continental sedimentation, northeastern North America. *Geol. Soc. Am., Spec. Paper*, no. 106, p. 21-74.

BANDO, Y. (1959) Origin of the some irregular types of sedimentation of the Mesozoic strata in the Kitakami Massif, northeast Japan. *Mem. Fac. Lib. Arts. and Educ. Kagawa Univ.*, no. 79, p. 1-14.

BARRET, P. J. (1965) Geology of the area between Axel Heiberg and Shackleton glaciers, Queen Maud Range, Antarctica. *New Zealand Jour. Geol. Geophy.* vol. 8, p. 344-370.

BARTOLINI, C. BERLATO, B. and BORTOLOTTI, U. (1975) Upper Miocene shallow-water turbidites from Western Tuscany. *Sediment. Geol.*, vol. 14, p. 77-122.

BLISSENBACH, E. (1954) Geology of alluvial fans in semiarid regions. *Geol. Soc. Am. Bull.*, vol. 65, p. 175-190.

BLUCK, B. J. (1967) Deposition of some Upper Old Red Sandstone conglomerates in the Clyde area: A study in the significance of bedding. *Scott. Jour. Geol.*, vol. 3, p. 139-167.

BOUMA, A. H. (1962) *Sedimentology of some flysch deposits: A graphic approach to facies interpretation.* Elsevier, Amsterdam, 168p.

BRENNER, R. L. and DAVIES, D. K. (1973) Storm-generated coquinoid sandstone: Genesis of high-energy marine sediments from the Upper Jurassic of Wyoming and Montana. *Geol. Soc. Am. Bull.*, vol. 84, p. 1685-1698.

CANT, D. J. and WALKER, R. G. (1976) Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Québec. *Can. Jour. Earth Sci.*, vol. 13, p. 102-119.

CASSHYAP, S. M. (1970) Sedimentary cycles and environments of deposition of the Barakar Coal Measures of Lower Gondwana, India. *Jour. Sediment. Petrol.*, vol. 40, p. 1302-1317.

CHIPPING, D. H. (1972) Sedimentary structures and environment of some thick sandstone beds of turbidite type. *Jour. Sediment. Petrol.*, vol. 42, p. 587-595.

COLEMAN, J. M. (1969) Brahmaputra River: Channel processes and sedimentation. *Sediment. Geol.*, vol. 3, p. 129-239.

COLLISON, J. D. (1969) The sedimentology of the Grindslow shales and the Kinderscout Grit: A deltaic complex in the Namurian of northern England. *Jour. Sediment. Petrol.*, vol. 39, p. 194-221.

——— (1970) Deep channels, massive beds and turbidity current genesis in the Central Pennine Basin. *Proc. Yorks. Geol. Soc.*, vol. 37, p. 495-519.

——— (1979) Lakes. *In* READING, H. G. (ed.), *Sedimentary environments and facies.* Blackwell Sci. Publ., p. 61-79.

CONRAD, G. (1969) L'evolution continentale post-Hercynienne du Sahara Algerien, (Saoura, Erg Chech-Tanezrouft, Anet-Movydir) *Centre Recherches sur les Zones Arides, Serie. Geol.*, no. 10, 527p.

CORBETT, K. D. (1972) Features of thick-bedded sandstones in a proximal flysch sequence, Upper Cambrian, South-West Tasmania. *Sedimentology*, vol. 19, p. 99-114.

CROWELL, J. C. (1957) Origin of pebbly mudstone. *Geol. Soc. Am. Bull.*, vol. 68, p. 993-1010.

DEGENS, E. T. (1965) *Geochemistry of sediments*, Prentice-Hall, New Jersey, 342p.

De RAAF, J. F. M., BOERSMA, J. R. and Van GELDER, A. (1977) Wave-generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland. *Sedimentology*, vol. 24, p. 451-483.

De RAAF, J. F. M., READING, H. G. and WARKER, R. G. (1965) Cyclic sedimentation in the Lower Westphalian of North Devon, England. *Sedimentology*, vol. 4, p. 1-52.

DOEGLAS, D. J. (1962) The structure of sedimentary deposits of braided rivers. *Sedimenology*, vol. 1, p. 167-190.

DZULYNSKI, S., KSIAZKIEWICZ, M. and KEUNEN, PH. H. (1959) Turbidites in flysch of Polish Carpathian Mountains. *Geol. Soc. Am. Bull.*, vol. 70, p. 1089-1118.

EGUCHI, M. and SHOJI, R. (1965) Sedimentary environment of the Jurassic limestone in the vicinity of Kashima-machi, Fukushima Prefecture, Japan. *Jour. Geol. Soc. Japan*, vol. 71, p. 237-246 (in Japanese with English abstract).

EHIRO, M. (1974) Geological and structural studies of the area along the Hizume-Kesennuma tectonic line, in Southern Kitakami Massif. *Jour. Geol. Soc. Japan*, vol. 80, p. 457-474 (in Japanese with English abstract).

ERIKSSON, K. A. (1982) Geometry and internal characteristics of archaean submarine channel deposits, Pilbara block, Western Australia. *Jour. Sediment. Petrol.* vol. 52, p. 383-393.

FERM, J. C. and CAVAROC, V. V. Jr. (1968) A non-marine model for the Allegheny of West Virginia. *In* KLEIN, G. de V. (ed), *Late paleozoic and mesozoic continental sedimentation, Northeastern North America, Geol. Soc. Am. Spec. Paper*, no. 106, p. 1-19.

FISHER, W. L. and McGOWEN, J. H. (1969) Depositional systems in the Wilcox Group (Eocene) of Texas and their relationship to occurrence of oil and gas. *Am. Ass. Petrol. Geol. Bull.*, vol. 53, p. 30-54.

FLEMING, B. W. (1978) Underwater sand dunes along the Southeast African Continental Margin: observations and implications. *Marine Geol.* vol. 26, p. 177-198.

FÖRSTNER, U., MÜLLER, G. and REINECK, H-E. (1968) Sedimente und sedimentgefuge des Rheindeltas im Bodensee. *Neues Jahrb. Mineral. Abhandl.*, vol. 109, p. 33-62.

FRIEDMAN, G. M. (1961) Distinction between dune, beach and river sands from their textural characteristics. *Jour. Sediment. Petrol.*, vol. 31, p. 514-529.

FUKADA, A. (1950) On the occurrence of *Perisphinctes* (s.s.) from the Ojika Peninsula in the southern Kitakami Mountainland. *Jour. Fac. Sci. Hokkaido Univ., Ser.* 4, vol. 7, p. 211-216.

GREENSMITH, J. T. (1966) Carboniferous deltaic sedimentation in Eastern Scotland: A review and reappraisal. *In* SHIRLEY, M. L. and RAGSDALE, J. A. (eds.), *Deltas in their geologic framework*, Houston Geol. Soc., Texas. p. 189-211.

HAYAMI, I. (1958) Some Hettangian pelecypods from the "*Trigonia*-sandstone" of the Shizukawa Group in northeast Japan. *Jap. Jour. Geol. Geogr.*, vol. 29, p. 99-110.

——— (1959a) Jurassic system in Mizunuma area of Inai village, Miyagi Prefecture, northeast Japan. *Jour. Geol. Soc. Japan*, vol. 65, p. 505-515.

——— (1959b) Pelecypods of the Mizunuma Jurassic in Miyagi Prefecture, with some stratigraphical remarks. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 34, p. 66-78.

——— (1959c) Some pelecypods from the Tsukinoura Formation in Miyagi Prefecture. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 35, p. 133-137.

——— (1959d) Bajocian pelecypods of the Aratozaki Formation in northeast Japan. *Jap. Jour. Geol. Geogr.*, vol. 30, p. 53-70.

——— (1960) Pelecypods of the Jusanhama Group (Purbeckian or Wealden) in Hashiura area, northeast Japan. *Ibid.*, vol. 31, p. 13-21.

——— (1961a) Successions of the Kitakami Jurassic. Jurassic stratigraphy of South Kitakami, Japan, (I) *Jap. Jour. Geol. Geogr.*, vol. 32, p. 159-177.

——— (1961b) Sediments and correlation of the Kitakami Jurassic. Jurassic stratigraphy of South Kitakami, Japan, (II) *Ibid.*, vol. 32, p. 179-190.

——— (1961c) Geologic history recorded in the Kitakami Jurassic. Jurassic stratigraphy of South

Kitakami, Japan, (III) *Ibid.*, vol. 32, p. 191-204.

——— (1961d) On the Jurassic pelecypod faunas in Japan. *Jour. Fac. Sci. Univ. Tokyo, sec.* II, vol. 13, p. 243-343.

——— (1962) Jurassic pelecypod faunas in Japan with special reference to their stratigraphical distribution and biogeographical provinces. *Jour. Geol. Soc. Japan*, vol. 68, p. 96-108.

———, SUGITA, M. and NAGUMO, Y. (1960) Pelecypods of the Upper Jurassic and Lowermost Cretaceous Shishiori Group in northeast Japan. *Jap. Jour. Geol. Geogr.*, vol. 31, p. 85-98.

