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Kazuyoshi Okami

ABSTRACT

The Joban coal field has been studied from the economic and academic points of view by many geologists, paleontologists and sedimentologists. The sedimentological studies on the Iwaki Formation had hitherto been concentrated to the condition of deposition of the coal beds and to the formation of the cyclothems whereas analysis of the rocks deposited in the sedimentary basin of the Iwaki Formation had remained untouched probably because of the difficulty in detail correlation of its laterally variable strata and also to the confusion in distinction from superjacent stratigraphic units. The Iwaki Formation was studied from the sedimentary petrographic side to clarify the characters of its sediments and to reconstruct the sedimentary basin in which it was deposited. The petrographic study was carried out on the conglomerate, sandstone, clay minerals, and on the assemblage, composition and distribution of the different lithofacies in both lateral and vertical sequence, and on the texture of the sediments such as grain size, grain shape and their distributions. From the analyses of the grains and their size distribution, the cumulative frequency curve for sandstone was classified into four types for the Iwaki and one for the superjacent Asagai Formation. Despite the change of the grain size in the sandstone that included much matrix, the distribution curve shows moderately — poor sorted·fine skewed uniformly, and coincides with Visher's (1969) curve indicating Recent delta-estuary sand. The relationship between sorting and skewness is that all samples belong to the group of river sand clan defined by Friedman (1961). The C-M pattern of the sandstone (Passega, 1957) shows that the samples fall in the R-Q and Q-P segments and therefore, the sedimentary environment may have been a river channel or a braided stream (Bull, 1962). The sandstones are composed of quartz, feldspar, mica, hornblende, pyroxene and other heavy minerals, and beside those minerals, there are also included many rock fragments of sandstone, slate, chert, green schist, porphyritic rocks and volcanic rock. The sandstone components were derived from many provenances. A noteworthy constituent is volcanic rock; under the microscope it is a hornblende-pyroxene andesite, but detail identification of the pyroxene was impossible because the material suffered intense weathering. The volcanics and chert are exotic constituents in the Iwaki Formation. The clay minerals identified by X-ray powder diffraction comprised mostly montmorillonite, kaolin and chlorite. And in the diffraction peaks, calcite and dolomite are identified in the cementing material. It is an important fact that the diffraction of clinoptilolite of the zeolite group is found in the X-ray analysis. In the analysis of the compositional change in vertical sequence of the sand size minerals quartz and feldspars always occupy 20–30 percent of every samples, the percentage of the volcanic rock content is usually 10 percent but in three horizons its percentage increased. The horizons at which the volcanic rocks increase are observed throughout the area after the deposition of the main coal seam, especially in the post-Tochikubo conglomerate deposits and in the uppermost horizon. The occurrence of clinoptilolite coincides well with the horizons at which the volcanic rock fragments increased. From this fact, the existence of three volcanic activities during deposition of the Iwaki Formation was confirmed. The last volcanic activity found in the uppermost part of the Iwaki Formation seems to serve to separate the Asagai Formation from the Iwaki and to indicate the initial phase of the main marine transgression. From the three periods of volcanic activity the deposition of the Iwaki Formation can be divided into three periods of (I) Early, (II) Middle and (III) Late.

CONTENTS

INTRODUCTION

To date, the Tertiary System of the Joban coal field distributed in Fukushima and Ibaraki prefectures along the eastern side of the Abukuma Plateau, has been studied from the economic and academic points of view. But owing to the variable lateral change in the lithofacies and difficulty in correlation of the beds throughout the area of distribution of the Iwaki Formation, the sedimentological study has been left almost untouched.

The writer studied the Iwaki Formation from the sedimentary petrographic view point, and aimed to clarify the character of the sediments, attempted correlation of the variable lithofacies throughout the area of distribution, reconstruction of the sedimentary basin of the formation, and also to know the geological history. Work was also undertaken to find the factors influencing or responsible for the deposition of the Iwaki Formation.

From the newly discovered fragments of pyroclastic rocks as constituents of the sandstone, and especially that the amount of the fragments increased at three horizons coincided well with the correlation of the stratigraphic units and wided in the recognition of the cyclothems. Studies were also made of the cementing material and matrix by X-ray diffraction, and the discovery of clinoptilolite and its horizon of occurrence coincided with the horizons of the pyroclastics.

The discovery of the three periods of volcanism during deposition of the Iwaki Formation served for the correlation of the Iwaki Formation throughout the sedimentary basin of the Iwaki Formation.

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PREVIOUS WORKS

The first geological survey of the Joban coal field was done by Nakamura (1913) who studied the Yumoto district, the center of the coal mining area, since then regional surveys of the field were carried out by Watanabe (1930, 1935), Kon'no (1938, 1939), and Tokunaga (1927). Concerning the coal field, there have been published later works on the geology, stratigraphy, paleontology, geostructure and sedimentology and others.

Arakawa (1953) studied the sedimentology of the Shiramizu Group based on the boring data from the Yumoto district and clarified the relationship between the relief of the basement and the deposition of the main coal seam of the Iwaki Formation, and also on the deposition of the interbedded conglomerate beds. The deposition of the coal seams distributed in different areas of the Joban coal field have been studied by Eguchi and Shoji (1953a, b), Eguchi, Shoji and Suzuki (1953) and Eguchi and Suzuki (1954). They described the cyclothems, attempted correlation of the coal beds by use of the cyclothems and also wrote on the deposition of the Iwaki Formation based on the boring data (1954).

The discovery of the buried hill and its influence on the deposition of the main coal seam, and paleotopography of the basement at the initial stage of the Iwaki deposition have been surveyed by several authors (Matsui and Kojima, 1954; Eguchi and Shoji, 1955; Asano, 1956a, b; Shoji, 1956, 1957a, b; 1960a, b; Eguchi, Shoji and Suzuki, 1966a). Asano wrote on the buried hill of granite at Yoshima in the Akai district of the Iwaki area, and Shoji described a buried hill of green schist at Hanakawa in the Taga area.

As the lithofacies of the Iwaki Formation changes remarkably both laterally and vertically as well as regionally, detail studies of the Iwaki Formation have been done in the entire area mostly based upon the coal seams developed in the lower part of the Iwaki Formation. And because of the obscurity of the boundary between the Iwaki and Asagai formations, reconstruction of the sedimentary basin of the Iwaki Formation has remained unsettled.

CHAPTER I

GEOLOGY OF THE JOBAN COAL FIELD

1. GENERAL GEOLOGY

The area studied is a long and narrow belt of N-S trend, attaining 100 km in length along the eastern side of the Abukuma Plateau, and between the southern part of Namie-cho, Fukushima Prefecture southwards to Hitachi City in Ibaraki Prefecture (Fig. 1). The basement rocks of the Tertiary System are distributed in the Abukuma Plateau under the Joban Tertiary System. The Tertiary rocks are arranged from west to east in order from the older to the younger.

The basement rocks of the Tertiary rocks are composed of the Takenuki and Gozaisho metamorphic rocks, Older granite intruding the former, non-metamorphosed Paleozoic rocks, Younger granite intruding all of the mentioned ones and many other intrusive rocks intruding them and the Futaba Cretaceous rocks.

The Tertiary System overlies the pre-Tertiary rocks with unconformity and has been classified into, in upward sequence, the Shiramizu Group of Paleogene age, the Yunagaya Group, Nakayama Formation and Takaku Group of Neogene age. These units are distributed from west to east in the order named (Fig. 2).

The arrangement of the Tertiary System and its basement rocks are roughly sigmoidal in shape owing to two major fault systems, one of NW-SE trend and another of N-S direction (Hoshino, 1965; Mitsui, 1967). The main faults of the former category are, from the north, Futatsuya and Yunotake faults, and the latter of the Futaba and Idosawa faults.

Sugai and Matsui (1957) classified the Joban coal field into five blocks each separated by these faults, namely, the Tomioka, Futaba, North Iwaki, South Iwaki and Taga, and described that each of them had a basin structure with NW-SE or N-S axes. The present paper deals only with the Iwaki Formation, which was classified based on the lithofacies into three areas as follows (Fig. 3):

1) **Futaba area**, the area is north of the Futatsuya fault. This area was divided into the North Futaba and South Futaba, the boundary between them being at Osaka in Naraha-cho.

2) **Iwaki area**, the area is between the Futatsuya and the Yunotake faults.

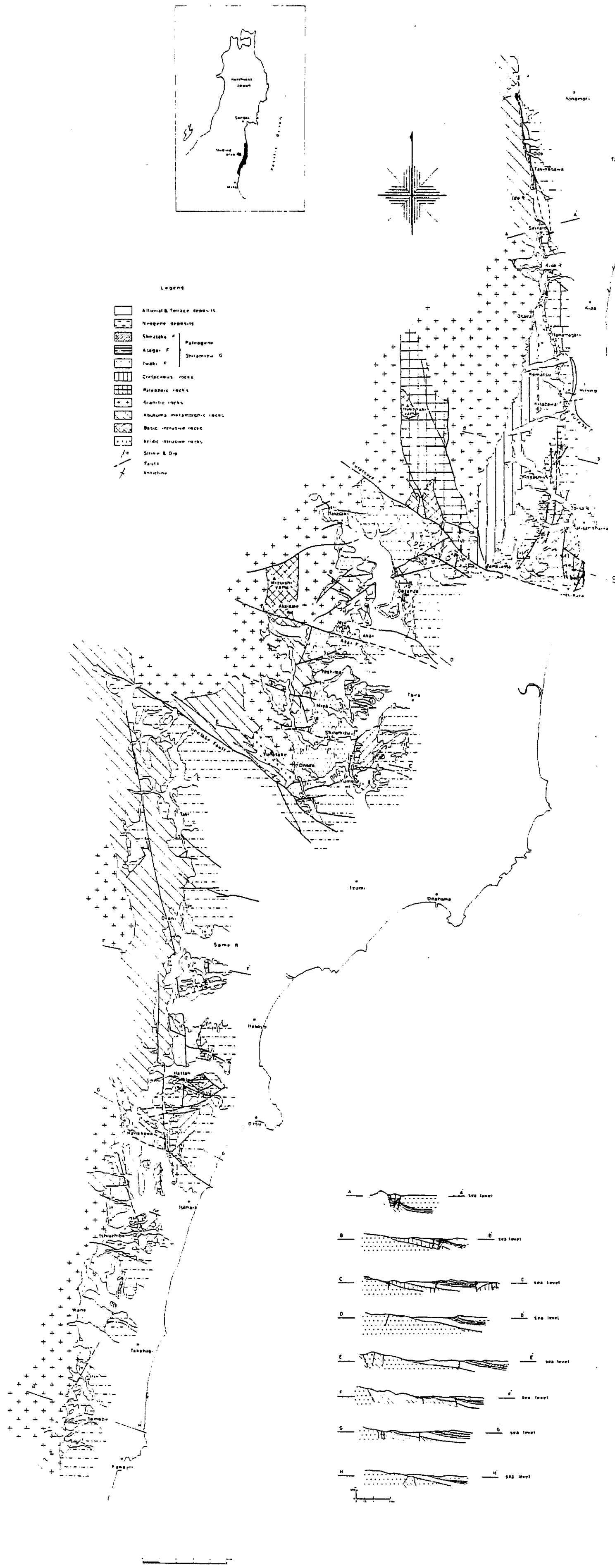
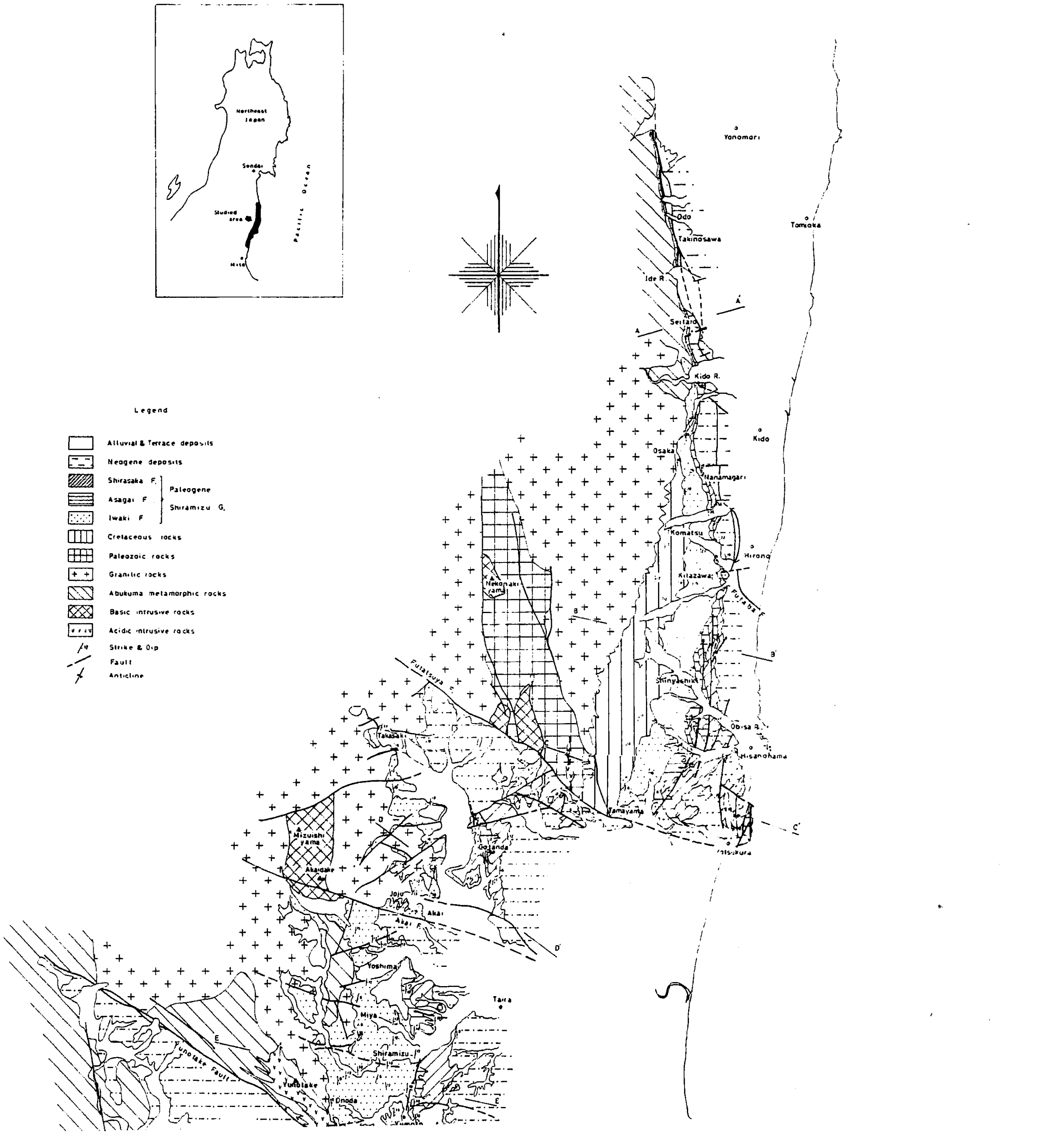


Fig. 1. Geological map and geological sections of the Paleogene Formation of the Joban coal field.


Northeast Japan
Sendai
Studied area
Pacific Ocean
Mito
Legend
Alluvial & Terrace deposits
Neogene deposits
Shirasaka F.
Asagai F
Iwaki F
Paleogene
Shiramizu G.
Cretaceous rocks
Paleozoic rocks
Granitic rocks
Abukuma metamorphic rocks
Basic intrusive rocks
Acidic intrusive rocks
Strike & Dip
Fault
Anticline
Yonomori
Tomioka
Odo
Takinosawa
Ide R.
Seitaro
Kido R.
Kido
Osaka
Nanamagari
Komatsu
Hirono
Kitazawa
Futaba F.
Shinyashiki
Obisa R.
Hisanohama
Nekonaki yama
Futatsuya F.
Takasaki
Tamayama
Gonanda
Mizuishi yama
Akaidake
Akai
Akai F.
Yoshima
Taira
Miya
Shiramizu
Yunotake Fault
Yunotake
Onoda

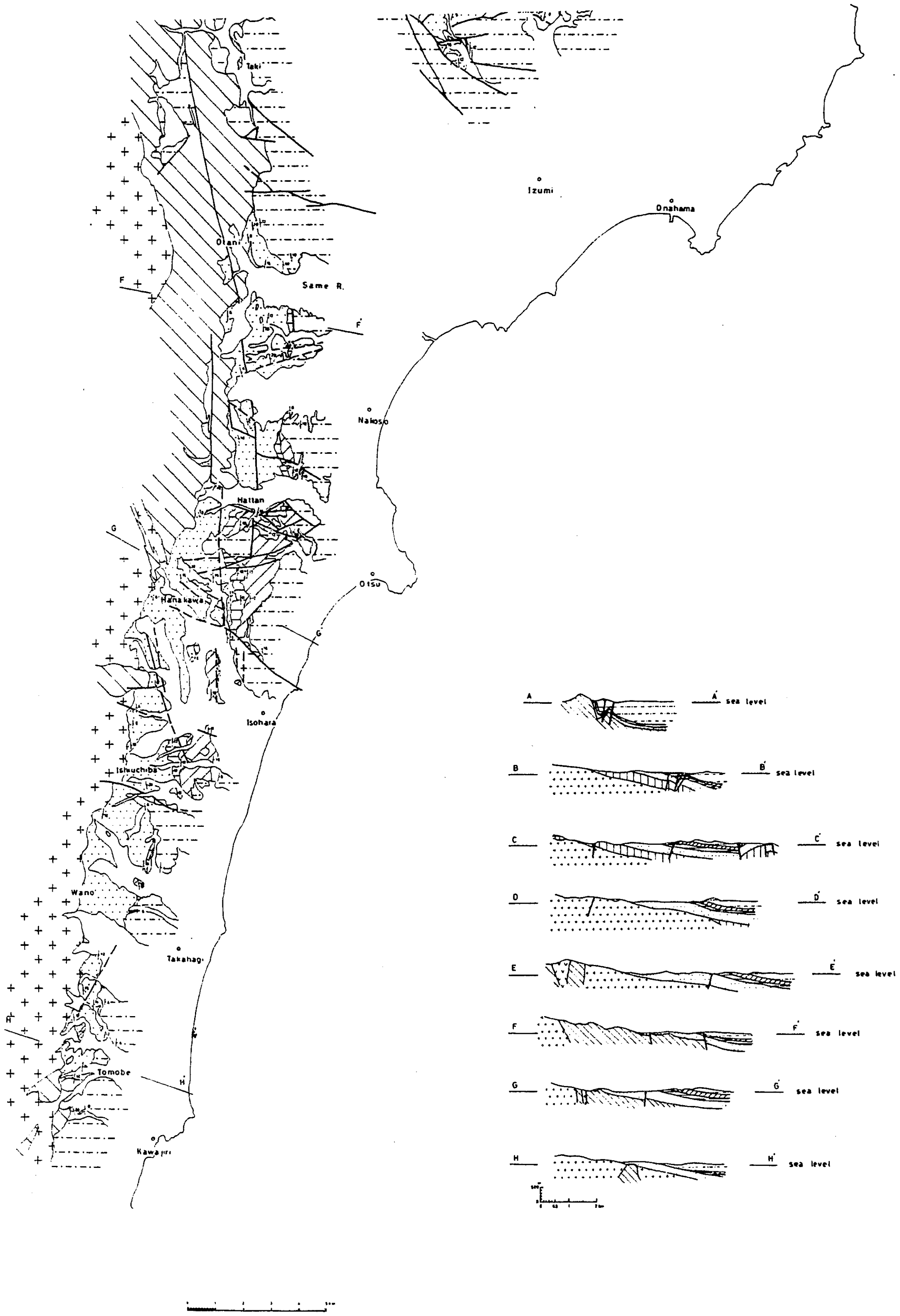


Fig. 1. Geological map and geological sections of the Paleogene Formation of the Joban coal field.

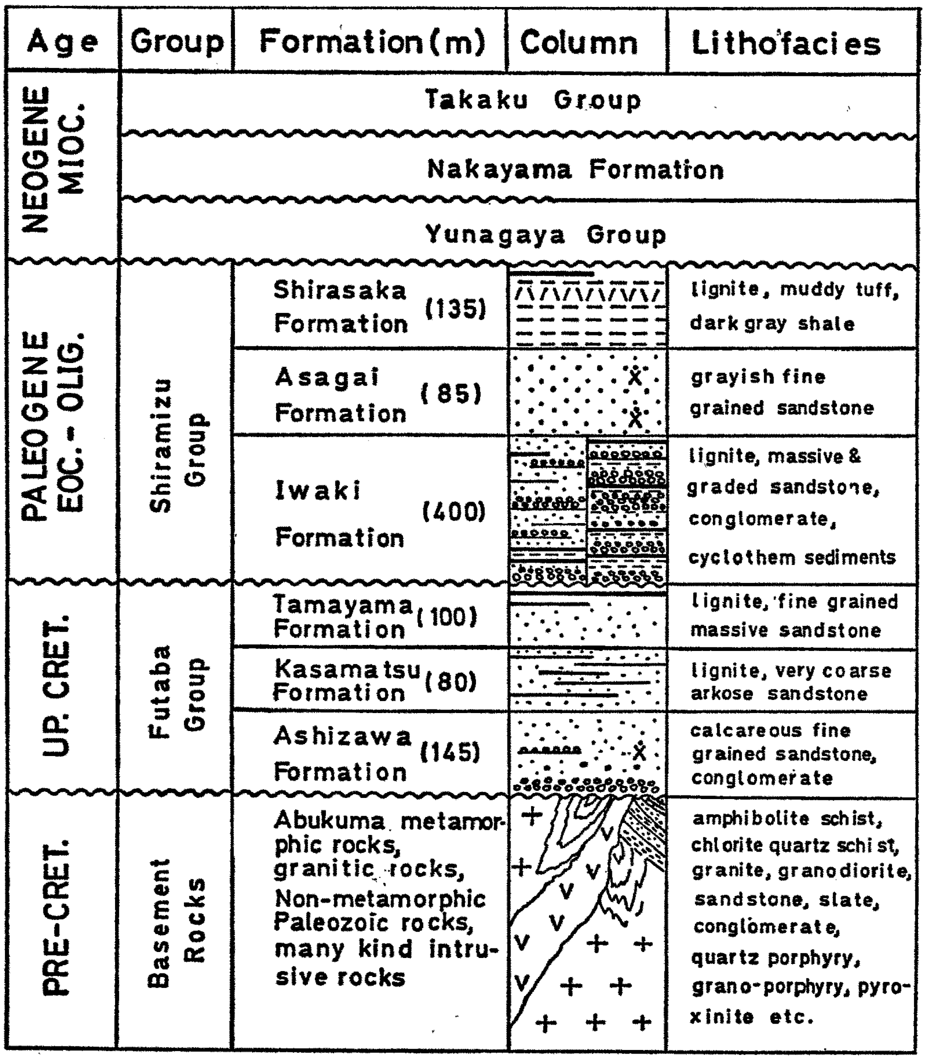


Fig. 2. Generalized columnar section of the Joban coal field

3) **Taga area**, the area is south of the Yunotake fault.

The area studied is situated on the western wing of the basin structure of Sugai and Matsui (1957). The Tertiary rocks are inclined, in general, eastward homoclinally. The geological structures of the area aside from the faults consist of an anticline observed at the Hattachi beach, Yotsukura-machi, South Futaba area, and the syncline in the west of Isohara, Kitaibaraki City. These structures can be recognized from the distribution of the Asagai and Shirasaka formations in the area considered (Fig. 1).

2. REMARKS ON THE STRATIGRAPHY

1) Basement Rocks

The basement rocks of the area consist of the Abukuma metamorphic rocks, granitic rocks, non-metamorphosed Paleozoic rocks, Cretaceous rocks and many intrusive rocks.

i) Abukuma Metamorphic Rocks

The grade of alteration of the Abukuma metamorphic rocks tend to be higher toward the west, especially in the western half, where gneissose rocks are developed as the result of the intrusion of granite and is called the Takenuki Series. The low grade metamorphic rocks are known as the Gozaisho Series. The high grade metamorphic rocks, Takenuki Series, do not contact with the Tertiary rocks directly. The low grade metamorphic rocks, Gozaisho Series, are overlain directly by the Tertiary rocks. The low grade metamorphic rocks are composed of green schist as amphibolite-quartz schist, actinolite-chlorite schist, chlorite-quartz schist besides others. The Gozaisho rocks are into direct contact with the Tertiary rocks in the North Futaba area, Joju-Yoshima district of the Iwaki area and Yunotake of the Iwaki area and at the north of Hanakawa, west of Isohara in the Taga area (Pl. 1). In the Yaguki and Takakurayama regions of the South Futaba area, low grade metamorphic rocks called the Yaguki Series and non-metamorphosed Paleozoic rocks are developed. Yanagisawa (1967) studied this area and described the stratigraphy of the Niidagawa Group (Yaguki Series=low grade metamorphic rocks) and the Takakurayama Group (=non-metamorphosed sedimentary rocks). The Niidagawa or Yaguki comprises actinolite schist, chlorite-quartz schist, chlorite schist and biotite schist, etc., and their original rocks are mainly of black shale. At the upper most part of the Yaguki there is developed crystalline limestone.

The Takakurayama Group of black shale, sandstone, conglomerate and fossiliferous limestone lenses is distributed along the eastern side of the Niidagawa Group, being separated from it by a fault. The fossils, mostly marine invertebrates occurred from the Takakurayama Group and indicate the Permian age (Yanagisawa, 1967). In the southern part of the area studied, the Kawajiri district of Hitachi City, the low grade metamorphic rocks of the Hitachi Paleozoic are the basement rocks.

ii) Granitic Rocks

In general the granitic rocks can be classified into two types, the older and the younger. The older granite is distributed in the Hitachi region and consists of cataclastic rocks and is concerned with the alteration of the Takenuki Series, in the upper stream of the Natsui River in the Iwaki area and in the western part of Isohara. The granite covered directly by the Tertiary rocks is the younger type and its radioactive age is about 10×10^7 years (Nozawa, 1970). The younger granite is composed of biotite granite and hornblende biotite granite. Under the microscope the feldspars are mainly of plagioclase (albite-oligoclase) with rare inclusion of orthoclase showing a perthite structure, albite twin and zonal structure. Quartz is monocrystaline with straight extinction and does not show polycrystalline undulatory extinction. Amphibole consists of hornblende but the amount is small. The rock shows equigranular texture and is of $1000\,\mu$ to $2000\,\mu$ sized crystals. Fissure filling secondary quartz is also observed under the microscope. Though the amount is very small, the heavy minerals as apatite, zircon, garnet, magnetite, illmenite and other opaque minerals are included in the granite (Pl. 1).

iii) Intrusive Rocks

Different kinds of intrusive rocks intrude the metamorphic rocks, granites and the Paleozoic rocks. Basic intrusive rocks consist of pyroxinite, peridotite, gabbro and serpentine. Pyroxinite and or peridotite are distributed in the north of Mizuishiyama (Pl. 1) and gabbro is found at Nekonakiyama in the Yaguki area and west of Hanakawa. The intrusive rock exposed in the Yaguki area had been judged to be pyroxene gabbro (Iwao and Matsui, 1961). Serpentine is distributed along the fault on the west side of Nekonakiyama. Acidic intrusive rocks as hornblende porphyry and quartz porphyry are distributed in Takakurayama and Yunotake. The quartz porphyry (Pl. 1) contains large phenocrysts of quartz, the feldspar which is orthoclase at 2000 μ and occasionally small size mica phenocrysts.

iv) Futaba Group

The upper Cretaceous Futaba Group is distributed in the South Futaba area in a long and narrow belt with N-S trend and overlies the Paleozoic rocks and younger granite with unconformity. In the Iwaki area where the Futaba Group is distributed below the surface, the distribution was confirmed by the boring data (Asano, 1956a, b; Exploration Research Group of the Joban Gas Field, 1962; Takayama and Obata, 1968).

Since the Futaba Group and its paleontology was first studied by Tokunaga (1923a) and Tokunaga and Shimizu (1926), many workers (Kon'no, 1938; Saito, 1961; Okami, 1966) have contributed to the geology and paleontology. The group includes the Ashizawa, Kasamatsu and Tamayama formations in the named order from the older to the younger. The Futaba Group has a general strike and dip of N10°E and 10°E, showing homoclinal structure. The Tertiary System overlying the Futaba Group has a general strike of N10°W –N-S and dips of 10°–15°E. So the widest distribution at the surface of the Futaba Group is found in the Tamayama district, Yotsukura-machi. Northwards it gradually dips below the Tertiary rocks.

The Ashizawa Formation, in thickness about 145 m, is composed of conglomeratic coarse grained sediments in the lower part and calcareous fine grained sandstone in the upper. Fossils indicating the Urakawan age have been recorded from the north of the Tamayama mineral spring, at Ashizawa, Obisagawa, Kitazawa, Minaminosawa and the Asami River (Tokunaga and Shimizu, 1926; Saito, 1961; Iwao and Matsui, 1961).

The Kasamatsu Formation, 85 m thick, overlies the Ashizawa Formation with conformity and consists of quartzose sandstone showing minor cyclothemic arrangement. A cyclothem consists, when complete, of coarse-medium grained sandstone, sandy shale and coaly shale in upward sequence; the thickness of one unit is about 2–3 m. In the sandstone part, cross stratification is well developed but no fossil has been found.

The Tamayama Formation, about 100 m in thickness, consists of massive coarse to medium grained partly pebbly sandstone, and overlies the Kasamatsu Formation with conformity. From the lithofacies and the type of cross stratification the sedimentary environment of the Tamayama Formation is considered to be deltaic. Recently, from the upper part of the Tamayama Formation, the new discovery of fossils points to that the age of the upper limit of the formation is not younger than the lower Santonian (Takayama and Obata, 1968; Obata and Suzuki, 1969; Obata, Hasegawa and Suzuki, 1970).

2) Shiramizu Group

Nakamura (1913) described this group as the "Lower Tertiary Bed" and as the lowest rock unit of this field. Tokunaga (1927) described the group as "Older Joban Series" and Watanabe (1930) named it the "Shiramizu Series". From the view point of stratigraphic nomenclature, Hatai and Kamada (1950) proposed to use the name of "Uchigo Group" and to retain the name of "Shiramizu" for a formation. This proposal was based on that the name of "Shiramizu" had been used for Series, Group, Formation and Member at the same time. Hanzawa (1957) agreed with Hatai and Kamada's proposal.

For the reason that the "Shiramizu Formation" merely represents the lower sandstone member of the Iwaki Formation, and is not distributed throughout the whole area of the coal field, Sugai and Matsui (1953, 1957) retained the name of "Shiramizu" as a Group name and lumped the rocks below the Asagai Formation into the Iwaki Formation

(Tokunaga, 1927). They included in the Shiramizu Group, the Iwaki, Asagai and Shirasaka formations in upward sequence. Mitsui (1970) accepted with this proposal.

To date, the geologic age of the Shiramizu Group has been discussed by Hatai and Kamada (1950) and Kamada (1962) from the evidence of the molluscan fossils, they stated that the group is Oligocene in age, Takai (1961) from the occurrence of "*Anthracothema tsuchiyai*" from the upper part of the main coal seam in the lower part of the Iwaki Formation, claimed the age is Priabonian (Upper Eocene), Tanai (1955) held that the plant fossils of the formation are younger than the *Woodwardia* Flora of Hokkaido, Asano (1962) and Asano and Takayanagi (1965) based upon the foraminifera concluded that the Iwaki is Upper Eocene and the Asagai Formation is Lattorfian in age (lowest Oligocene).

The Shiramizu Group has general strike and dips respectively of N10°W–N-S, 10°–15°E and is distributed in a long and narrow belt with N-S trend showing homoclinal structure.

i) Iwaki Formation

The Iwaki Formation was first proposed by Tokunaga (1927) for the rocks distributed in the environs of Hiwatari, Joban Yumoto in Iwaki City, Fukushima Prefecture. The formation is about 400 m in maximum thickness in this area.

Nakamura (1913) described and mapped the rocks forming the lowest unit and classified the rocks into three parts of Basal bed, Coal bearing bed and Iwaki sandstone bed. Tokunaga (1927) proposed the name of Iwaki Formation for the same sequence of rocks. Kon-no (1938) merely called the rocks the Iwaki coal bearing bed. Hatai and Kamada (1950) and Hanzawa (1957) recognized two beds in this formation, namely, the Shiramizu sandstone bed and Iwaki sandstone bed. Sugai and Matsui (1953, 1957) accepted Tokunaga's proposal and used the name Iwaki Formation (Tokunaga, 1927). Mitsui (1967, 1970) supported Tokunaga's proposal. The writer also uses the name of the Iwaki Formation.

The lithofacies of the Iwaki Formation changes locally, the details will be described in the section "Change of the Lithofacies". The general characters of the Iwaki Formation are given below.