HAYES, O. (1980) General morphology and sediment patterns in tidal inlets. *Sediment. Geol.*, vol. 26, p. 139-156.

HEEZEN, B. C. MENZIES, R. J., SCHNEIDER, E. D., EWING, W. M. and GRANELLI, N. C. L. (1964) Congo submarine Canyon. *Am. Ass. Petrol. Geol. Bull.*, vol. 48, p. 1126-1149.

HEIN, F. J. and WALKER, R. G. (1982) The Cambro-Ordovician Cap Enrage Formation, Quebec, Canada: Conglomeratic deposits of a braided submarine channel with terraces. *Sedimentology*, vol. 29, p. 309-329.

HEWARD, A. P. (1978) Alluvial fan and lacustrine sediments from the Stephanian A and B (La Magdalena, Cinera-Matallana and Sabero) coolfields, northern Spain. *Sedimentology*, vol. 25, p. 451-488.

HOUBOLT, J. J. H. C. and JONKER, J. B. M. (1968) Recent sediments in the eastern part of the Lake of Geneva (Lac Leman). *Geol. Mijnb.*, vol. 47, p. 131-148.

HSÜ, K. J. (1964) Cross-laminations in graded bed sequences. *Jour. Sediment. Petrol.*, vol. 34, p. 379-388.

HUBERT, J. F. and HYDE, M. C. (1982) Sheet-flow deposits of graded beds and mudstones on an alluvial sandflat-playa system. Upper Triassic Blomidon redbeds, St. Mary's Bay, Nova Scotia. *Sedimentology*, vol. 29, p. 457-474.

ICHIKAWA, K. (1951) Triassic system of the South Kitakami Mountains. *In* Geological Survey of Japan (ed): Triassic stratigraphy of Japan. *Geol. Surv. Japan, Spec. Rept.*, no. A, p. 7-23 (in Japanese).

INAI, Y. (1939) Geology of the environs of Sizugawamati, Miyagi Prefecture. *Jour. Geol. Soc. Japan*, vol. 46, p. 231-242 (in Japanese with English abstract).

INAI, Y. and TAKAHASHI, T. (1940) On the geology of the southernmost Kitakami mountainland. *Contr. Inst. Geol. Pal. of Tohoku Imp. Univ.*, 34 (in Japanese).

ITIHARA, M. and ITIHARA, Y. (1971) On marine clay and fresh water clay of the Osaka Group. *Prof. H. TAKEHARA Mem. Vol.*, p. 173-181 (in Japanese with English abstract).

JOHNSON, H. D. (1977) Shallow marine sand bar sequences: an example from the late Precambrian of North Norway. *Sedimentology*, vol. 24, p. 245-270.

KAMADA, K. (1979) The Triassic Inai Group in the Karakuwa area, Southern Kitakami Mountains, Japan, Part 1: stratigraphy and paleogeography. *Jour. Geol. Soc. Japan*, vol. 85, p. 737-751 (in Japanese with English abstract).

KANES, W. H. (1970) Facies and development of the Colorado River delta in Texas. In MORGAN, J. P. and SHAVER, R. H. (eds.): *Deltaic sedimentation, modern and ancient. Soc. Econ. Paleont. Mineral. Spec. Pub.*, no. 15, p. 78-106.

KANO, H. (1958) On a basal conglomerate of the Inai Formation (Lower Triassic) in the Toyoma district, Southern Kitakami-mountainland, Japan. *Jour. Geol. Soc. Japan*, vol. 64, p. 464-473 (in Japanese with English abstract).

——— (1959) On the granitic pebbles from the Shishiori Formation (Upper Jurassic) and their origin. *Ibid.*, vol. 65, p. 750-759 (in Japanese with English abstract).

KASE, T. (1979) Stratigraphy of the Mesozoic formations in the Hashiura area, Southern Kitakami Mountainland, northern Japan. *Jour. Geol. Soc. Japan*, vol. 85, p. 111-122 (in Japanese with English abstract).

KATO, M., KUMANO, S., MINOURA, N., KAMADA, K. and KOSHIMIZU, S. (1977) *Perisphinctes ozikaensis* from the Karakuwa Peninsula, Northeast Japan. *Jour. Geol. Soc. Japan*, vol. 83. p. 305-306. (in Japanese)

KEITH, B. D. and FRIEDMAN, G. M. (1977) A slope-fan-basin-plain model, Taconic sequence, New York and Vermont. *Jour. Sediment. Petrol.*, vol. 47, p. 178-199.

KEITH, M. L. and DEGENS E. T. (1959) Geochemical indicators of marine and fresh-water sediments. *In* ABELSON, P. H. (ed.): *Researches in geochemistry*, John Wiley, New York. p. 38-61.

KIMURA, T. (1954) The sandstone and the limestone of the Nakanosawa Formation. *Jour. Geol. Soc. Japan*, vol. 60, p. 67-80 (in Japanese with English abstract).

———, YOSHIDA, S. and TOYOHARA, F. (1975) Paleogeography and earth movements of Japan in the Late Permian to early Jurassic Sambosan stage. *Jour. Fac. Sci. Univ. Tokyo, sec.* II, vol. 19, p. 149-177.

KOBAYASHI, T. (1947) On the occurrence of *Seymourites* in Nippon and its bearing on the Jurassic palaeogeography. *Jap. Jour. Geol. Geogr.*, vol. 20, p. 19-31.

KSIAZKIEWICZ, M. (1970) Observations on the ichnofauna of the Polish Carpachians. *In* CRIMES, T. P. and HARPER, J. C. (eds.), *Trace fossils*, p. 283-

322, Liverpool.

——— (1977) Trace fossils in the flysch of the Polish Carpathians. *Palaeont. Polonica*, no. 36, p. 1-208.

KUENEN, PH. H. and MIGLIORINI, C. I. (1950) Turbidity currents as a cause of graded bedding. *Jour. Geol.*, vol. 58, p. 91-127.

LEOPOLD, L. B. and WOLMAN, M. G. (1957) River channel patterns; braided, meandering and straight. *U. S. Geol. Survey, Prof. Paper*, vol. 282-B, p. 39-85.

LINK, M. H. (1975) Matilija Sandstone (Eocene of Califormia): A transition from deep-water turbidite to shallow-marine deposition. *Jour. Sediment. Petrol.*, vol. 45, p. 63-78.

LOVEL, J. P. B. (1969) Tyee Formation: A study of proximality in turbidites. *Jour. Sediment. Petrol.*, vol. 39, p. 935-953.

MABUTI, S. (1933) Jurassic stratigraphy of the southern part of the Kitakami mountainland, northeast Japan. *Proc. Imp. Acad. Japan*, vol. 9, p. 313-316.

MASATANI, K. (1950) A study of the Jurassic formation in the Soma district, Fukushima Prefecture. *Jour. Geol. Soc. Japan.*, vol. 56, p. 499-505 (in Japanese with English abstract).

——— and TAMURA, M. (1959) A stratigraphic study on the Jurassic Soma group on the eastern foot of the Abukuma mountainland, northeast Japan. *Jap. Jour. Geol. Geogr.*, vol. 30, p. 245-257.

MASUDA, F., AMANO, K., KATSURA, Y. and ITO, M. (1981) Shallow marine facies of Neogene and Quaternary strata at the northwest and southeast parts of Teshio Town in Hokkaido. *Human Culture and Environmental Studies in Northern Hokkaido 2.* (Univ. Tsukuba. JAPAN), p. 1-41. (in Japanese with English abstract)

MCBRIDE, E. F., WEIDE, A. E. and WOLLEBEN, J. A. (1975) Deltaic and associated deposits of Difunta Parras and La Pora Basins, Norchwestern Mexico. *In* BROUSSARD, M. L. (ed.): *Deltas, models for exploration.* Houston Geol. Soc., p. 485-522.

MCCABE, P. J. (1977) Deep distributary channels and giant bedforms in the Upper Carboniferous of the Central Pennines, northern England, *Sedimentology*, vol. 24, p. 271-290.

——— (1978) The Kinderscoutian delta (Carboniferous) of northern England: a slope influenced by dencity currents. *In* STANLEY, D. J. and KELLING, G. (eds.): *Submarine Canyon and Fan Sedimentation*, Dowden, Hutchingson and Ross, p. 116-126.

MCGOWEN, J. H. and GARNER, L. E. (1970) Physiographic features and stratifiction types of coarse-grained pointbars modern and ancient examples. *Sedimentology*, vol. 14, p. 77-111.

——— and GROAT, C. G. (1971) Van Horn Sandstone, West Texas: an alluvial fan model for mineral exploration. *Report of Investigations, Bureau of Economic Geology, Univ Texas*, Austin. no. 72, 57p.

MECKEL, L. D. (1970) Paleozoic alluvial deposition in the Central Appalachians: A summary. *In* FISHER, W., PETTIJOHN, F. J., REED, J. C. Jr. and WEAVER, K. N. (eds.): *Studies of Appalachian Geology, Central and Southern*, Interscience Publ, p. 49-67.