In the Iwaki area, Nakamura (1913) divided the formation into Basal bed, Coal bearing bed and Iwaki sandstone bed. It covers the basement rocks of granite and green schist with basal conglomerate and sandstone with unconformity (Pl. 2). The lower part is represented by coal seams, the middle by conglomeratic coarse grained sediments grading upwards to medium — fine grained sandstone of the upper part. The thickness of the Iwaki Formation in this area is 300–400 m.

In the South Futaba area, south of Osaka, Naraha-cho, the Iwaki Formation lies on the Futaba Group with unconformity and consists of conglomeratic and other clastic sediments showing cyclothemic development.

The North Futaba area, north of Osaka, has been studied in detail by Mitsuta (1951). In this area the formation lies on the green schist with unconformity. It is composed dominantly of sandy sediments. The thickness of the Iwaki Formation in the Futaba area is thicker towards the southern part and thinner northwards, in the southern environs of Tamayama it attains about 200 m and only about 50 m at Yonomori in the northernmost part of its distribution.

In the Taga area at the southern part of the field, the Iwaki Formation overlies the granite and green schist with unconformity. In this area the Iwaki Formation is composed of sandy sediments intercalated with coal and showing cyclothemic development. No remarkable conglomeratic sediments are observed in the Taga area. Although attaining

250–300 m in thickness the lithofacies shows resemblance to the North Futaba area. Buried hills are developed in the area and occur at the surface as outcrops of the green schist in the distribution area of the Iwaki Formation.

Although the occurrence of the fossils are few (only *Ostrea* bed) from the surface outcrops at the basal part of the cyclothem, marine molluscan fossils have been reported from boring cores drilled in the northern Iwaki area and southern Taga area (Eguchi and Shoji, 1953a, b). The writer discovered marine molluscan fossils from the uppermost cyclothem of the Iwaki Formation along the Nanamagari route, Futaba area (Pl. 6). The collected fossils are as follows.

Molluscan fossils from the Iwaki Formation
Loc.: Nanamagari route, Futaba area
Collecters: Okami and Mitsui
Acila (Truncacila) oyamadaensis Hirayama
Venericardia (Cyclocardia) tokunagai Yokoyama
Papyridea harrimani Dall
Papyridea harrimani nipponica Yokoyama
Liocyma furtiva (Yokoyama)
Macoma sejugata (Yokoyama)
Mya (Arenomya) grewingkii Makiyama
Mya (Arenomya?) sp.
Dentalium yotsukuraensis Hirayama
Turritella (Haustator) importuna Yokoyama
Turritella sugaii Mizuno and Fujii
Pliscofusus ishijimai Hirayama

ii) Asagai Formation

The Asagai Formation was proposed by Tokunaga (1927), for the rocks distributed near the Kasamatsu pond in the eastern part of Hottsaka, Joban Yumoto, Iwaki City, Fukushima Prefecture. The Asagai Formation conformably overlies the Iwaki Formation and its thickness is about 85 m.

In the South Futaba area, as observed along the Hattachi beach, Yotsukura-machi (Pl. 3), the basal part of the Asagai Formation covers the uppermost bed (coal seam) of the Iwaki Formation with slight erosion surface and sometimes with washout structure. The basal conglomerate of the Asagai Formation can be traced to the northern Seitaro route in the North Futaba area (Pl. 3).

The Asagai Formation is represented by homogeneous lithofacies in lateral and vertical sequence and the thickness of the formation is invariable. The formation consists of fine grained sandstone, colored grayish blue in a fresh sample and brown on weathered surface and shows onion-structure. The rock appears to be massive, but in detail the formation interbeds 2–3 cm thick shale layer or a very fine grained sandstone bed at the interval of 0.5–1 meters so as to develop stratification. From the Asagai Formation abundant marine molluscan fossils called the "Asagai Fauna" are known to occur. Yokoyama (1924), Makiyama (1934), Hatai and Kamada (1950), Kamada (1962) and others studied the Asagai fauna and described this assemblage to be of "North Type" and ecologically of shallow marine to embayment facies. This is supported by the study on the foraminifers by Asano (1949). The following Foraminifera and molluscs were collected from the formation.

Foraminifera from the Asagai Formation (Asano, 1949)
Ammobaculites yumotoensis Asano
Trochammina asagaiensis Asano

Cyclammina sp. (cf. *incisa* Stach)
Lenticulina fukushimaensis Asano
Saceneria (?) sp.
Nonion cf. *boueanum* d'Orbigny
Elphidium asagaiense Asano
Elphidium yumotoense Asano
Faujasina (?) sp.
Cibicides cf. *lobatulus* (Walker and Jacob)
Cibicides sp.

Molluscan fossils from the Asagai Formation
Loc.: Nanamagari route, Futaba area
Collectors: Okami and Mitsui
Portlandia (*Megayoldia*) *asagaiensis* (Makiyama)
Portlandia (*Megayoldia*) *yotsukuraensis* Uozumi
Acila sp.
Papyridea sp.
Venericardia sp.
Liocyma furtiva (Yokoyama)
Macoma sejugata (Yokoyama)
Macoma sp.
Pandora n. sp.
Mya (*Arenomya*) *grewingkii* Makiyama
Calyptraea aokii Hirayama
Crepidula n. sp.
Ampullina asagaiensis Makiyama
Turritella (*Haustator*) *importuna* Yokoyama
Priscofusus ishijimai Hirayama

iii) Shirasaka Formation

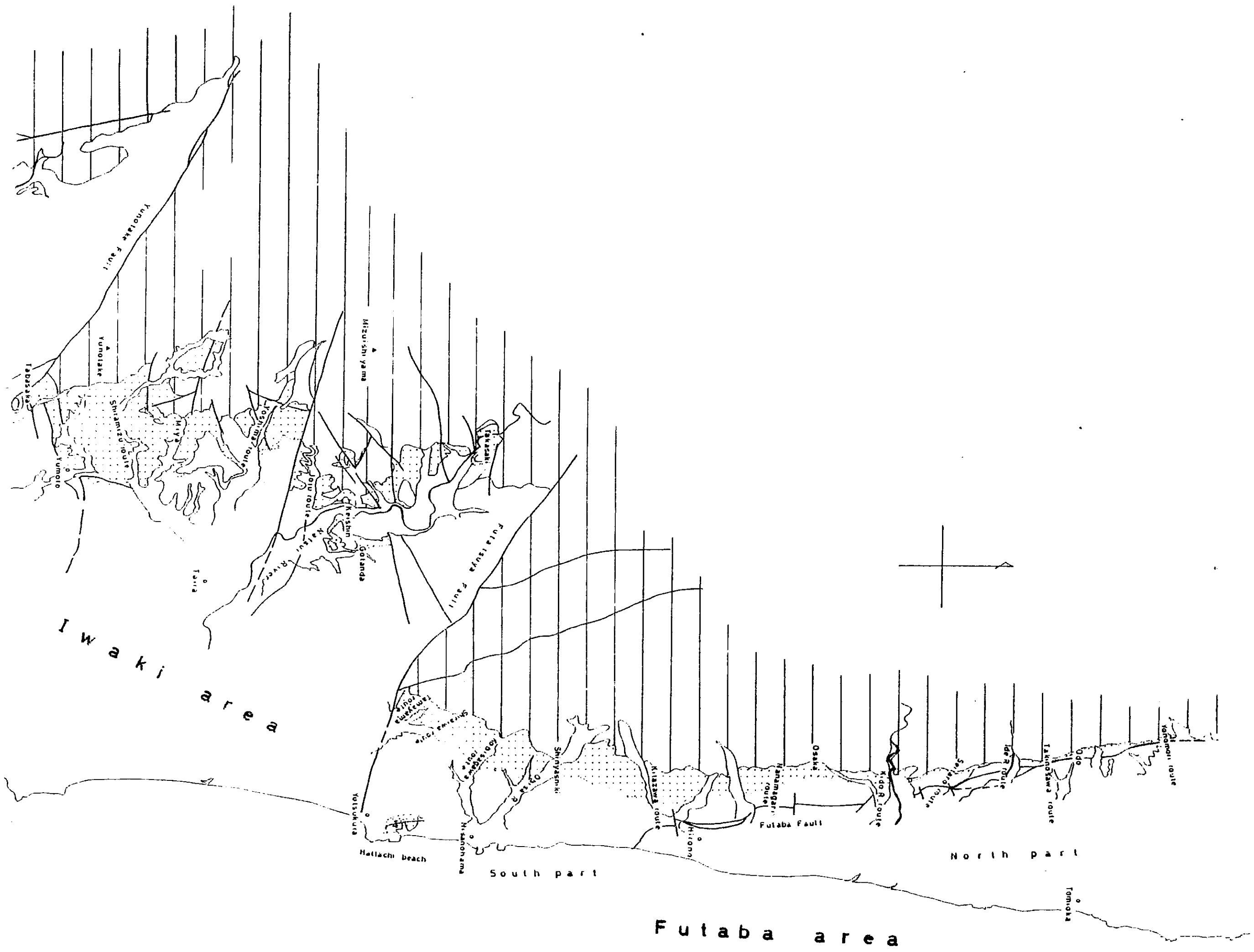
The Shirasaka Formation, first named by Tokunaga (1927), is distributed typically in the environs of Shirasaka, Joban Yumoto, Iwaki City, Fukushima Prefecture. It consists of massive, bluish shale, is transitional from the fine grained sandstone of the Asagai Formation through the sandy shale and has a thickness about 135 m in maximum. The thickness is variable because the upper part was eroded away by the overlying Yunagaya Group. The surface distribution of the Shirasaka Formation is not observed in the North Futaba and southern Taga areas. In the Shirasaka Formation, joints are well developed in the shale that weathers into small angular chips.

From the Shirasaka Formation marine molluscan fossils showing resemblance with the assemblage from the Asagai Fauna occur rarely. The fossils are as follows.

Molluscan fossils from the Shirasaka Formation
Loc.: Kyoritsu Hospital, Uchigo, Iwaki City
Collectors: Okami and Mitsui
Yoldia (*Yoldia*) *laundabilis* Yokoyama
Liocyma cf. *furtiva* (Yokoyama)
Macoma sejugata (Yokoyama)
Macoma ? sp.

Specimens of "Gen-no-ishi" (hammer stone) have also been collected from the formation (Pl. 4). As already pointed out by Hiki (1915), Hanzawa (1957) and Ikegami (1965, 1967) they were deposited in a deep sea of low temperature. Kamada has recorded a "Septaria" (Twenhofel, 1961) from the Shirasaka Formation. This kind of concretion is restricted to muddy deposits.

Fig. 3. Map showing the main sampling routes and localities


Futaba area
North part
South part
Iwaki area
Yonomori route
Odo
Tomioka
Takinosawa route
Ide R. route
Kido R. route
Osaka
Nanamagari route
Futaba Fault
Hirono
Kitazawa route
Shinyashiki
Nisanohama
Hattachi beach
Yotsukura
Futatsuya Fault
Takasaki
Mizuishi yama
Keishin
Gotanda
Natsui River
Jobu route
Yoshima route
Taira
Miya
Shiramizu route
Yunotake
Yunotake Fault
Yumoto
Tabasaka

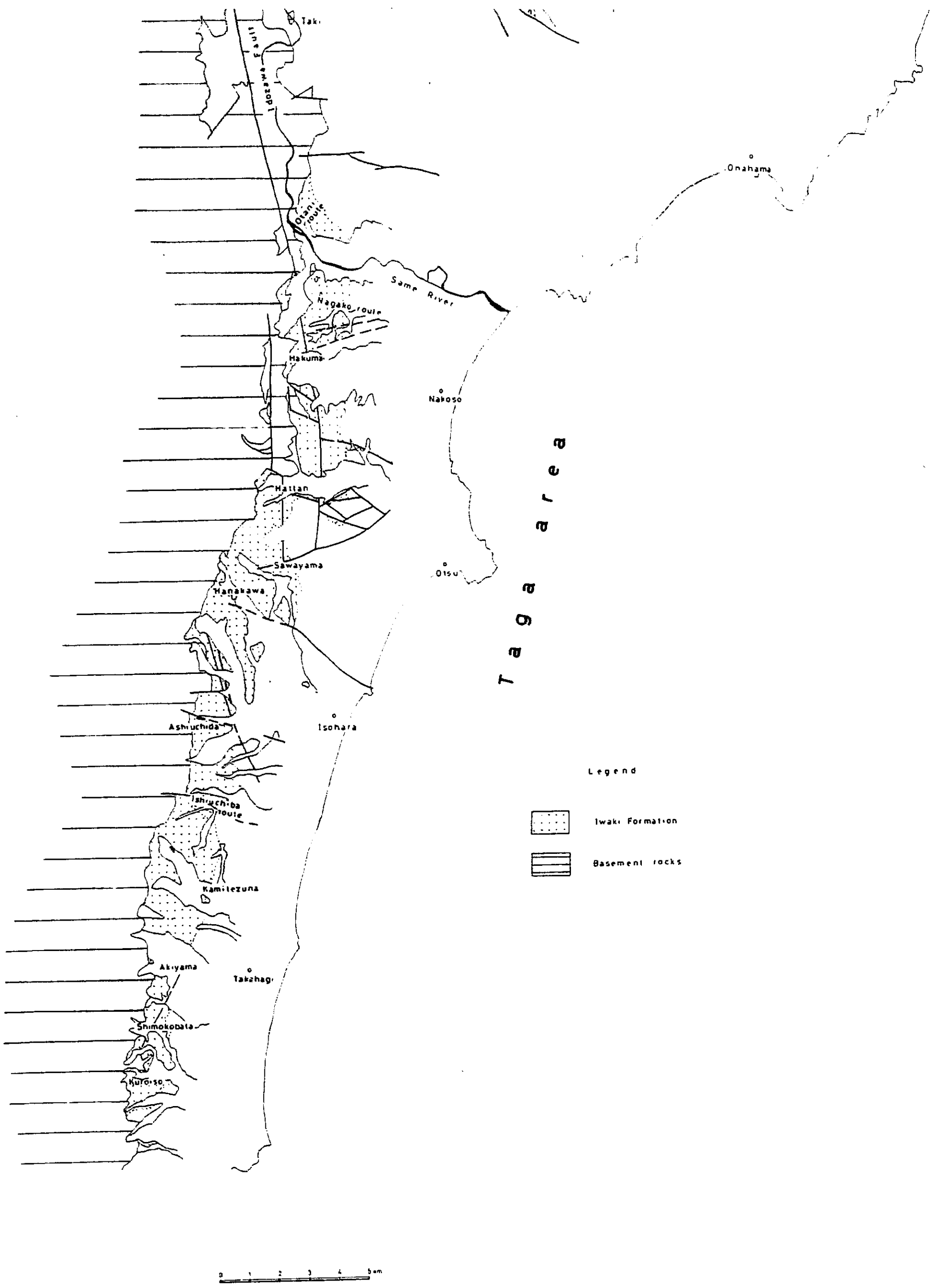


Fig. 3. Map showing the main sampling routes and localities

As already mentioned, the Shiramizu Group consists of the Iwaki, Asagai and Shirasaka formations, and from the lithofacies and fossils, the group shows progressive transgressive facies of terrestrial to deep sea sediments. It is a part of a mega sedimentary cycle.

CHAPTER II

DEPOSITIONAL FEATURES OF THE IWAKI FORMATION

1. RELIEF OF THE BASEMENT

From the evidence of the field and boring data, the relief of the surface of the basement rocks prior to the deposition of the Iwaki Formation has been determined. The highly convex part of the relief is generally called buried hill. This bottom configuration has influenced the deposition of the coal seam, and for this reason the study of buried hill and such bottom topography has been carried out in exploitation of coal (Matsui and Kojima, 1954; Eguchi and Shoji, 1955; Asano, 1956a, b). The buried hills are found in the granite region of the Iwaki area and metamorphic rocks region in the Taga area, but not in the southern part of the Futaba area where the Futaba Group is distributed, or in the northern part where amphibolite schist existed.

At Joju, Iwaki City, and the granite region of the Iwaki area, the small buried hills formed by granite are found and on each side of them there are recognized characteristic sediments (Fig. 4, and Pl. 5). The buried hill of this type was existed to the deposition of the second cyclothem. Asano (1956b) studied the lower part of the Iwaki Formation in the Yoshima district, Iwaki area, and reported that the deposition of the coal seams was influenced by the relief of the basement and that the deposition of the first and second coal seams "Kaso" took place in the hollowed parts of the basement where the relief of the basement there is nearly 30 m, and that the main coal seam "Honso" directly covers the basement rocks.