MIKAMI, T. (1969) A sedimentological study of the lower Permian Sakamotozawa Formation. *Mem. Fac. Sci. Kyushu Univ., ser. D (Geol.)*, vol. 19, p. 331-372.

——— (1971) Preliminary notes on the Palaeozoic sandstones from the Hikoroichi area, South Kitakami Mountains. *Mem. Geol. Soc. Japan*, no. 6 p. 33-37 (in Japanese with English abstract).

MINATO, M. (1966) Stratigraphie des Palaeozoikums des Kitakami Gebirges und Abe-Orogenese in Japan. *Prof. S. Matsushita Mem. Vol.*, p. 143-159 (in Japanese with Deuche abstract).

MOGI, A. (1963) On the shore types of the coasts of Japanese Island. *Ass. Japan. Geographers*, vol. 36. p. 245-266. (in Japanese with English abstract)

MORI, Kazuo (1949) On the Jurassic formations in the Hashiura district, province of Rikuzen, Japan. *Jap. Jour. Geol. Geogr.*, vol. 21, p. 315-321.

MORI, Kei (1963) Geology and paleontology of the Jurassic Somanakamura Group, Fukushima Prefecture, Japan. *Sci. Rep. Tohoku Univ., Ser.* 2, vol. 35, p. 33-65.

MÜLLER, G. (1963) Die rezenten Sedimente im Obersee des Bordensees. *Naturwissenschaften*, vol. 50, p. 1-350.

——— and GEES, R. A. (1970) Distribution and thickness of Quaternary sediments in the Lake Constance basin. *Sediment. Geol.* vol. 4, p. 81-87.

MURATA, M. (1976) Problems concerning the Hikami granites, one of the pre-Silurian basement rocks in the Kitakami Massif, northeast Japan. *Earth Science (Chikyu Kagaku)*, vol. 30, p. 347-357 (in Japanese with English abstract).

NAKAZAWA, K. and MURATA, M. (1966) On the Lower Cretaceous fossils found near the Omine mine, Iwate Prefecture, Northeast Japan. *Mem. Coll. Sci. Univ. Kyoto. ser. B*, vol. 32, p. 303-333, and *Prof. S. Matsushita Mem. Vol.*, p. 261-291.

——— and NEWELL, N. D. (1968) Permian bivalves of Japan. *Mem. Fac. Sci. Kyoto Univ., ser* B, vol. 35, p. 1-108.

NESTEROF, W., DUPLAIX, S., SAUVAGE, J., LANCELOT, Y., MELIERES, F. and VINCENT, E. (1968) Les dépots récents du Canyon de Cape-Breton. *Soc. Geol. France Bull., ser.* 7, vol. 10, p. 218-252.

NIO, S. D. (1976) Marine transgressions as a factor in the formation of sand wave complexes. *Geol. Mijinb.*, vol. 55, p. 18-40.

NORMARK, W. R. and PIPER, D. J. W. (1969) Deep-sea fan-valleys, past and presetn. *Geol. Soc. Am. Bull.*,

vol. 80, p. 1859–1866.
OGAWA, K. and TSU, H. (1976) Magnetic interpretation using interactive computer graphics. *Rep. Techn. Res. Cen., Jap. Petrol. Devl. Corp.*, no. 3, p. 19–39.
OKAMI, K. (1969) Sedimentary petrographic study of the quartzose sandstone of the Tomizawa Formation. *Sci. Rep., Tohoku Univ.* vol. 41, p. 95–108.
——— MASUYAMA, H. and MORI, T. (1976) Exotic pebbles in the eastern terrain of the Abukuma Plateau, Northeast Japan (Part 1). The conglomerate of the Jurassic Somanakamura Group. *Jour. Geol. Soc. Japan*, vol. 82, p. 83–98.
OKADA, H. (1971a) Classification of sandstone. Analysis and proposal. *Jour. Geol.*, vol. 79, p. 509–525.
——— (1971b) A pattern of sedimentation in clastic sediments in geosycline. *Mem. Geol. Soc. Japan*, no. 6, p. 75–82 (in Japanese with English abstract).
ONUKI, Y. (1956) *Geology of the Kitakami mountains. Explanatory text of the Geologic map of Iwate Prefecture* (1:100,000). Iwate Pref. (in Japanese). 189p.
——— (1969) Geology of the Kitakami Massif, northeast Japan. *Contr. Inst. Geol. Paleont. Tohoku Univ.*, no. 69, p. 1–239 (in Japanese with English abstract).
——— and MORI, K. (1961) Geology of the Ofunato district, Iwate Prefecture, southern part of the Kitakami Massif, Japan. *Jour. Geol. Soc. Japan*, vol. 67, p. 641–654 (in Japanese with English abstract).
OTSUKA, K., KAGAMI, H., HONZA, E., NASU, N. and KOBAYASHI, K. (1973) Submarine slumping as a cause of turbidity currents in Sagami Bay. *Marine Sci.* (*Kaiyo Kagaku*), vol. 5, p. 14–20 (in Japanese with English abstract).
OYAMA, T. (1954) On the fossil flora of the Cycadophyta from Samenoura, Ojika Peninsula, Miyagi Prefecture in Japan. *Bull. Fac. Lib. Arts Ibaraki Univ., Nat. Sci.*, no. 4, p. 97–113.
PETTIJHON, F. J. (1975) *Sedimentary rocks (3rd ed)*. Harper and Row Publ. 683p.
PICARD, M. D. (1957) Criteria used for distinguishing lacustrine (sic) and fluvial sediments in Tertiary beds of Unita Basin, Utah. *Jour. Sediment. Petrol.*, vol. 27, p. 373–377.
——— and HIGH, L. R. Jr. (1972) Criteria for recognizing lacustrine rocks. *In.* RIGBY, J. K. and HAMBLIN, W. K. (eds.) Recognition of Ancient Sedimentary Environments., *Spec. Publ. Soc. Econ. Paleont. Miner.*, no. 16, Tulsa. p. 108–145.
——— and HIGH L. R. Jr. (1973) *Sedimentary structures of ephemeral streams. (Developments in Sedimentology*, no. 17) Elsevier, Amsterdam. 223p.
PICHA, F. and NIEM, A. R. (1974) Distribution and extent of beds in flysch deposits, Ouachita Mountains, Arkansas and Oklahoma. *Jour. Sediment. Petrol.*, vol. 44, p. 328–335.
PICKERING, K. T. (1982) A Precambrian upper Basin-slope and prodelta in Northeast Finnmark, North Norway: A possible ancient upper continental slope. *Jour. Sediment. Petrol.*, vol. 52, p. 171–186.
POLLARD, J. E., STEEL, R. J. and UNDERSRUD, E. (1982) Facies sequences and trace fossils in lacustrine/fan delta deposits, Hornelen Basin (M. Devonian), Western Norway. *Sediment. Geol.*, vol. 32, p. 63–87.
PUIGDEFABREGAS, C. (1973) Miocene point-bar deposits in the Ebro Basin, Northern Spain. *Sedimentology*, vol. 20, p. 133–144.
READING, H. G. (1970) Sedimentation in the Upper Carboniferous of the southern flanks of the central Cantabrian Mountains, Northern Spain. *Proc. Geol. Assoc.*, vol. 81, p. 1–41.
REINECK, H. E. and SINGH, I. B. (1973) *Depositional sedimentary environments—with reference to terrigenous clastics*. Springer-Verlag, Berlin. 439p.
RICH, J. L. (1951) Three critical environments of deposition, and criteria for recognition of rocks deposited in each of them. *Geol. Soc. Am. Bull.*, vol. 62, p. 1–20.
RUST, B. R. (1979) Coarse alluvial deposits. *In* WALKER, R. G. (ed.): *Facies Models*, Geol. Ass. Canada. Publ. Toronto. p. 9–21.
SANDERS, J. E. (1968) Stratigraphy and primary sedimentary structures of fine-grained, well-bedded strata, inferred lake deposits, Upper Triassic, Central and Southern Connecticut. *In* KLEIN, G. V. (ed.): Late Paleozoic and Mesozoic continental sedimentation, northeastern North America. *Geol. Soc. Am. Spec. Pap.*, no. 106. p. 265–305.
SATO T. (1958) Presence du Berriasien dans le stratigraphie de Plateau de Kitakami (Japon septentrional). *Bull. Soc. Geol. France*, ser. 6, tome 8, p. 585–599.
——— (1962) Etudes biostratigraphiques des ammonites du jurassique du Japon. *Mem. Soc. Geol. France, nourv. ser.* 41, fasc. 1, no. 94, p. 1–122.
——— (1967) Jurassic. *In* ASANO, K., MATSUMOTO, T., TORIYAMA, R. and TAKAI, F. (eds.): *Historical Geology* (II), (in Japanese) Asakura Publ. p. 362–407 (in Japanese).
——— (1972) Some Bajocian ammonites from Kitakami, northeast Japan. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, no. 85, p. 280–292.
SEILACHER, A. (1964) Biogenic sedimentary structure. *In* IMBRIE, J. and NEWELL, N. (eds): *Approaches to palaeoecology*, Wiley, New York, p. 296–316.
SELLY, R. C. (1965) Diagnostic characters of fluviatile sediments of the Toridonian Formation (Precambrian) of Northwest Scotland. *Jour. Sediment. Petrol.*, vol. 35, p. 366–380.
——— (1970) *Ancient sedimentary environments, A brief survey*. Chapman and Hall, London. 237p.
——— (1976) *An introduction to sedimentology*, Academic

Press, London, 408p.