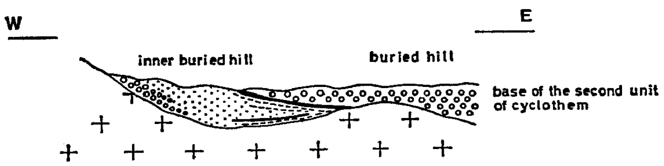


Fig. 4. Modified section of the buried hill at Joju

The remarkable development of a buried hill is observed in the western part of Isohara, Kitaibaraki City in the Taga area. The basement rocks in this area consists of granite and metamorphic rocks. The buried hill is considered to be a result of selected erosion governed by the difference in resistance of the those rocks. The metamorphic rocks are more resistant than the granitic rocks, resulting in that the metamorphic rocks would be convex to make a buried hill along the schistosity trend of the metamorphic rocks.

The existence of the buried hill is easily recognized by field survey from the outcrops of the basement and their relation with the distribution of the other rocks. For example, in Fig. 1, the buried hill is recognized from the outcrop of the metamorphic rock in the distribution of the Iwaki Formation at Otani, Nagako in Nakoso City and at Hanakawa, Isohara, Kitaibaraki City. The buried hill in this area has a general strike of N70°W and the hight of the buried hill at Hanakawa is estimated to be about 50 m from the thickness of the sediments. At Karamushi, north of Hanakawa, the buried hill reaches about 150 m in height (Shoji, 1957 a, b).

Around the buried hill of metamorphic rocks (green schist) there are developed dark gray muddy fine grained sandstones.

The buried hill is considered to have existed before the beginning of Iwaki deposition and its presence aided in the development of marsh or lagoon environment or possibly a minor enclosed bay favoring the deposition of coal.

2. CHANGE OF THE LITHOFACIES

The lithofacies of the Iwaki Formation is variable locally as well as regionally and can be observed in the areas of Taga, Iwaki and Futaba. The characteristics of the lithofacies in each area are given below.

A) **Iwaki Area:** At the type locality, the Iwaki Formation is divided as follows by Nakamura (1913) and Watanabe (1930).

Iwaki sandstone bed	Upper sandstone belt	4th sandstone zone
		Takakura sandstone zone
		3rd sandstone zone
	Lower sandstone belt	Tochikubo conglomerate
		2nd sandstone zone
		Nametsu conglomerate
		1st sandstone zone
Coal bearing bed		Upper coal bearing zone
		Shiramizu sandstone zone
		Lower coal bearing zone
Basal conglomerate and sandstone bed		

The rock units given above can be recognized in the Shiramizu district, but northward from Yoshima to the Joju district the lithofacies changes and remarkable cyclic sedimentation is developed. In the Yoshima and Joju districts the sequence begins with locally of basal conglomerate, sandstone and "Gainome clay bed" superposed with the 1st coal seam (1st Kaso group), and at Yoshima by the coal seam called "2nd Kaso group" (Asano, 1956 a, b). After deposition of the "1st Kaso group", continued cyclic sedimentation, then the "Honso" was intercalated followed by the "Joso" coal seam and so on. These cyclothems are well developed especially in the Yoshima to Joju district in the Iwaki area. This kind of cyclic deposition occurs throughout the formation in this district in the Iwaki area.

In the Yumoto district the coal seams tend to decrease in their development from the "Joso" horizon upwards and the sediments become pebbly. Cyclic deposition intercalating coal seams do not occur in the upper horizon as is observed in the lower horizon. In the upper part of the formation, the sediments became pebbly and massive sandstones are dominant. The sandstones are sometimes graded, changing upwards into fine grained sandstone showing fine lamination and stratification (Pl. 5). The thickness of the Iwaki Formation is about 400 m in the Yoshima district but decreases northwards to 300 to 250 m (Fig. 6).

B) **Futaba Area:** This area is divided into the South Futaba and North Futaba areas. In the South Futaba area, the Iwaki Formation overlies the Cretaceous rocks with unconformity, and pebbly sediments are dominant (Fig. 5). The basal conglomerate distributed in this area is about 30 m in thickness but decreases northwards.

The rocks of the Iwaki Formation is shown by cyclothemic arrangement of, in a complete unit, conglomerate, sandstone, sandy shale and coal, comprising in this area a total of eight cycles. The cycles are named from the lower as Komatsu, Toshimo, Dogameki, Yuzawa, Onairi, Nanamagari, Nabezuka and Takakura (Eguchi and Shoji,

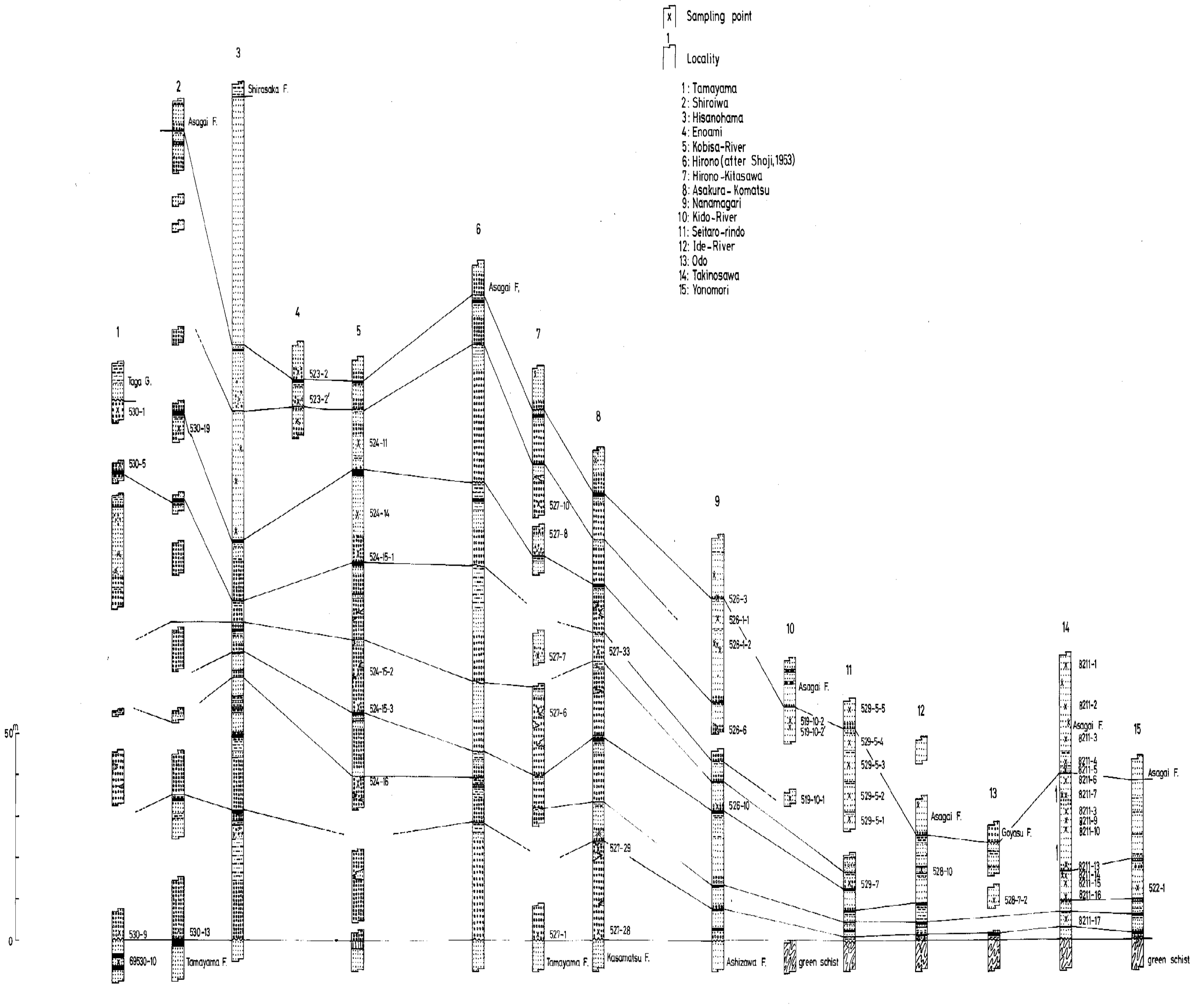


Fig. 5. Columnar section of the Iwaki Formation in the Futaba area, in the legend, 6: Hirono (after Shoji, 1958) is read 6: Hirono (after Eguchi and Shoji, 1953a)

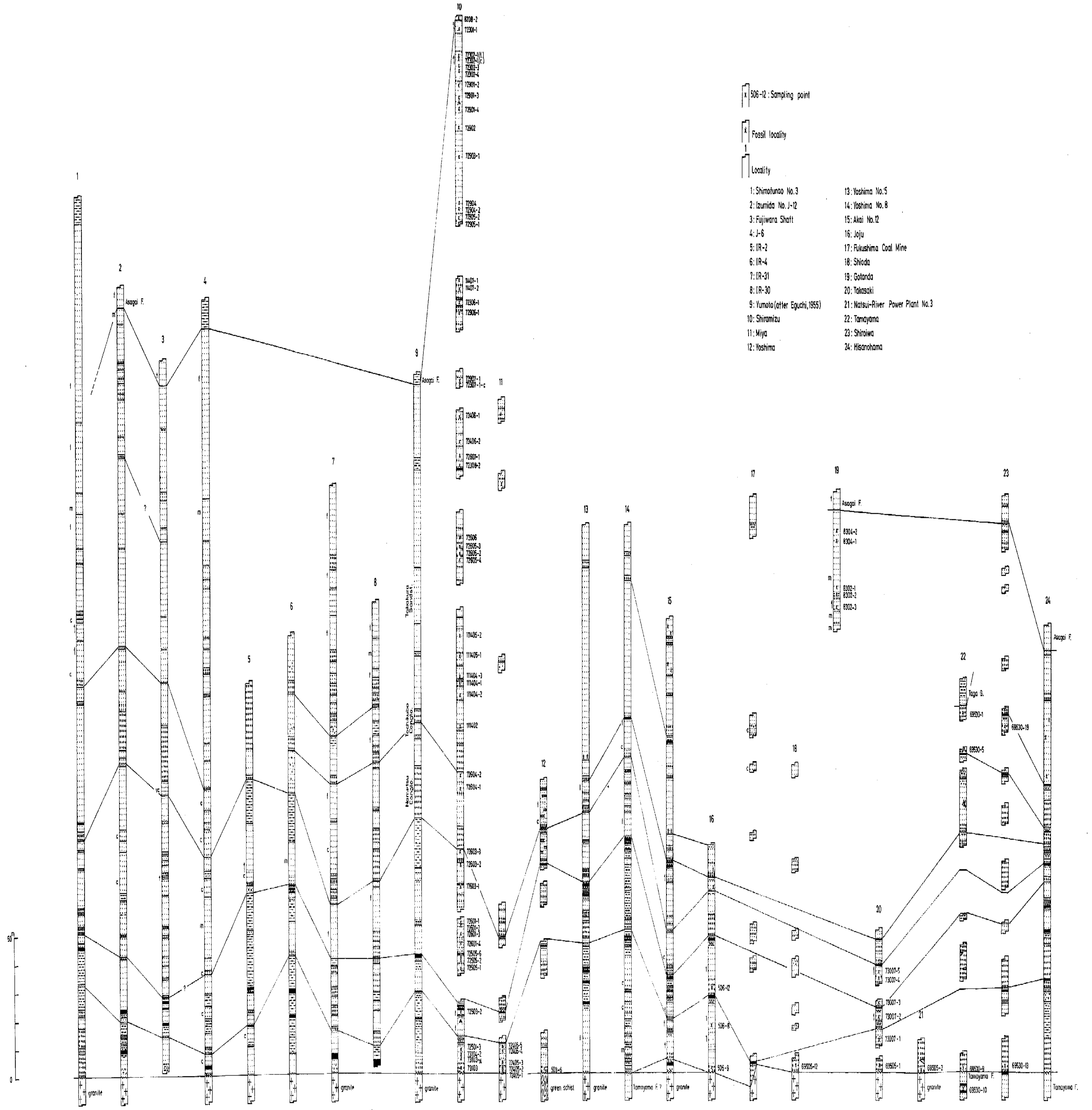


Fig. 6. Columnar section of the Iwaki Formation in the Iwaki area, in the legend, 9: Yumoto (after Eguchi, 1955) is read 9: Yumoto (after Eguchi *et al.*, 1955)

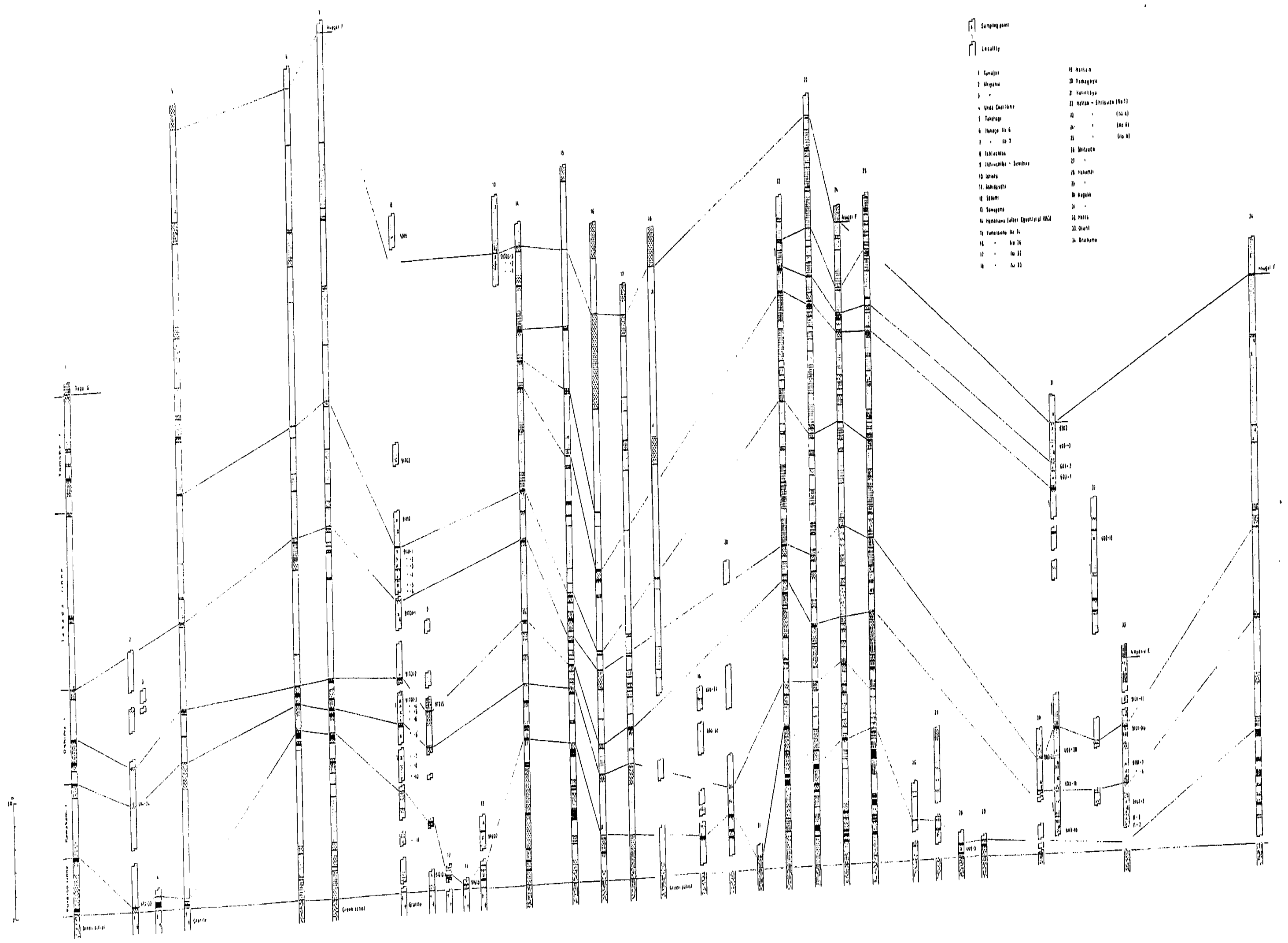


Fig. 7. Columnar section of the Iwaki Formation in the Taga area

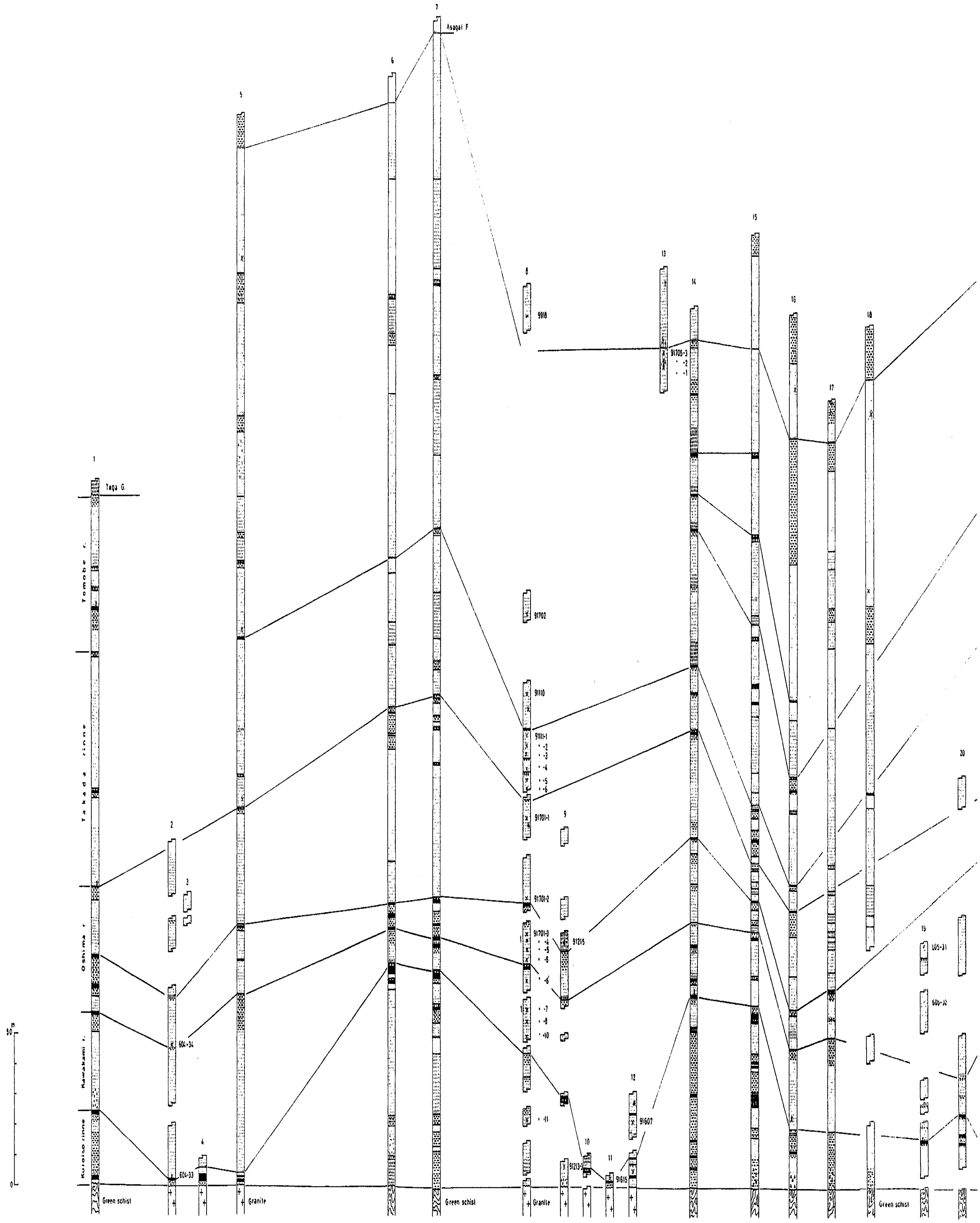
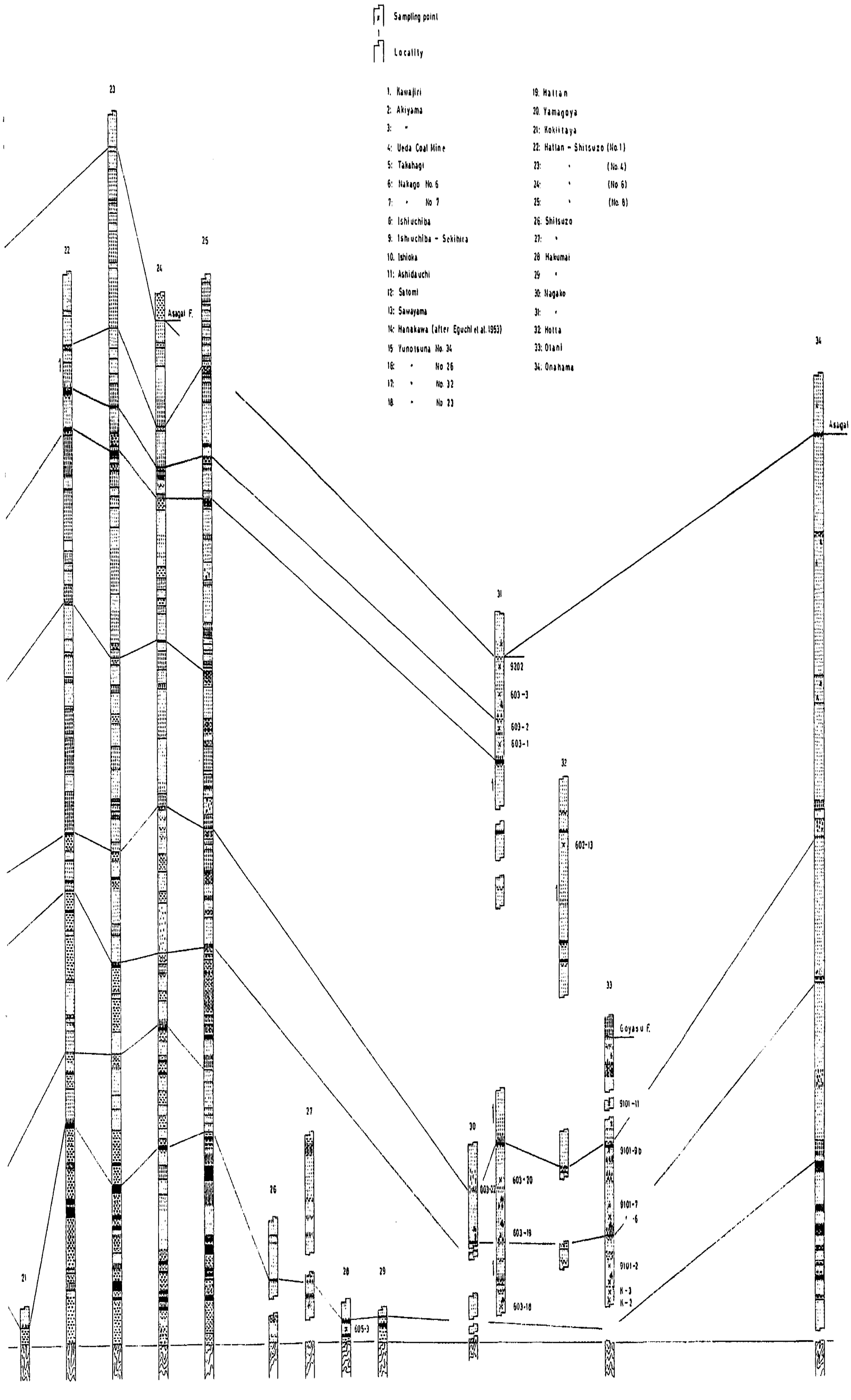


Fig. 7. Columnar section of the Iwaki Formation in the Taga are


Sampling point
Locality
1. Kawajiri
2: Akiyama
3: "
4: Ueda Coal Mine
5: Takahagi
6: Nakago No. 6
7: " No 7
8: Ishiuchiba
9: Ishiuchiba - Sekihira
10. Ishioka
11: Ashidauchi
12: Satomi
13: Sawayama
14: Hanakawa (after Eguchi et al. 1953)
15 Yunotsuna No. 34
16: " No 26
17: " No. 32
18 " No 23
19. Hattan
20. Yamagoya
21: Kokiitaya
22: Hattan - Shitsuzo (No. 1)
23: " (No. 4)
24: " (No 6)
25: " (No. 8)
26. Shitsuzo
27: "
28 Hakumai
29 "
30: Nagako
31: "
32 Hotta
33: Otani
34: Onahama
Asagai F.
Goyasu F.
9202
603-3
603-2
603-1
602-13
9101-11
9101-9b
9101-7
" -6
9101-2
K-3
K-2
603-20
603-22
603-19
603-18
605-3

1953 b). Conglomerate is the dominant rock facies, and facies gradually changes into sandy in the northern part of the South Futaba area. Along the Nanamagari route molluscan fossils were found from the uppermost horizon (Pl. 6).

In the North Futaba area, the basement rocks directly underlying the Iwaki Formation consist of green schist, and the basal member of the Iwaki is composed of a clayey bed including angular pebbles of green schist. The rocks show cyclothemic arrangement of sandstone, sandy shale and coal. Pebbly sediments are developed only in the middle part along the Seitaro route. Coal seams are well developed in the lower part of the formation, and the upper part of the cyclothem of the upper part of the formation consists of fine grained sediments and shale replaces the coal seams. The typical sequence of the Iwaki Formation in this area is observed along the Takinosawa route.

The Iwaki Formation in the Futaba area has a maximum thickness of 200 m along the Shiraiwa route, Yotsukura-machi, becomes thin northwards, along the Nanamagari route, it attains about 90 m, and the thickness decreases to 50 m at Yonomori.

C) **Taga Area:** Taga area is at the southern part of the field. The rocks resemble those in the North Futaba area, consisting of cyclothemic arrangement of coarse grained to fine grained sandstone and coal seams. The basal sediments consist of "Gainome clay" which is superposed by coal seams ("Kaso and Honso") where the base consists of granite (Eguchi, Shoji and Suzuki, 1966a, 1967). In the region of metamorphic rocks, the Iwaki Formation has two types of basal sediments, one is basal conglomerate of small size breccia and the other is dark green colored clayey siltstone.

According to Kon-no (1938), at the west of Isohara, the rocks of the lower part of the Iwaki Formation consist of, in the basal part, coal bearing bed and conglomerate correlative with the Nametsu conglomerate of the Iwaki area, and shows resemblance with the lower part of the formation in the Yumoto district, and the same sequence is observed along the Ishiuchiba-Sekihira route. Nine cycles are recognized in the Hanakawa district, west of Isohara, and they are named from the lower, Azuhata, Kurumaoki, Hikitori, Yamashita, Maehanzo, Nakahira, Kizawa, Nemoto and Sekine. This division can be applied only to this district. Toward the south as in the Takahagi region the cyclothems become obscure and their number decreases (Fig. 7).

Cross stratification of large wedge shaped tabular type along the dip (Pettijohn and Potter, 1964; Allen, 1963) characteristic of fluviatile deposition (Pl. 6) is developed in the sandstone part of the Iwaki Formation in each area.

The cross stratification observed at Miya, Iwaki City, in the upper part of the formation is a large one, dipping at nearly 5° (Pl. 6). The common cross stratifications as observed at Yoshima and Nagako dip at 10° to 20°. The development of the cross stratification is observed also in the pebbly sediments.

The cross stratification generally dips towards the east, and indicates that the sediments were supplied from the west. Reconstruction of the route of the transportation of the sediments could not be determined owing to that the cross stratification was not traceable along the same depositional plane. Rarely westward dipping cross stratification could be observed in the basal part of the cyclothems (Pl. 5).

3. CYCLOTHEMIC ARRANGEMENT AND ITS CORRELATION

Literature points that most of the coal bearing beds of Japan were deposited by cyclic sedimentation. The origin of the cyclothemic deposition is interpreted by "diastrophic control" and "sea level control" (Wanless and Shepard, 1936; Weller, 1956; Wheeler and Murray 1957; Krumbein, 1964). Shoji (1960 a, b) held the view that the origin of the cyclothemic deposits intercalating coal bearing beds in Japan may be related to volcanic activity, as diastrophic control. This view is expressed from that the coal bearing beds are interbedded with pyroclastic sediments. However, in the case of the Iwaki Formation, the coal bearing beds intercalated in the cyclothems, do not include pyroclastic sediments.

One of the cyclothems in the Iwaki Formation has a thickness about 20 m and is composed of from the lower to upper, conglomerate, coarse to fine grained sandstone, coaly shale and coal. Complete units are very rare, and generally the fine grained sediments and coal seam of the upper part of a cyclothem are eroded away by deposition of the next cyclothem. So the commonly observed cyclothem is incomplete and the coaly sediments are usually missing. There are cases where sandstone beds with brackish to marine fossils are deposited in place of the conglomerate at the basal part of a cyclothem.

The cyclothems observed in the Iwaki Formation can be classfied into three types as shown in Fig. 8, as follows:

1. Ideal type
2. Pebbly type
3. Sandy type

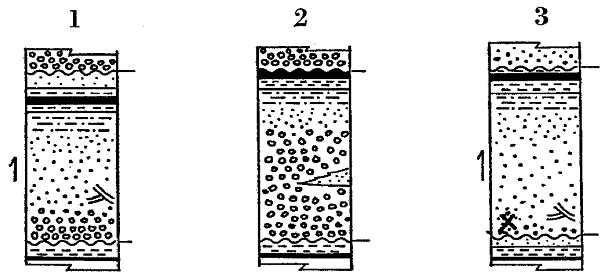


Fig. 8. Cyclothems in the Iwaki Formation

A) **Ideal type:** This type is very rare and has been observed only at Joju, Iwaki City, and along the Nanamagari route, Naraha-machi. The basal conglomerate of the cyclothem of this type lies on the coal bed of the lower horizon with diastem, and has a thickness about 2–3 m. The sandstone changes from coarse to fine grained upwards and then grades into coaly sediments (Fig. 8–1).

B) **Pebbly type:** This type is developed in the lower part of the formation in the Takasaki district of the Iwaki area and the South Futaba area. In the South Futaba area this type is observed throughout the formation (Fig. 8–2).

C) **Sandy type:** This type is found in the North Futaba area and Taga area. The basal part consists of pebbly sandstone or muddy sandstone with brackish water to marine molluscan fossils (Fig. 8–3).

Wedge-shaped cross stratification is developed in the coarse grained sandstone at the lower part of the cyclothem.

The number of cyclothems developed in any district is the same and therefore applicable for correlation of the Iwaki Formation. A good example is the Futaba area where eight cycles are developed regardless of the change in lithofacies. For example the facies is conglomeratic in the southern part and sandy in the northern part, yet the same number of units are developed, and therefore, can be used for correlation (Fig. 5).

The lower part of the Iwaki Formation in the Iwaki area shows the development of cyclothems that intercalate coal seams, but cyclothemic arrangement in the middle to upper part becomes obscure because of the predominating sandy sediments. For this reason only the former can be used for correlation purposes. The correlation with the other areas included in the Joban coal field is shown in Fig. 6.

In the Hanakawa district, west of Isohara in the Taga area, nine cycles are recognized, and these are important for correlation in this district.

Correlation by means of the cyclothems have been reported on a local scale (Eguchi and Shoji, 1953 a, b; Eguchi, Shoji and Suzuki, 1953; Eguchi and Suzuki, 1960; Asano, 1956a), and also by the writer on a larger scale, that is, throughout the entire coal field as shown in Figs. 5, 6 and 7.

CHAPTER III

SEDIMENTARY PETROGRAPHIC STUDY

1. CONGLOMERATE

In the Iwaki and South Futaba areas conglomerate beds are well developed, especially in the South Futaba area, a conglomeratic cyclothem is developed (Fig. 5) and it occupies nearly 80 percent of the whole sequence of rocks.

Gravels are dominantly of cobble size and rounded to subrounded. The matrix consists of coarse grained sandstone. The paleogeology and provenance of the gravels were studied based upon the areal change of the gravel composition.

1) Methods of Study and Samples

The methods for the study of the gravels have been described by Krumbein and Griffith (1935), Krumbein and Sloss (1963), Emery (1955) and Hirabayashi (1970 a, b) and studies on the paleogeology, provenance and paleoenvironment based on the gravel composition and texture have been carried out by Plumly (1948), Bluck (1965) and Shideler (1970). The writer follows those methods in the present study.

The lithologic assemblage of the gravels has been analyzed on 50 to 100 pieces (Krumbein and Griffith, 1935; Krumbein and Sloss, 1963) in the field and doubtful pieces by thin section under the microscope. The analyses were carried out on cobble size gravels ranging from 3 to 5 cm in diameter. The frequency of the gravels was measured using a square grid measuring 1 m in width and 50 cm in height. At Tamayama, Shinyashiki in the South Futaba area and the Natsui No. 3 Power Plant in the northern Iwaki area, the gravel size distributions were estimated from measuring the b axis after the method of Emery (1955). Analyses and measurements were done at 60 sampling points which are shown in the geologic columnar sections (Figs. 5, 6, 7). Analysis were also made on the basal conglomerate of the Asagai (5 points) and the Taki formations (3 points) (Table 1).