SHELTON, J. W. (1973) Models of sand and sandstone deposits: A methodology for determining sand genesis and trend. *Okla. Geol. Survey, Bull.* 118, 122p.

SHEPARD, F. P., DILL, R. F. and Von RAD, U. (1969) Physiography and sedimentary processes of La Jolla submarine fan and fan-valley, California. *Bull. Am. Ass. Petrol. Geol.*, vol. 53, p. 390–420.

SHIIDA, I. (1940) On the geology in the environs of Kesennuma, Miyagi Prefecture. *Contr. Geol. Pal. Inst. Tohoku Imp. Univ.* no. 33, p. 1–72 (in Japanese).

——— (1940–1941) Stratigraphy of the Jurassic deposits developed near Kesennuma, Miyagi Prefecture, northeast Japan. *Jubilee Pub. Comm. Prof. H. Yabe' 60th Birthday*, vol. 2, p. 893–910 (in Japanese with English abstract).

SHIKI, T. (1968) On "Graywacke": Part 2, origin of variety of "Graywackes". *Earth Science (Chikyu Kagaku)*, vol. 22. p. 240–250 (in Japanese with English abstract).

SIMONS, D. B., RICHARDSON, E. V. and NORDIN, C. F. (1965) Sedimentary structures generated by flow in alluvial channels. In Middleton, G. V. (ed.): Primary sedimentary structure and their hydrodynamic interpretation. *Spec. Publ. Soc. Econ. Paleont. Miner.*, no. 12, Tulsa. p. 34–52.

SMITH, N. D. (1970) The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, North-Central Appalachians. *Geol. Soc. Am. Bull.*, vol. 81, p. 2993–3014.

STANLEY, D. J. (1968) Graded bedding-sole marking-graywacke assemblage and related sedimentary structures in some Carboniferous flood deposits, eastern Massachusetts. *In* KLEIN, G. V. (ed.), Late Paleozoic and Mesozoic continental sedimentation, northeastern North America. *Geol. Soc. Am, Spec. Paper* no. 106, p. 211–239,

——— and KELLING, G. (1978) *Sedimentation in submarine canyons, fans, and trenches.* Dowden, Hutchingson and Ross Stroudsburg, 395p.

——— and UNRUG, R. (1972) Submarine channel deposits, fluxoturbidites and other indicators of slope and base-of-slope environments in modern and ancient marine basins. *In* RIGBY, J. K. and HAMBLIN, W. K. (eds.): Recognition of ancient sedimentary environments. *Spec. Publ. Soc. Econ. Paleont. Miner.*, no. 16. p. 287–340.

STAUFFER, P. H. (1967) Grain flow deposits and their implications, Santa Ynez Mountains, California. *Jour. Sediment. Petrol.*, vol. 37, p. 487–508.

STEEL, R. J. (1974) New Red Sandstone floodplain and piedmont sedimentation in the Hebridean province. *Jour. Sediment. Petrol.*, vol. 44, p. 336–357.

SWIFT, D. J. P., STANLEY, D. J. and CURRAY, J. R. (1971) Relict sediments on continental shelves: a reconsideration. *Jour. Geol.*, vol. 79, p. 322–346.

TAKAHASHI, T. (1941) Mesozoic plant beds of Ozika peninsula, Miyagi Prefecture. *Jub. Pub. Comm. Prof. H. Yabe' 60th Birth*, vol. 2, p. 695–703 (in Japanese with English abstract).

TAKAHASHI, H. (1962) Mesozoic formations of Ojika peninsula. *Bull. Fac. Arts and Sci. Ibaraki Univ., Nat. Sci.*, no. 13, p. 89–99 (in Japanese with English abstract).

——— (1964) Some sedimentary structures in the rocks of the Triassic Inai Group. *Bull. Fac. Arts and Sci. Ibaraki Univ., Nat. Sci.*, no. 15, p. 97–104 (in Japanese with English abstract).

——— (1969) Stratigraphy and ammonite fauna of the Jurassic System of the Southern Kitakami Massif, northeast Honshu, Japan. *Sci. Rep. Tohoku Univ.*, 2nd *ser.*, vol. 41, p. 1–93.

——— (1973) The Isokusa Formation and its late Upper Jurassic and early Lower Cretaceous ammonite fauna. *Ibid. Spec. Vol.*, no. 6 (*HATAI Mem. Vol.*), p. 319–336.

TAKIZAWA F. (1970) Ayukawa Formation of the Ojika Peninsula, Miyagi Prefecture, northeast Japan. *Bull. Geol. Surv. Japan*, vol. 21, p. 567–578.

——— (1975) Lower Cretaceous sedimentation in the Oshika peninsula, Miyagi Prefecture, northeast Japan. *Bull. Geol. Surv. Japan*, vol. 26, p. 267–305. (in Japanese with English abstract).

——— (1976) Sedimentary cycles of probably fluvial origin in the Upper Jurassic, Oshika Peninsula, South Kitakami, northeast Japan. *Jour. Geol. Soc. Japan*, vol. 82, p. 625–642 (in Japanese with English abstract).

——— (1977) Some aspects of the Mesozoic sedimentary basins in the South Kitakami belt, northeast Japan. *Monogr. Assoc. Geol. Col. Japan*, no. 20, p. 61–73 (in Japanese with English abstract).

——— (1981) Folded structure and attitude of slaty cleavages of the Ogachi and Oshika districts, South Kitakami. *Jour. Tectonic Research Group, Japan*, vol. 26, p. 43–57 (in Japanese).

———, ISSHIKI, N. and KATADA, M. (1974) Geology of the Kinkasan district. Quadrangle series, scale 1:50,000, Akita (6) No. 100. *Geol. Surv. Japan*, p. 1–62 (in Japanese with English abstract).

———, KAMBE, N., KUBO, K., HATA, M., SAMGAWA, A. and KATADA, M. (1984) Geology of the Ishinomaki district. Quadrangle series, scale 1:50,000, Akita (b) no. 90. *Geol. Surv. Japan*, p. 1–103 (in Japanese with English abstract).

TAMURA, M. (1959) On the Torinosu pelecypod-fauna in the Jurassic group of Soma in Fukushima prefecture. *Jour. Geol. Soc. Japan*, vol. 65, p. 280–289.

——— (1961) The Torinosu Series and fossils therein. *Japan. Jour. Geol. Geogr.*, vol. 32, p. 219–251.

TANAKA, K. and TERAOKA, Y. (1973) Stratigraphy and sedimentation of the Upper Cretaceous Himenoura Group in Koshiki-jima, Southwest Kyushu, Japan, *Bull. Geol. Survey Japan,* vol. 24, p. 157–184 (in Japanese with English abstract).

TWENHOFEL, W. H. (1932) *Treatise on sedimentation* (2nd ed.): Williams and Wikins Co., Baltimore, 926p.

TAYLOR, J. H. (1963) Sedimentary features of an ancient deltaic complex: the Wealden rocks of southeastern England. *Sedimentology*, vol. 2, p. 2–28.

VISHER, G. S. (1965a) Fluvial processes as interpreted from ancient and recent fluvial deposits. *In* MIDDLETON, G. V. (ed.): Primary sedimentary structures and their hydrodynamic interpretation. *Soc. Econ. Paleont. Miner., Spec. Publ.*, no. 12, p. 116–132.

——— (1965b) Use of vertical profile in environmental reconstruction. *Bull. Am. Ass. Petrol. Geol.* vol. 49, p. 41–61.

——— (1969) Grain size (sic) distributions and depositional process. *Jour. Sediment. Petrol.*, vol. 39, p. 1074–1106.

WALKER, R. G. (1967) Turbidite sedimentary structures and their relationship to proximal and distal depositional environments. *Jour. Sediment. Petrol.*, vol. 37, p. 25–43.

——— (1969) The Juxtaposition of turbidite and shallow-water sediments: Study of a regressive sequence in the Pensylvanian of North Devon, England. *Jour. Geol.*, vol. 77, p. 125–143.

——— (1970) Deposition of turbidites and agitated-water siltstones: a study of the Upper Carboniferous Westward Ho! Formation, North Devon. *Proc. Geol. Ass.* vol. 80, p. 43–67.

——— (1971) Nondeltaic depositional environments in the Catskill clastic wedge (Upper Devonian) of central Pennsylvania. *Geol. Soc. Am. Bull.*, vol. 82, p. 1305–1326.