2) Composition of the Gravels

i) Description of the Gravels

The gravels are of chert, granite, porphyry, pyroxinite, green schist, mica schist, sandstone, slate, vein quartz and basaltic andesite. Their shapes are generally rounded-subrounded, but those of slate and schist are shaped disk-like with rounded corners. Cobble size gravels were most common. The lithology of the major gravels are as follows:

a) Chert: Chert showed varied color of red, black, white, blue and dark blue. Under the microscope, chert is of microcrystalline quartz about 10 μ in size and of equigranular texture. Occasionally chalcedonic quartz was observed. The chert contained small amounts of clay minerals in the pore space, no bedding was observed. Chert gravels are distributed widely and amount to about 50 percent in the Iwaki area. The roundness of the chert gravel is high and the majority belong to the rounded form (Fig. 8).

b) Porphyry: Porphyry gravels were mainly of quartz porphry, with large phenocrysts of quartz and feldspar of about 2000 μ in size. Sometimes quartz of idiomorphic form of high quartz type are found. The matrix consists of microcrystalline quartz, feldspar and mica, and small phenocrysts of hornblende. The degree of roundness is high, and the amount is generally 20 percent but this varies regionally.

c) Granite: Granite is composed of equigranular crystals of about 2 to 4 mm in size and of quartz, feldspar, mica and hornblende. Feldspar shows albite twin and perthite texture. The characteristics of the granite gravel under the microscope resemble the younger granite of the basement rocks.

d) Sandstone: The sandstone gravel is of moderately sorted medium grained sandstone that can be classified into feldspathic — subgraywacke according to Folk's classification (1954).

It is noteworthy that a single orthoquartzite gravel was found from the basal conglomerate distributed at Shinyashiki, Obisa-machi, Iwaki City in the Futaba area. The gravel has a diameter of 6 cm and under the microscope it consists of well sorted and rounded quartz grains about 0.3 mm in size and generally cemented by secondary quartz. The characteristics of the orthoquartzite resemble the orthoquartzite from the Kishu Shimanto Belt, and thus consideration of the provenance of the orthoquartzite seems necessary (Skolnic, 1965; Kishu-shimanto Dantai Research Group, 1968; Tokuoka, 1970).

e) Volcanic Rock (Basaltic andesite): One basaltic andesite gravel was discovered in the conglomerate bed of the uppermost cyclothem of the Iwaki Formation, at Shinyashiki in the South Futaba area. Under the microscope, the rock shows a porphyritic texture and has idiomorphic phenocrysts of 600–300 μ in size of pyroxene and amphibole. Both pyroxene and amphibole have suffered deep weathering. The feldspars are of long strip shape and occasionally crystallized into a large one of about 200 μ, shows zonal structure, and they may be andesine to labradorite (Pl. 8).

ii) Areal Change of the Gravel Composition

A) The Composition of the Basal Conglomerate

The assemblage, composition and distribution of the gravels in the basal conglomerate are thought to be important to interpret the distribution of the basement rocks and the provenance of the gravels during the early stage of Iwaki deposition. The basal conglomerate in the South Futaba area and Iwaki area has a maximum thickness about 30 m. In the North Futaba and Taga areas, the basal conglomerate is hardly developed, so the study on the basal conglomerates was restricted to the South Futaba and Iwaki areas.

Fifteen sampling points of about the same intervals were chosen from the two areas to study the composition. The localities are from the north, Komatsu, Toshimo, Shinyashiki, Shiraiwa and Tamayama in the Futaba area, Natsui River No. 3. Power Plant, Summit of the mountain east of the Natsui River No. 3 Power Plant, Takasaki, Shiode, Keishin, Joju (a), (b), Yoshima and Onoda in the Iwaki area (Fig. 9). At the sampling points at Shinyashiki and Tamayama (Futaba area)and Natsui River No. 3 Power Plant (Iwaki area), the gravel size distribution was measured and the distribution showed resemblance to that shown in Fig. 10. Every sample showed the value of mean size nearly –3.0 ϕ and sorting 1.8 according to Inman's formula (1952). From the result of these and the sedimentary feature at the outcrops (Pls. 7, 8), these three basal conglomerates are considered to have been deposited in a similar environment (Fig. 10).

Table 1. Composition of the areal gravel

No.		Ch	Gr	Gs	Vq	Ph	So	Py	Mc	Ap	Ry	Ba	?	Sl	St
528-6*	(1)	8.3	58.3	16.8	-	12.5	-	-	-	-	-	-	-	4.1	-
528-1	(2)	43.7	37.5	12.5	-	6.2	-	-	-	-	-	-	-	-	-
529-1*	(3)	10.3	31.1	37.9	-	17.2	-	-	-	-	-	-	3.4	-	-
529-3+	(")	30.8	-	7.7	-	53.9	-	-	-	-	-	-	-	-	7.7
529-7	(")	45.4	27.3	6.0	-	6.6	3.0	-	-	-	-	-	-	-	12.1
519-10-2+	(4)	23.8	-	19.1	-	38.1	-	-	-	-	-	-	-	14.3	4.7
526-29	(")	54.5	15.2	-	-	6.0	-	-	-	-	-	-	-	-	24.2
526-3+	(5)	44.5	-	-	-	11.1	-	-	-	-	-	-	-	16.7	27.8
526-6	(")	50.0	-	-	-	7.7	11.5	-	-	-	-	-	-	3.8	26.9
526-10	(")	63.5	-	-	-	9.1	-	-	-	-	-	-	-	9.1	18.2
519-3	(6)	22.2	3.7	-	-	14.8	-	-	-	-	11.5	-	-	7.4	40.7
519-6	(")	51.5	43.5	-	-	4.3	-	-	-	-	-	-	-	8.7	26.1
527-33	(7)	52.0	4.0	-	-	20.0	12.0	-	-	-	-	-	-	-	12.0
527-29	(")	51.9	3.7	-	-	29.7	-	-	-	-	-	-	-	-	14.8
527-28	(")	50.0	-	-	-	20.8	8.3	-	-	-	-	-	-	4.1	16.7
527-10	(8)	44.4	18.5	-	-	7.4	7.4	-	-	-	-	-	-	-	22.2
527-8	(")	45.0	-	-	-	16.6	8.3	-	-	-	-	-	-	4.1	25.0
527-7	(")	65.2	15.4	-	7.7	-	3.8	-	--	-	-	-	-	-	7.7
527-6	(")	46.1	19.2	-	-	-	15.4	-	-	-	-	-	-	3.8	15.4
527-1	(")	34.8	30.4	-	-	4.3	13.0	-	-	-	-	-	-	-	17.4
527-18	(9)	56.5	8.7	-	-	4.3	8.7	-	-	-	-	-	-	4.3	17.4
527-24	(")	39.1	-	-	-	30.4	17.4	-	-	-	-	-	-	4.3	8.7
520-28+	(")	52.3	-	-	-	21.0	-	-	-	-	4.7	-	-	-	22.4
520-4	(10)	46.1	11.5	-	-	7.7	-	-	-	-	-	3.8	-	11.5	19.2
520-10	(")	46.6	-	-	-	16.6	3.3	-	-	-	-	-	-	6.6	26.6
520-13	(")	22.7	13.6	-	-	31.8	4.5	-	-	-	-	-	-	18.4	9.1
520-22	(11)	34.7	4.3	-	4.3	13.1	17.4	-	-	-	-	-	-	4.3	21.7
520-19	(")	46.1	3.8	3.8	-	3.8	-	-	-	-	-	-	-	11.5	30.8
520-18°	(")	19.1	4.7	4.7	-	52.4	-	-	-	-	-	-	-	-	19.1
524-1*	(12)	26.3	14.5	-	-	26.3	-	-	-	-	-	-	-	10.5	26.3
524-15-1	(")	47.4	2.6	-	5.2	2.6	5.2	-	-	-	-	-	-	7.7	29.0
524-15-2	(")	59.0	-	-	-	9.1	-	-	-	-	-	-	-	9.1	22.7
524-15-3	(")	52.9	3.1	-	-	12.5	-	-	-	-	-	-	-	6.2	25.0
524-16	(")	52.5	-	-	-	31.5	-	-	--	-	-	-	-	5.2	10.5
523-23	(13)	51.2	-	-	-	22.8	2.8	-	-	-	-	-	-	2.8	20.0
523-21	(")	40.5	2.3	-	-	31.0	4.7	-	-	-	-	-	-	4.7	16.6
523-2+	(")	45.4	-	-	-	9.1	-	-	-	-	-	-	-	31.8	13.6
523-2	(")	45.0	5.0	-	-	15.0	2.5	-	-	-	-	-	-	10.0	22.5
530-19	(14)	52.9	-	2.9	-	14.7	5.8	-	-	-	-	-	-	-	23.5
530-13	(")	50.0	3.3	16.6	-	10.0	-	-	-	-	-	-	-	3.3	16.6
530-1	(15)	40.7	3.8	-	3.8	7.4	14.8	-	-	-	-	-	-	7.4	22.2
530-5	(")	62.1	14.3	-	-	9.5	4.7	-	-	-	-	-	-	-	34.2
530-9	(")	39.5	-	-	-	42.5	-	-	-	-	-	-	-	3.0	15.0
505-4	(16)	48.4	3.4	1.7	-	27.5	-	-	-	-	-	-	-	5.2	13.8
505-2	(17)	43.0	10.3	7.1	-	17.8	-	-	-	-	-	-	-	3.5	17.8
505-1	(18)	51.0	2.8	8.6	-	17.1	-	- -	5.7	-	-	-	-	5.7	8.5
505-12	(19)	46.0	3.8	7.7	-	15.5	-	11.5	-	-	-	-	-	27.6	27.6
723-1	(20)	54.1	-	-	-	12.1	-	-	-	-	-	-	-	-	33.3
506-14	(21)	50.0	15.0	-	-	5.0	-	-	-	-	-	-	-	10.0	20.0
506-12	(22)	63.1	21.1	-	-	-	-	-	-	5.2	-	-	-	-	10.5
506-9	(")	-	26.6	6.0	-	-	-	6.6	-	6.6	-	-	-	-	-
506-1	(")	50.0	6.2	15.6	-	9.4	-	-	-	-	-	-	-	-	18.8
503-6	(23)	45.0	5.0	20.0	-	15.0	-	-	-	-	-	-	-	5.0	10.0
72603	(24)	72.3	-	6.4	-	8.2	-	-	-	-	-	-	-	-	12.1
71303	(")	16.6	23.3	33.3	-	26.6	-	-	-	-	-	-	-	-	-
602-1	(25)	-	6.2	81.2	12.5	-	-	-	-	-	-	-	-	-	-
9101-5	(")	16.7	-	70.8	-	4.1	-	-	-	-	-	-	-	-	8.3
603-26	(26)	-	-	74.2	25.8	-	-	-	-	-	-	-	-	-	-
91215	(27)	15.0	7.8	69.8	-	3.9	-	-	-	-	-	-	-	-	3.3
604-34	(28)	47.3	26.3	15.8	10.5	-	-	-	-	-	-	-	-	-	-

Ch: chert Gr: granitic rocks Gs: green schist Vq: quartz vein
Ph: porphyritic rocks So: soft rock (Creta.-Tertiary sediments) Py: pyroxinite
Mc: mica schist Ap: aprite Ba: basalt ?: unknown Sl: slate
St: sandstone

*= Base of Yunagaya Group; += Base of Asagai Formation; °= Cretaceous rock

(1) Odo, (2) South of Takinosawa, (3) Seitaro, (4) Kiso River, (5) Nanamagari, (6) Nabezuka, (7) Komatsu, (8) Kitazawa, (9) Toshimo, (10) Shinyashiki, (11) West of Obisa, (12) Kobisa River, (13) Hattachi, (14) Shiraiwa, (15) Tamayama, (16) Summit of mountain east of the Natsui No. 3 Power Plant, (17) Natsui No. 3 Power Plant, (18) Takasaki, (19) Shiota, (20) Tato, (21) Keishin, (22) Joju, (23) Yoshima, (24) Shiramizu, (25) Otani, (26) Nagako, (27) Ishiuchiba, (28) Akiyama

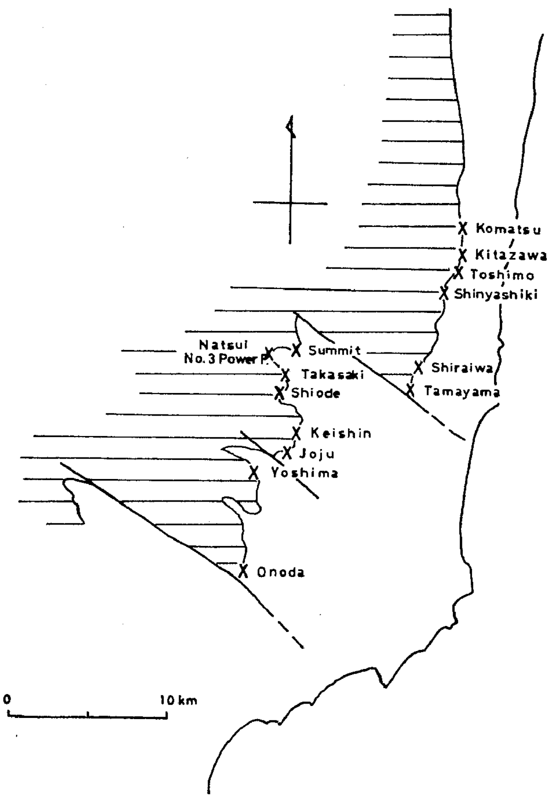


Fig. 9. Localities of the sampling points of the basal conglomerate of the Iwaki Formation

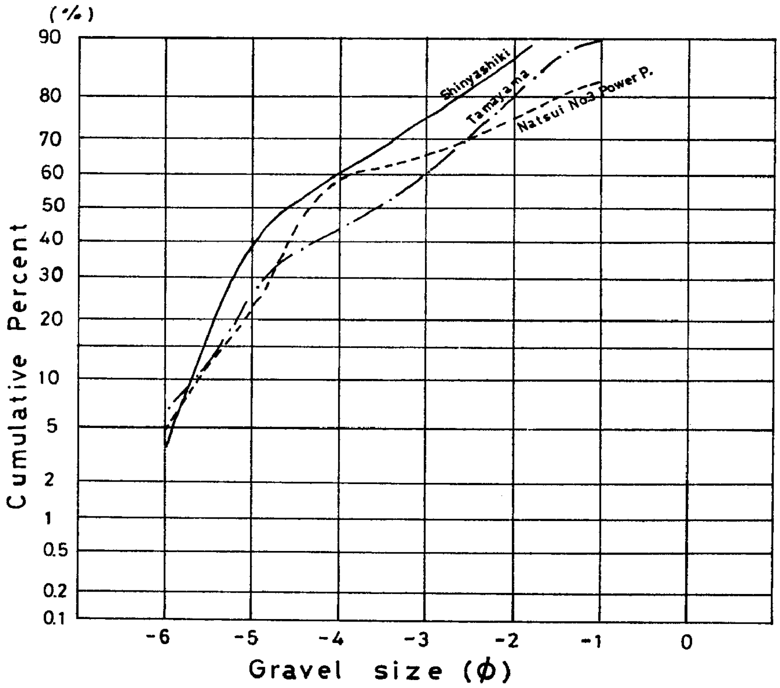


Fig. 10. Cumulative curves of the basal conglomerate of the Iwaki Formation

The gravel composition of the basal conglomerate is variable, but in the Iwaki area, the frequency of the chert gravel content ratio was about 50 percent and the sandstone gravel 15 percent, showing no areal change. The changes in composition according to area are as follows (Figs. 11, 12).

a) At Kitazawa, the frequency of granite gravel showed relatively high value.

b) At Shinyashiki and Toshimo, the porphyry gravel had a high content ratio and at Shinyashiki the content ratio of the granite gravel increased. An orthoquartzite gravel was found at this place.

c) At Tamayama, in the southrenmost part of the Futaba area, porphyry gravel showed a very high content ratio but no granite gravel was found.

d) At the Natsui No. 3 Power Plant, (Iwaki area), granite and green schist gravels content ratios showed high value and the content ratio of porphyry gravel decreased.

e) At Takasaki, only one piece of mica schist gravel was noted. At Shiode, a high amount of pyroxenite gravel was found.

f) At Joju, the sediments around the buried hill can be classified as follows, Joju (a) the sediments of the outer part of the buried hill, Joju (b) the sediments of the inner part of the buried hill, and Keishin. The sediments of the second cycle basal conglomerate overlie the buried hill directly. The composition of the conglomerate at Joju (a) and Keishin resemble the composition of many other places, but at Joju (b), at the inner part of the buried hill, green schist gravels associated with granite and pyroxinite gravels are distributed, and the composition is much different from the sediments of the other places in this respect.