——— (1975) Nested submarine-fan channels in the Capestrano Formation, San Clemente, California. *Geol. Soc. Am. Bull.*, vol. 86, p. 915–924.

——— (1978) Deep-water sandstone facies and ancient submarine fans: Models for exploration for stratigraphic traps. *Bull. Am. Ass. Petrol. Geol.*, vol. 62, p. 932–966.

——— (1979) Shallow marine sands. *In* WALKER, R. G. (ed.): *Facies Models*, Geol. Ass. Canada. Publ., Toronto. p. 75–90.

——— and CANT, D. G. (1979) Sandy fluvial systems. *Ibid.*, p. 23–32.

——— and MUTTI, E. (1973) Turbidite facies and facies associations. *In* MIDDLETON, G. V. and BOUMA, A. H. (eds.): *Turbidites and deep water sedimentation. Soc. Econ. Paleont. Mineral. Pacific Sect., Short Course Notes.* p. 119–157.

WILLIAMS, P. F. and RUST, B. R. (1969) The sedimentology of a braided river. *Jour. Sediment. Petrol.*, vol. 39, p. 649–679.

WURSTER, P. (1964) Delta sedimentation in the German Keuper basin, *In* Van STRAATEN, L. M. J. U. (ed.): *Deltaic (sic) and shallow marine deposits. Developments in Sedimentology*, vol. 1, Amsterdam, Elsevier Pub. p. 436–446.

YAMASHITA, N. (1957) *The Mesozoic*, (II). *Geosci. Ser.* II, Assoc. Geol. Collab. Japan (in Japanese).

YOSHIDA, T. (1975) Development of northeast Japan geosyncline in the Paleozoic and Mesozoic. *Monogr. Assoc. Geol. Collab. Japan*, no. 19, p. 103–114 (in Japanese with English abstract).

南部北上帯におけるジュラ紀層の堆積

滝沢文教

要旨

南部北上帯のジュラ紀層は，中生層における3列の向斜状配列の内，西列（志津川・橋浦・水沼の各地域）と中列(唐桑・牡鹿・相馬)とに点在して分布し，南北約160 km，東西25 kmの狭長な範囲に分布する．それらは，岩相・含有化石・堆積構造等の諸特徴に着目して層相解析がなされ，19の層相(Facies)が識別された．各層相の形成条件の吟味と層相相互の提携関係とから，大まかな堆積環境に対応する6つの堆積相群（Facies association）が識別される．

すなわち，①沖積組相（山麓扇状地・側方移動河川・分流河川)，②湖沼組相，③浜堤—湿地組相，④浅海組相（瀕海・潟を含む)，⑤フリッシュ組相（タービダイト・葉理頁岩など)，及び⑥堆積盆底泥組相の諸組相で，それぞれ60-650 mの厚さをもつ．これらの垂直的出現順序は，④→⑥→⑤→③→②・①であり，中列のジュラ系では，この海成層→陸成層の堆積サイクルが2回くり返えされる．牡鹿地方のみは白亜系にも1堆積サイクルが認められる．

以上の層相解析に古流向や粗粒砕屑物の組成を加味して，堆積様式や古地理を次のように考察した．

i）陸成層は中列の地層の30%以上を占め，上部ジュラ系に良く発達する．西列は層厚が中列の3分の1程度と薄く，全て海成層で占められる．粗粒砕屑物は前者で優勢，後者は主に泥質岩からなる．このような両列の層相の対立と堆積盆の分化は，ジュラ紀後期に最も顕著に現れた．

ii）中列における沖積組相は，北向きの河川流と東または北東からの側方扇状地の発達が，オックスフォード階に認められる．

iii）中列によく発達する上部ジュラ系フリッシュ組相は　北に向って前進・成長したデルタの斜面とその前面部に形成された．その主要な構成物である級化砂岩層（タービダイト）や厚層理砂岩層の多くは，河川の洪水流に起源する北向きの堆積物重力流によって形成された．海成葉理頁岩の頻繁な発達も河川の強い影響を受けたデルタ環境での生成を示唆している．

iv）上記のi)，ii) 及び砕屑物の組成から判断して，堆積盆の東側には片状花崗岩・変成岩を有する構造帯的陸地の存在が推定される．ジュラ紀堆積盆は全体として内海的環境にあり，一時は西方に沖合相を配し，古日本列島の内側の海とも連絡していた．

v）相馬のジュラ系—白亜系は，北上プロパーの唐桑—牡鹿のそれと層相や砕屑物の構成の大部分において共通し，両者は同一系列の堆積盆と後背地に由来した．

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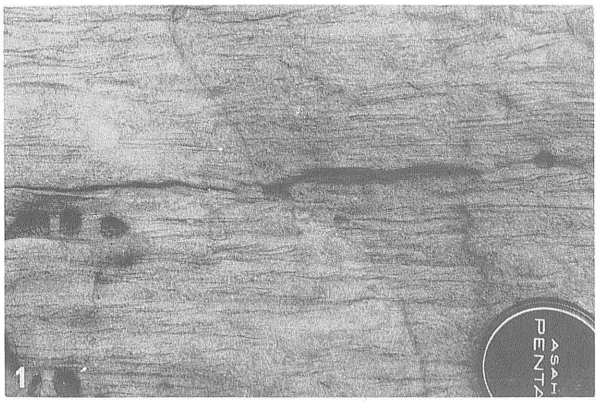
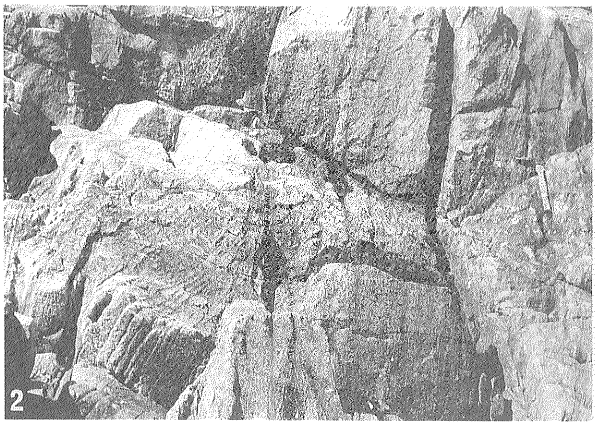
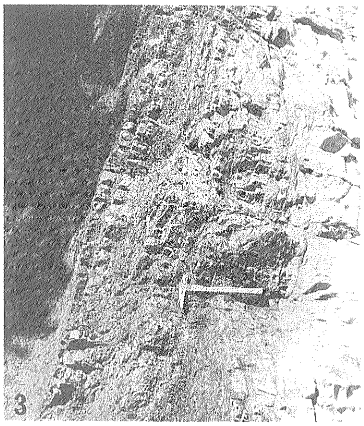
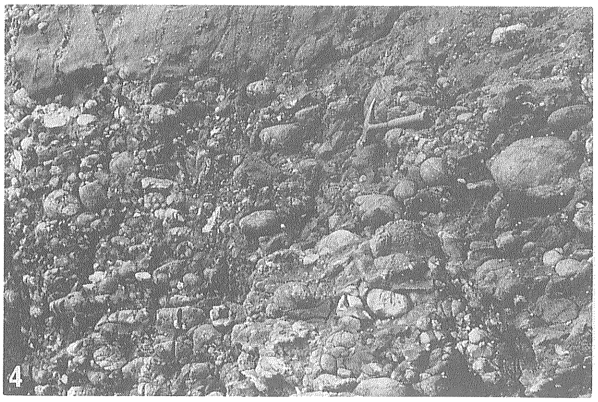


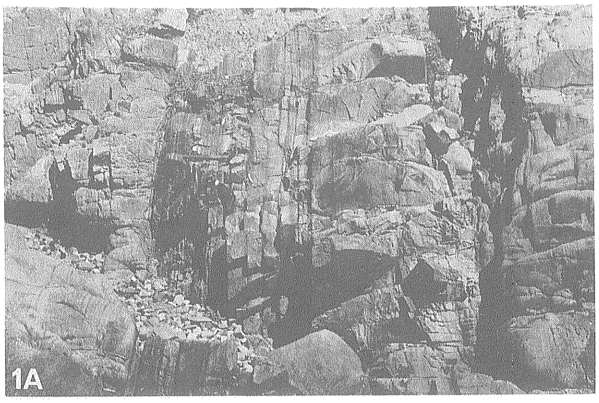


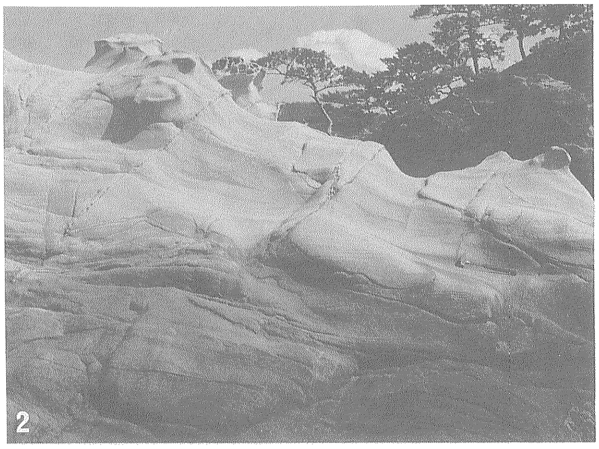


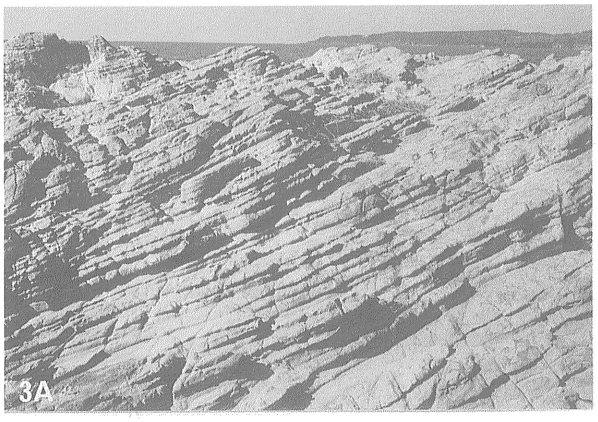


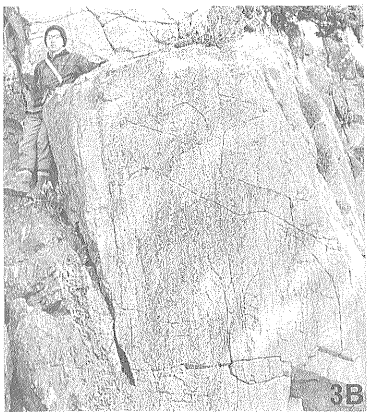
Alluvial Facies Association.

1. Ripple-drift cross-laminated fine-grained sandstone in middle part of a fining-upward sequence of non-marine deposits, Makinohama Sandstone Member, Oshika.
2. Large-scale cross-bedding of tabular or trough type in coarse-grained sandstone of Subfacies c_1, Kogoshio Formation, Karakuwa. This sandstone is regarded as point-bar deposits originated from a meandering river. Stratigraphic top to left.
3. Trangitional sequence from lower sandstone part to upper shale part in fining-upward sequence of non-marine deposits, Kogoshio Formation, Karakuwa. This sequence is characterized by shale (siltstone) thinly interbedded or interlaminated with fine-grained sandstone, and is probably originated from levee deposits of a meandering river.
4. Poorly sorted orthoconglomerate containing intraformational shale clasts, Makinohama Sandstone Member, Oshika. This facies is referable to alluvial fan deposits (probably mid-fan deposits).





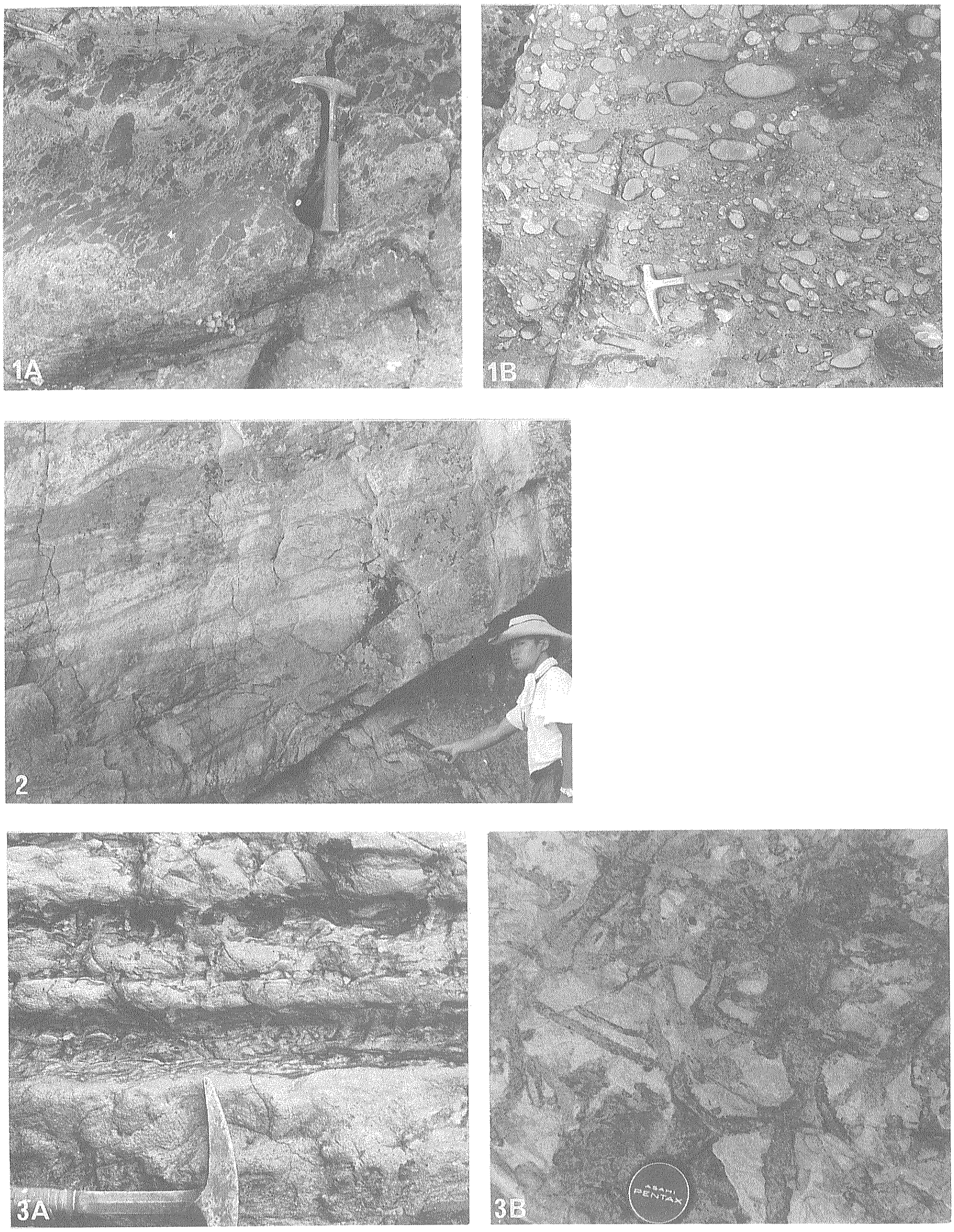




Alluvial and Lake Facies Association

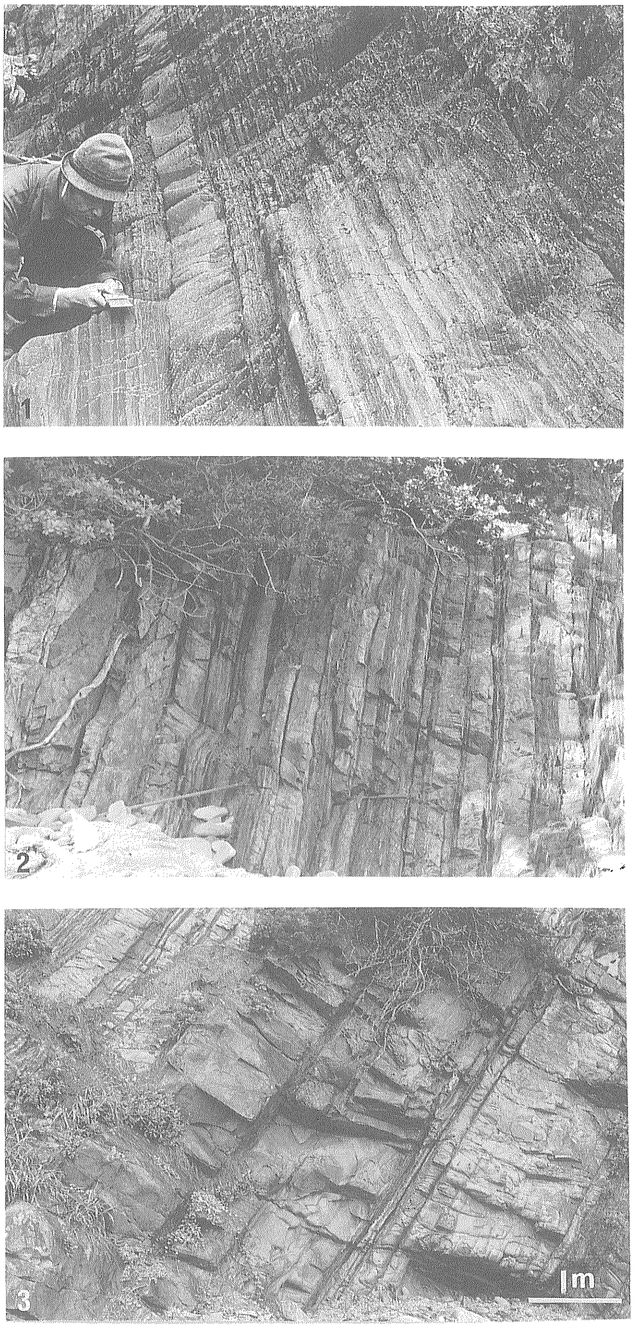
1. Facies d, bedded and laminated fine- to medium-grained sandstone interbedded with shale occasionally containing plant beds. 1A: Unit Ky-5 of the Kiyosaki Sandstone Member, Oshika. Stratigraphic top to the right. 1B: Sakaguchiirizawa Sandstone Member. The sequence of Plate 1A shows coarsening and thickening upward sequence. The sequence of Plat 1B consists of sandy laminite (Subfacies i_3), and shows ripple-drift cross-lamination (upper half) with parallel lamination (lower half). These facies are considered to be agitated lake deposits (probably lake delta deposits).
2. Subfacies b_2, massive to thick-bedded medium-grained sandstone frequently showing cross-bedding, uppermost part of the Makinohama Sandstone Member, Oshika. This sandstone is considerably well-sorted, and is possibly originated from beach ridge (coastal sand dune) deposits.
3. Subfacies c_2, Massive to very thick-bedded coarse-grained sandstone frequently showing large-scale cross-bedding and no or weakly upward decreases in grain size. IIIA: Lower part of the Kiyosaki Sandstone Member (Aji-shima), IIIB: Middle part of the Kiyosaki Sandstone Member, Oshika. Both sandstones of the Kiyosaki Member are probably originated from distributary channel deposits.