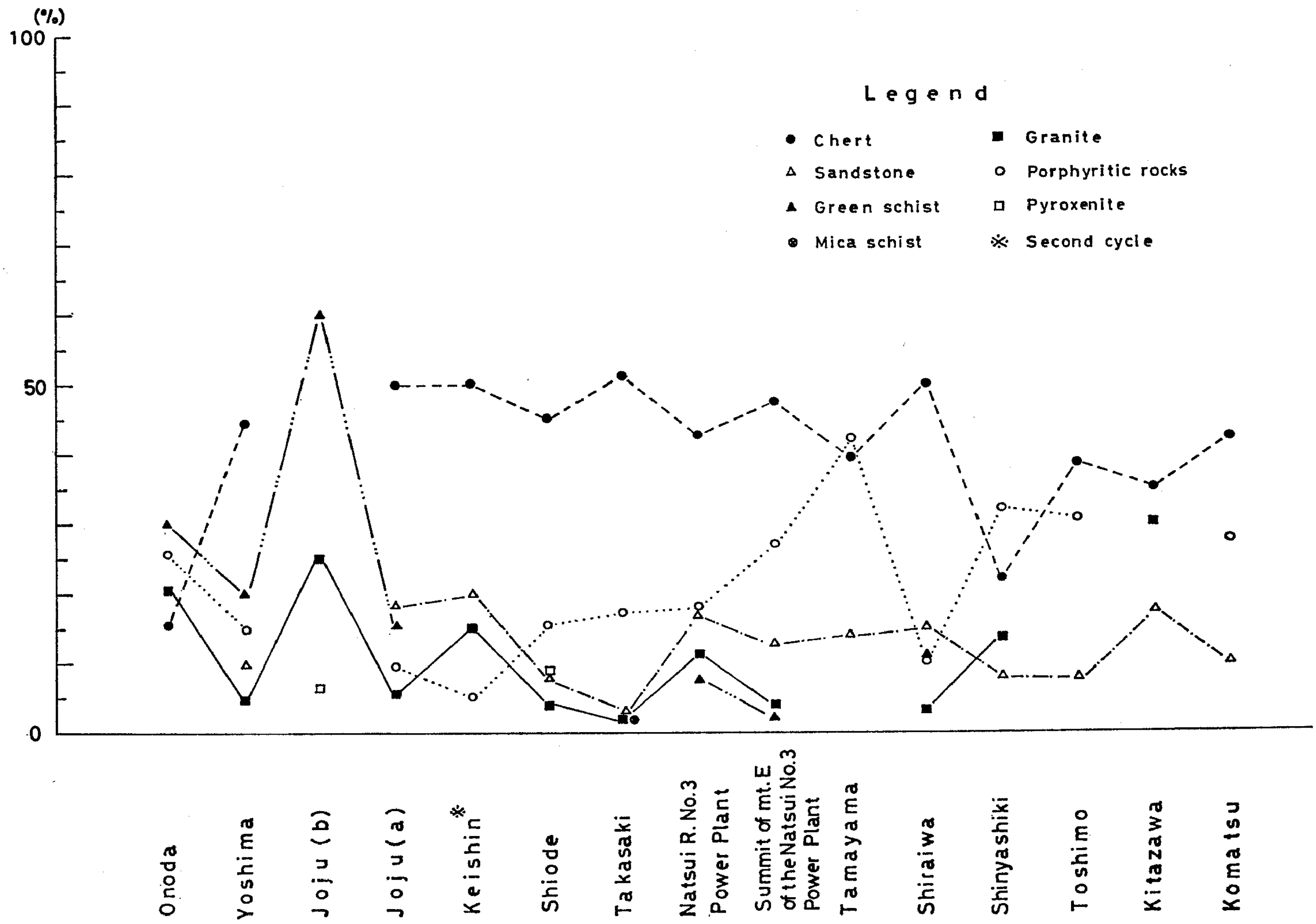


Fig. 12. Areal gravel composition of the basal conglomerate of the Iwaki Formation

g) At Onoda, the content ratio of chert gravel decreased whereas that of granite, green schist and porphyry gravels were nearly of the same ratio.

It is difficult to accept that the result of the analysis of the sediment composition mentioned above reflects the basement geology at the early stage of the Iwaki deposition, because the durability and distance of transportation of the gravels are not the same. However, the composition of the basal conglomerate deposited at the inner part of the buried hill (Fig. 9 and Fig. 12, Joju (b)), can be interpreted as showing the peculiarity of the basement rocks at that place.

Krumbein (1937) and Kuenen (1958) studied the durability of gravels, and Kuenen (1958) made experiments on the relationship between distance of transportation, and loss of the gravel weight and roundness of many kind of rocks. From his study, it was clarified that, the mean weight loss of chert and porphyry gravel is only 0.03 percent per kilometer, the mean weight losses of granite and sandstone gravel are 0.3 percent per kilometer, the difference between the two groups being about ten times. The high content ratio of the gravels in the composition and the low ratio of gravel with low durability are thought to be important for assuming the provenance of the gravels. Also the rock species of the gravels in a restricted region are thought to be important in the consideration of the provenance. For example, at Shioda and Joju (b) pyroxinite gravels are included at places; at Shiraiwa, Natsui River No. 3 Power Plant, summit of the mountain east of the Natsui River No. 3 Power Plant, Joju (a), (b), Yoshima and Onoda, green schist gravels are found at places.

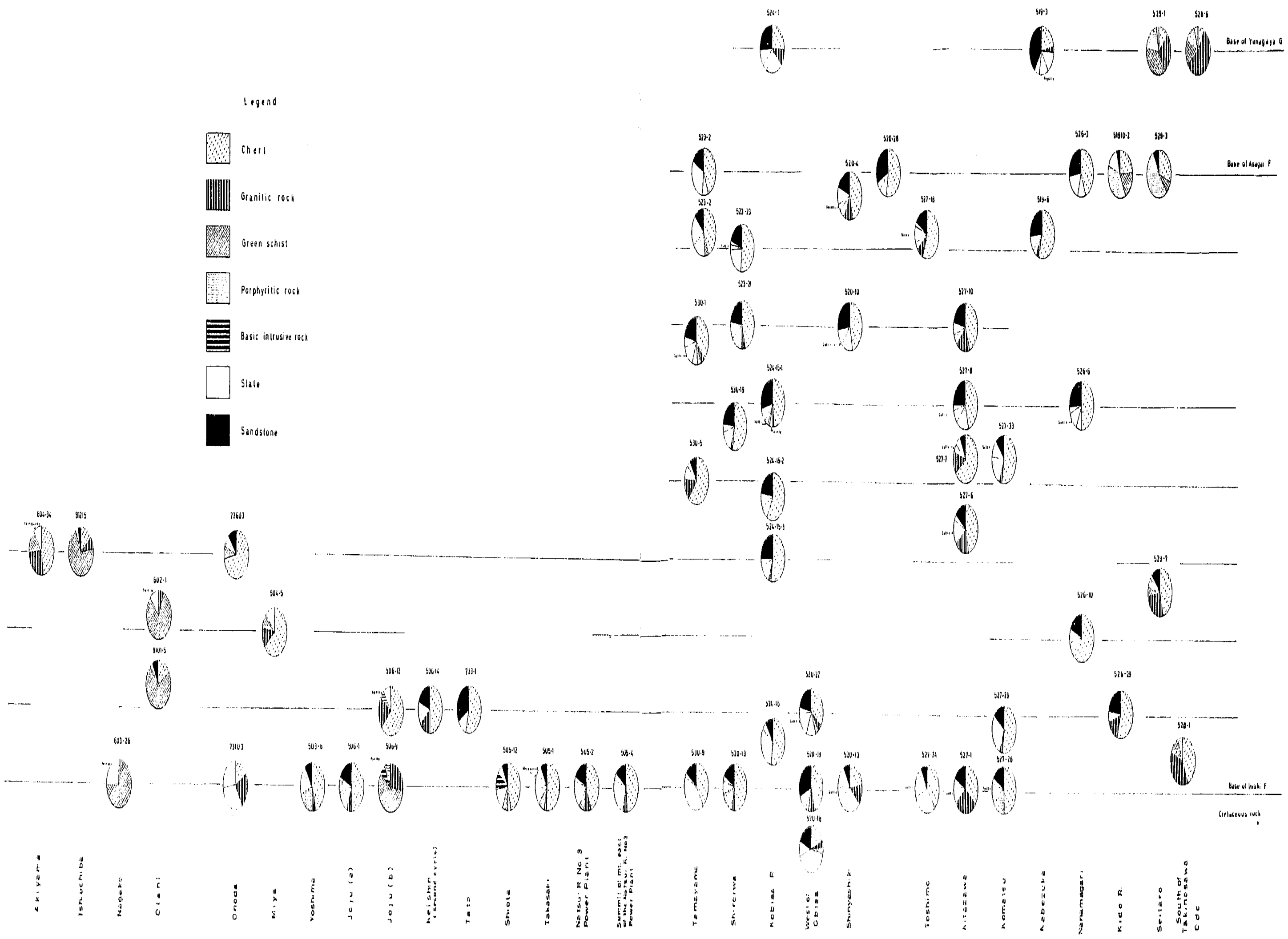
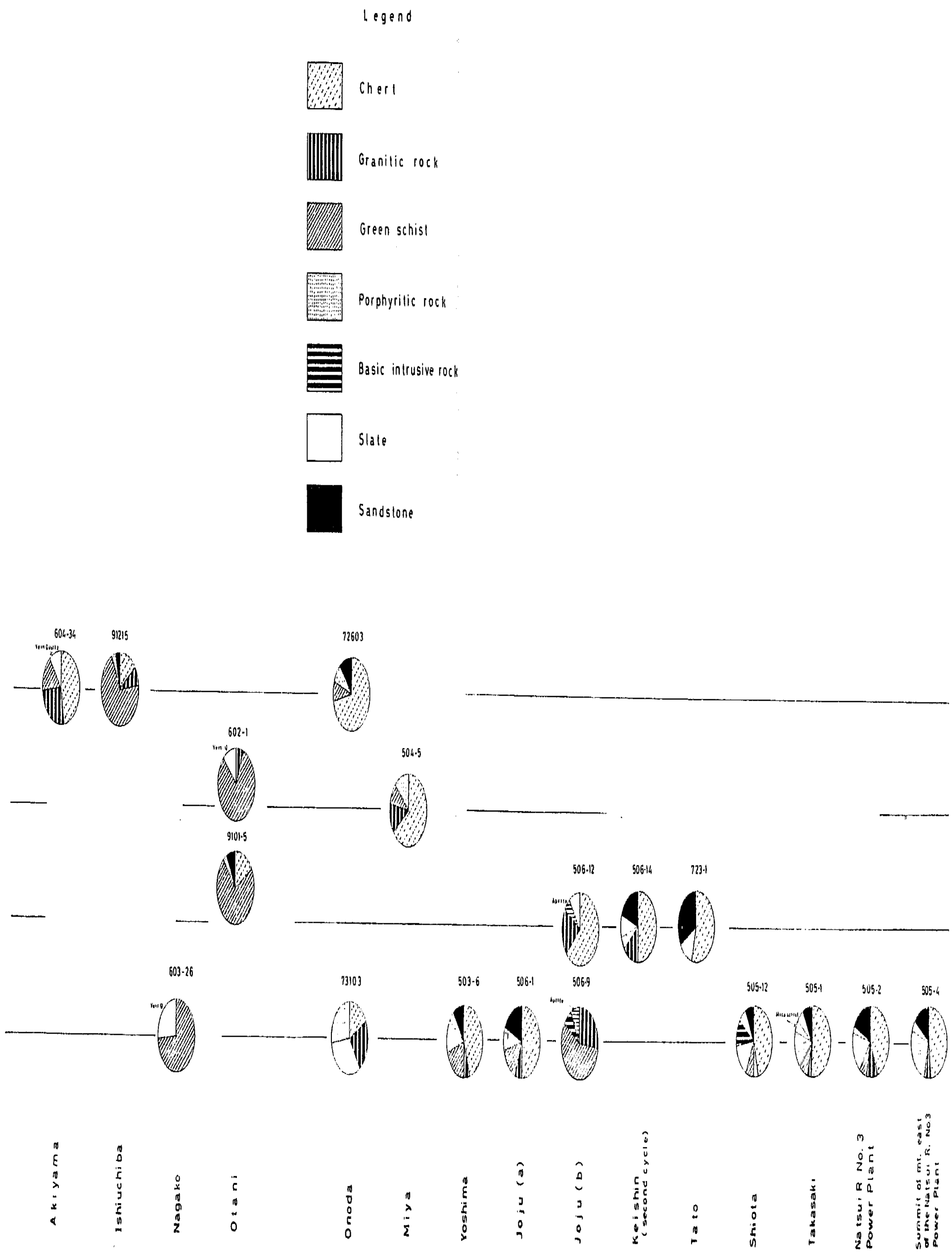
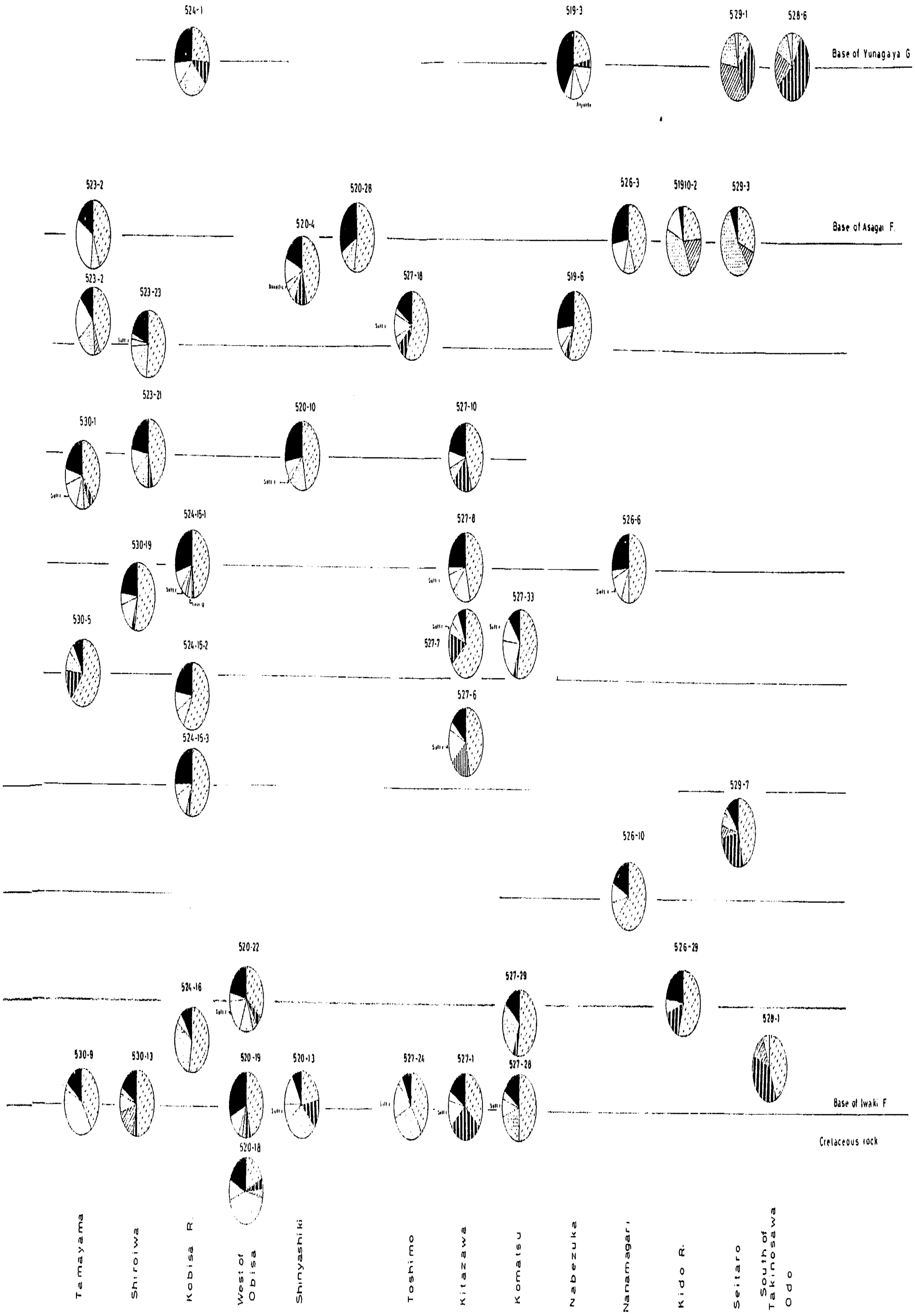


Fig. 11. Areal gravel composition



Legend
Chert
Granitic rock
Green schist
Porphyritic rock
Basic intrusive rock
Slate
Sandstone
604-34
91215
72603
602-1
504-5
9101-5
506-12
506-14
723-1
603-26
73103
503-6
506-1
506-9
505-12
505-1
505-2
505-4
Akiyama
Ishiuchiba
Nagako
Otani
Onoda
Miya
Yoshima
Joju (a)
Joju (b)
Keishin
(second cycle)
Tato
Shiota
Takasaki
Natsui R No. 3
Power Plant
Summit of mt. east
of the Natsui R. No3
Power Plant

Fig. II. A1



eal gravel composition

It is thought that the supply of the gravels of the places mentioned above are from considerable restricted provenances. The pyroxenite and green schist gravels are generally low in durability and both are of disk shape, and from such evidence it is difficult to consider that they were supplied by long distance transportation. The two gravels of very restricted distribution mentioned above that coincide with the distribution of the basement rocks of pyroxenite and green schist at the early stage of Iwaki deposition are thought to have had relation therewith.