Note a hammer encircled by white line which is 33 cm long.



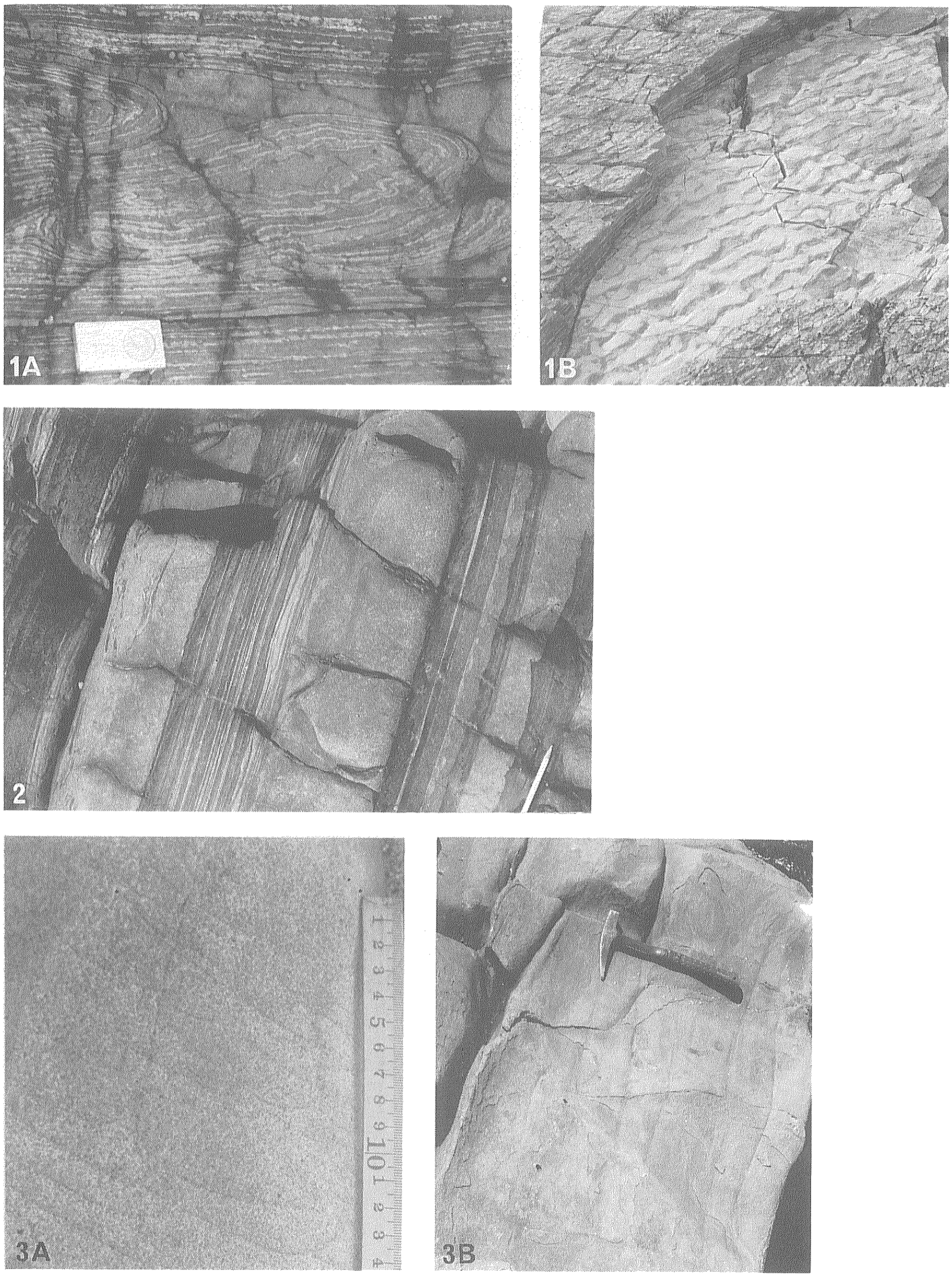
Shallow Marine Facies Association.

1. Intraformational limestone-clast conglomerate of the lowermost part of the Ayukawa Formation at the northern extremity of Aji-shima, Oshika (1A), and the lowermost part of the Kogoshio Formation at the eastern extremity of Oshima, Karakuwa (1B). Matrix consists of calcareous coarse arkosic sandstone. Limestone clasts are dark gray impure limestone containing abundant fragments of corals, calcareous algae, crinoids and molluscs.
2. Tabular cross-bedded quartzose sandstone, occasionally containing intraformational limestone clasts, lowermost part of the Ayukawa Formation, Aji-shima.
3. Vertical burrows within silty fine-grained sandstone in the lowermost of the Kozumi Shale Member (3A) at the west of Kozumi, and horizontal burrows on the top surface of a sandstone bed of Subfacies b_2 type in the middle part of Ayukawa Formation (3B), Oshika, Aji-shima.



Flysch Facies Association in the Fukkiura Sandstone and Shale Member, Oshika.

1. Thin-bedded shale-sandstone alternation (Facies j_2: "shaly flysch"), western extremity of Makinosaki. Stratigraphic top to right.
2. Medium-bedded sandstone-shale alternation (Facies j_1: "normal flysch"), near Atsui-zaki. Stratigraphic top to left. Hammer gives scale.
3. Thick-bedded medium-grained sandstone (Facies e: fluxoturbidites), near Tomari. Stratigraphic top to left. This sandstone occasionally shows dish structure as shown in Plate V-3.



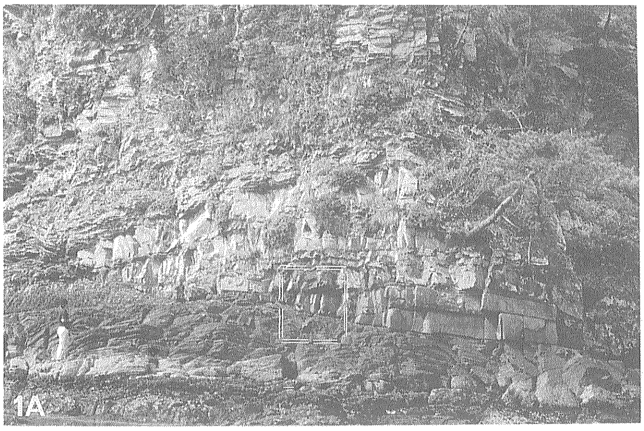
Flysch Facies Association in the Fukkiura shale and Sandstone Member, Oshika.

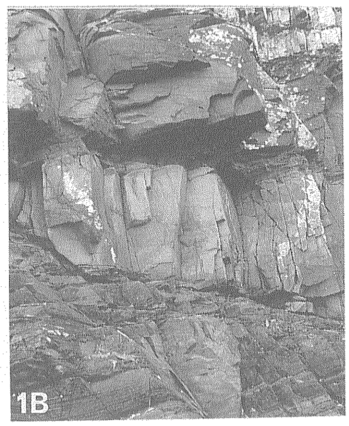
1A. Laminated shale (mainly Subfacies i_2) showing slump over folds in small scale, near Atsui-zaki. This facies is considered to be not distal turbidites but slope deposits.

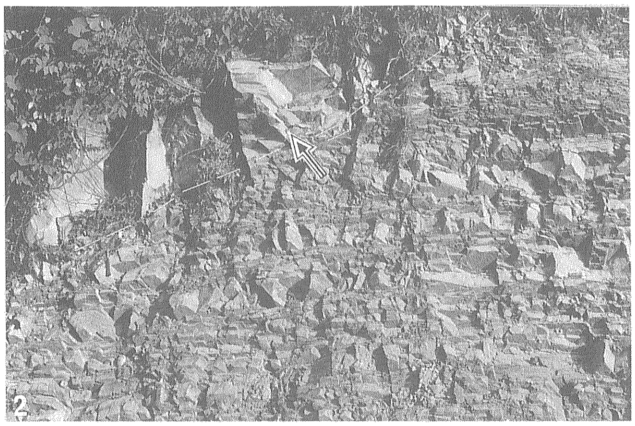
1B. Strongly undulatory current-ripple marks, almost tending to the lingoid type, Tomari. Ripple marks of this type frequently occur on top surface of cross-laminated sandstones within Subfacies i_2.

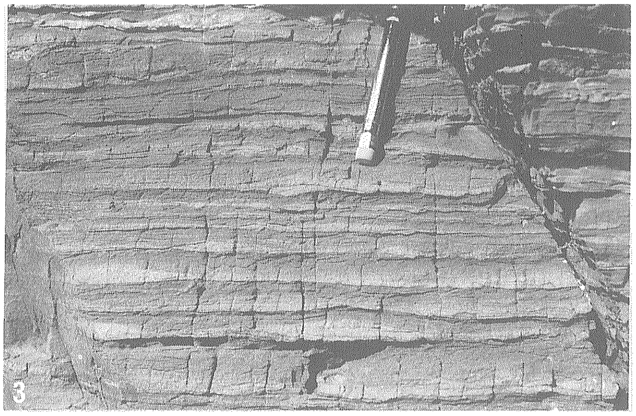
2. Graded sandstone beds (turbidites) interbedded with laminated shale (Subfacies i_1), Tomari. Stratigraphic top to left. Pencil (lower right of the picture) gives scale.

3. Dish structure of a common type (A) and a large-scale type (B) in Facies e, thick-bedded medium-grained sandstone. A: Fukkiura, B: Tomari.



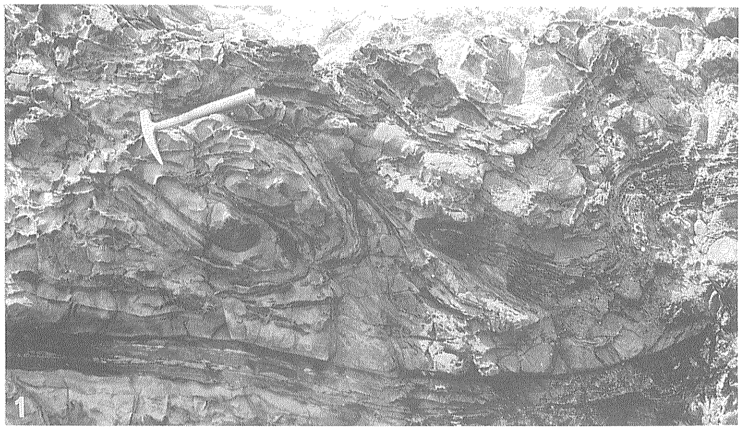


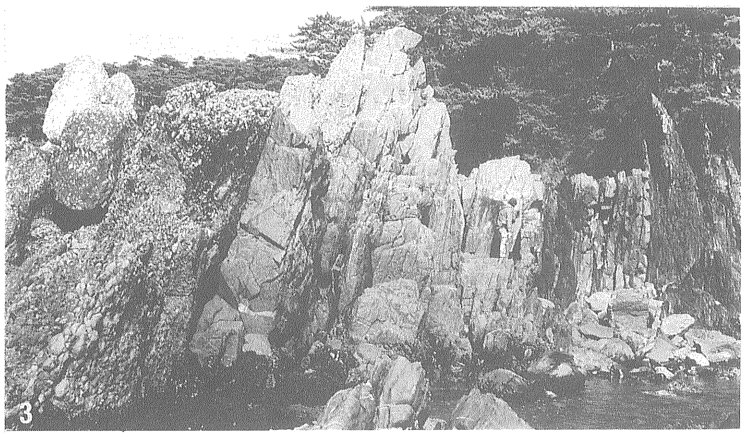




Flysch Facies Association in the Shizugawa area.

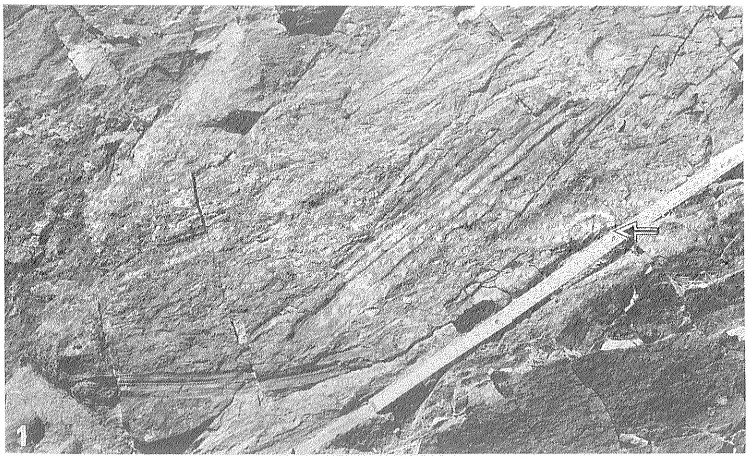
1. Submarine channel cutting into laminated shales (Subfacies i_1) and filled with thick-bedded sandstones (Facies e, fluxoturbidites), lower part of the Arato Formation, Akaiwa-zaki of Shizugawa. This channel structure indicates a stretch of the northeast direction. Its close-up view whithin the quadrangle is given in Plate 1B.
2. Medium-bedded sandstone-shale alternation (Subfacies j_1) in the lower part of the Arato Formation, Nakazai of Shizugawa. Arrow indicates channel-like sandstone body.
3. Thin-bedded shale-sandstone alternation (Subfacies j_2) in the lower part of the Arato Formation, Arato. Pencil gives scale.

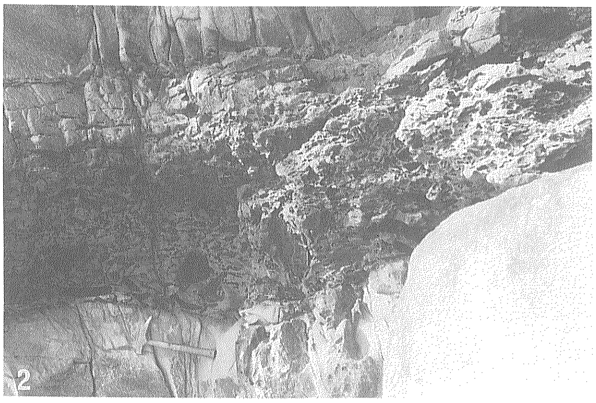


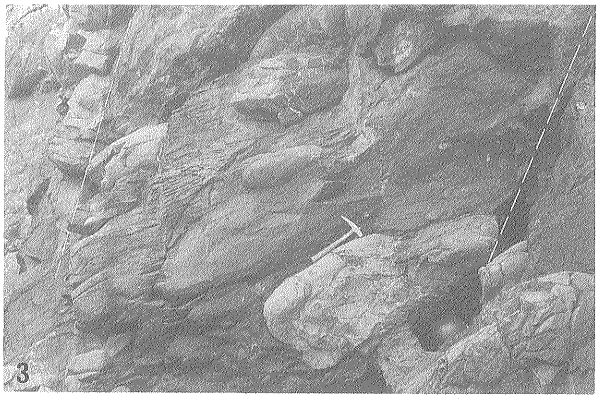


Coarser flysch sequenses in the Kitsunesaki Sandstone and Shale Member, the Oshika area.

1. Slump overfolds in sandstone-shale alternation near Ohara-hama of Oshika. Slump movement probably from right (east) to left (west).
2. Submarine slide conglomerate bed cutting into laminated shales, southeastern extremity of Makinosaki, Oshika. Such conglomerate facies is distributed in the very restricted area, only eastern part of the Oshika area. Clinometer (basal part of the conglomerate bed) gives scale.
3. A coarsening upward sequence in flysch facies association, consisting of laminated shale (right side), medium-bedded sandstone-shale alternation, thick- to medium-bedded sandstone and orthoconglomerate, Makinosaki, eastern part of the Oshika area. Stratigraphic top to left.







1. Large plant (wood) fossil fragments with ammonoid fossil (encircled by white line) within medium-bedded sandstone-shale alternation (Facies j_1: turbidites), Fukkiura Member, Tomari, Oshika. Scale at lower right of the picture is 16 mm width.
2. Aggregative intraformational shale clasts within Facies e, thick-bedded medium-grained sandstone, Fukkiura Member, Fukkiura, Oshika.
3. Largest calcareous nodules within Facies f, thick- to medium-bedded black shale, Tsukinoura Formation near Yoriiso, Oshika. Note these elongation not parallel to the bedding plane (indicated by dashed lines) but parallel to the slaty cleavage. Younging to the right. Hammer (33 cm long) gives scale.