In spite of the chert gravel having a high durability, content ratio shows no change, the porphyry gravel has a durability as high as chert but shows remarkable change in areal composition. This is thought to result from the difference of the supply of gravels and the areal difference in distribution of the porphyry rocks in the basement. Considering from the evidence given above, an intimate relationship should exist between the supply of the porphyry gravels and the basement geology at the early stage of Iwaki deposition.

Considering the basal conglomerate, there was observed no definite texture as imbrication or orientation of the long axis of the gravels, probably because they are mostly rounded or subrounded in shape. But from the eastward dips of the cross stratification in the sandstone overlying the basal conglomerate, the provenance area can be inferred to have been west of the sedimentary basin. In the westward area the basement rocks are distributed, and it is thought that the gravels were mostly supplied from the basement rocks of the hinterland then existing.

Although chert has not been recorded from the present provenance area, there is no evidence for assuming that no chert existed in the part eroded away of the original provenance.

The compositions of the conglomerate are plotted in the triangle diagram modified from Pettijohn (1957). In the diagram (Fig. 13), the points are relatively concentrated in the S-M region due to the high content of the chert gravels. The points for the conglomerate of the Futaba area are accumulated at the base line of the triangle diagram and those of the Iwaki area to the central part probably owing to the difference in transportation and complexity of the basement rocks between the Futaba and Iwaki areas.

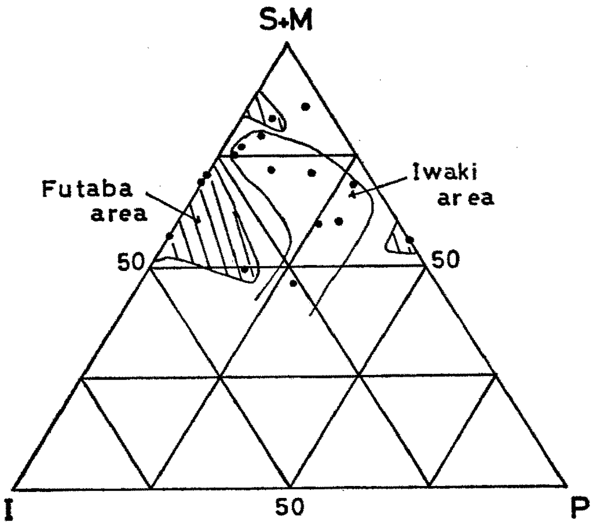


Fig. 13. Triangle representation of the gravel composition of the basal conglomerate of the Iwaki Formation.
S; Sedimentary rocks, P; Plutonic rocks, I; Intrusive rocks

B) The Conglomerate Bed except the Basal Conglomerate

Although the lower part of the basal conglomerate shows remarkable changes in the composition of its gravels, that of its upper part shows no change in its gravel compositions as shown in Fig. 11. The composition consists of generally 50 percent chert, 15–20 percent sandstone, and nearly 5 percent granite, porphyry and slate gravels. The rather homogeneous composition of the upper part of the basal conglomerate is considered to be due to the addition of the sediments from the lower horizon and to the increased area of supply. However at some places differences are recognized, namely at

Kitazawa in the South Futaba area, there is a high content ratio of granite gravel from the lower to upper horizon, compared with other places. Thus it is inferred that the exposure of the granite in the provenance area must have been extensive.

Along the Seitaro and Kido River routes in the North Futaba area, the addition of green schist gravel shows the composition of gravel to be different from the other places. At Miya and Onoda in the Iwaki area, all conglomerate beds from the lower to middle parts contain green schist gravels. In the Taga area, there is a decrease of the content ratio of the chert gravel with an increase of green schist content. Along the Nagako route in Nakoso, Iwaki City, the basal conglomerate overlying the buried hill consists of green schist gravels the same as that making the buried hill; vein quartz gravel is rare.

Basaltic andesite gravel has been found in the uppermost conglomerate bed of Shinyashiki in the South Futaba area.

C) The Basal Conglomerate of the Asagai Formation

In the Futaba area, the basal conglomerate of the Asagai Formation overlies the upper part of the Iwaki Formation with diastem. The gravel composition of the conglomerate in the Asagai Formation is interpreted as reflecting the change of the regional supply at the early stage of dissection of the provenance area. The composition of the basal conglomerate of the Asagai Formation (Fig. 14) is similar to that in the area from Hattachi beach of Yotsukura-machi to the Nanamagari route of Naraha-machi. Namely, the chert gravel ratio is nearly 50 percent, and sandstone and porphyry is 15–20 percent. But at the northern part from Osaka, North Futaba area, the porphyry gravel content ratio has a tendency of increasing and especially at the Kido River and along the Seitaro route the conglomerate contains green schist gravel and is different from that in the South Futaba area in this respect. The basal conglomerate of the Iwaki Formation, and that of the Asagai are thought to reveal the geology of the area during the early stage of deposition.

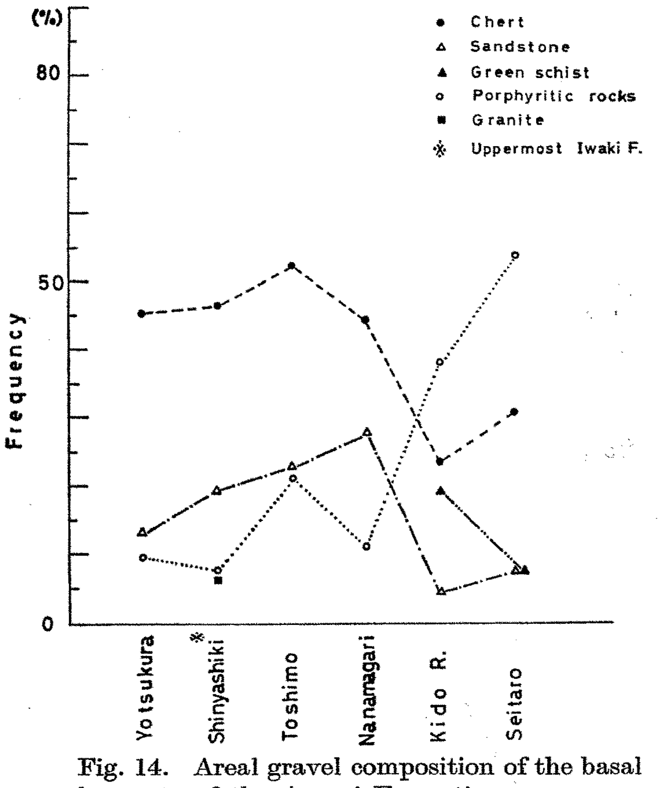


Fig. 14. Areal gravel composition of the basal conglomerate of the Asagai Formation

iii) Discussion

In considering the distribution of the basement rocks during the age of Iwaki deposition from the composition and content ratio of the conglomerate, the assemblage of the gravel species has valuable criteria. The content ratio of the gravel species is thought to be under the control of durability, transportation distance, distribution and development of the provenance rocks.

The conglomerate of the Iwaki Formation contains chert gravel of high durability but chert is not distributed in the provenance area at present. The provenance area of the gravels is judged to be westward of the sedimentary basin as is inferred from the eastward dipping cross stratification in the sandstone covering the conglomerate.

The area of distribution of the low durable gravels as granite, green schist and pyroxenite though the actual content is of low ratio, does not coincide with the content ratio, but with the exposed area of those rocks in the present provenance area. For such reason the paleogeology of the provenance area is thought to have been similar to the present. Despite the wide distribution and high durability, the porphyry gravel content ratio shows notable regional difference in composition. The places showing a high content ratio coincides with the distribution of the present porphyry rocks in the basement area, and this may support the assumption mentioned above. Concerning the origin of the chert gravel which occupies almost 50 percent in ratio content in the conglomerate, discussion will be given in a later section. However the supply of the chert gravel may be interpreted in comparison with the other kinds of gravels and the provenance rock of chert may have originally existed but was subsequently eroded away. Problems still remain concerning the provenance rocks of the sandstone and chert gravels.

2. SANDSTONE

1) Methods of Study and Samples

With regard to the sandstone, analyses of the grain size distribution, mineral composition and grain shape were made, and studies advanced to the supply of the sediments, environment of the depositional basin and whether the difference of the provenance can be recognized from the lateral and vertical changes of the composition, and if the change in composition can aid in correlation. The details are given in the following lines.

A) Grain size distribution: The grain size distribution was analyzed by the methods of sieving, settling velocity and thin section. The sandstone of the Iwaki Formation is so well consolidated that the analysis was done by the thin section method (Krumbein, 1935; Greenman, 1951a, b; Rosenfeld *et al.*, 1953; Friedman, 1958; Folk, 1966; Ramesam, 1966).

In the analysis about 300 grains are estimated in an axis according to the Ramesam (1966) using the mechanical stage, and the grain size distribution was calculated by the square method. Namely according to Table 2, an example of eight size intervals, the grain size distributions have been estimated in the lateral clan and basing on the data the cumulative curves in probability ordinates were drawn to examine the property of the grain size distribution.

B) Mineral composition: The mineral composition was analyzed using the same grains of the size analysis at the time of the estimation of the grain size. The composition was calculated by the square method shown in Table 2 of the lengthwise clan of each minerals.

C) Grain shape: The compositional grain shape was analyzed on over 50 pieces of minerals according to Powers' classification (1953). And the grains were classified into six grades as, well rounded, rounded, subrounded, subangular, angular and very angular.

The samples of the thin sections prepared for the analysis were collected from the outcrops of the rocks and cylothems along each route according to their characteristics. The thin section was of the grains sectioned parallel to the bedding plane and in graded sandstone those perpendicular to the bedding plane were also made. The collecting points of the samples are shown in Figs. 5, 6 and 7.

Table 2. Table of calibration of the grain size distribution and mineral composition of sandstone (Example of four minerals and eight size interval)

Size \ Minerals	A	B	C	D		Matrix	
a	l_1	m_1	n_1	o_1	Sum a′	q_1	Sum a
b	l_2	m_2	n_2	o_2	Sum b′	q_2	Sum b
c	l_3	m_3	n_3	o_3	·	·	·
d	l_4	m_4	n_4	·	·	·	·
e	l_5	m_5	·	·	·	·	·
f	l_6	·	·	·	·	·	·
g	l_7	·	·	·	·	·	·
h	l_8	m_8	n_8	o_8	Sum h′	q_8	Sum h
	Sum A	Sum B	Sum C	Sum D	Sum X′	Sum Mat.	Sum X

"$l_i, m_i, n_i, \cdots q_i$=number"

Grain size: Sum a′=Square Value of *Size a*

$$=\left(\frac{a}{2}\right)^2 \times \Sigma(l_1+m_1+n_1+o_1) \quad \text{(exclude Mat. } q_1\text{)}$$

$$\text{Sum b}'=\left(\frac{b}{2}\right)^2 \times \Sigma(l_2+m_2+n_2+o_2) \quad \text{(exclude Mat. } q_2\text{)}$$

and so on ·····

Matrix include

$$\text{Sum a} = \left(\frac{a}{2}\right)^2 q_1+\text{Sum a}', \text{ equaly Sum b, Sum c}$$

$$\text{Sum X=Sum a+Sum b+Sum c++Sum h}$$

$$\frac{\text{Sum a}'}{\text{Sum X}} = \text{Square peacentage of } \textit{Size a} \text{ in a Sample}$$

$$\frac{\text{Sum b}'}{\text{Sum X}} = \quad〃 \quad 〃 \quad \textit{Size b}$$

$$\frac{\text{Sum X-Sum X}'}{\text{Sum X}} = \quad〃 \quad \text{Matrix}$$

Mineral composition

$$\text{Sum A}=\sum_{n=1}^{8} l_i \times \left\{\left(\frac{a}{2}\right)^2+\left(\frac{b}{2}\right)^2+\left(\frac{c}{2}\right)^2+\cdots+\left(\frac{h}{2}\right)^2\right\}$$

=Square Value of Mineral A

Sum B= 〃 B

$$\frac{\text{Sum A}}{\text{Sum X}} = \text{Square percentage of Mineral A in a Sample}$$

2) Study on the Grain Size Distribution

i) The Grain Size Distribution

The cumulative curves of the grain size distribution of the sandstone of the Iwaki Formation were divided into four types. The characters of the each distribution curve are as follows;

a) Type I (Fig. 15): Type I is in contact with the basement rocks. It is a typically "Gainome" sandstone and a very clayey coarse grained sandstone. The distribution curve has a roundish curve from the coarse to fine grained part and a sorting value of 1.5. The samples of this type were recognized in the lower part of the sequence at Joju, Miya, Hakumai and Ishiuchiba route (Pl. 9).

b) Type II (Fig. 16): Type II is the pebbly coarse grained sandstone. It is

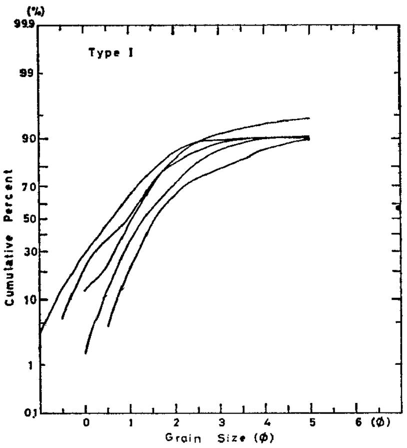


Fig. 15. Cumulative curves of Type I

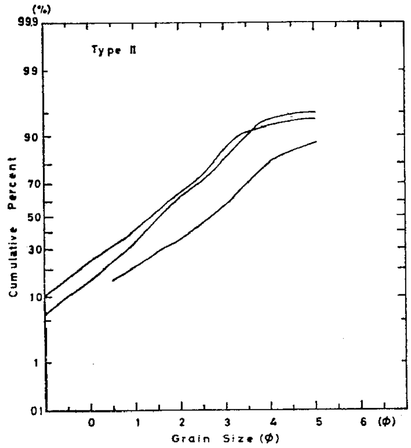


Fig. 16. Cumulative curves of Type II

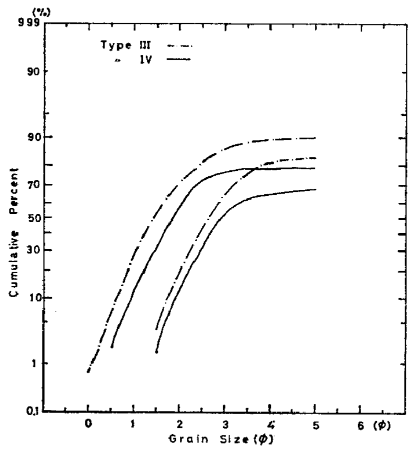


Fig. 17. Cumulative curves of Types III and IV

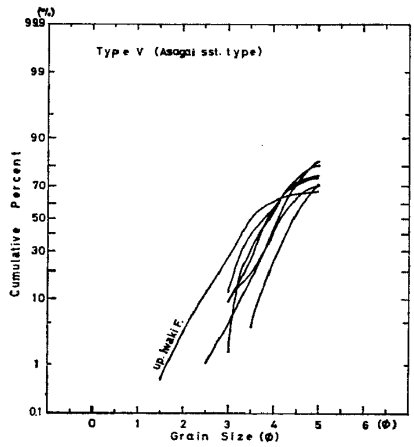


Fig. 18. Cumulative curves of Type V

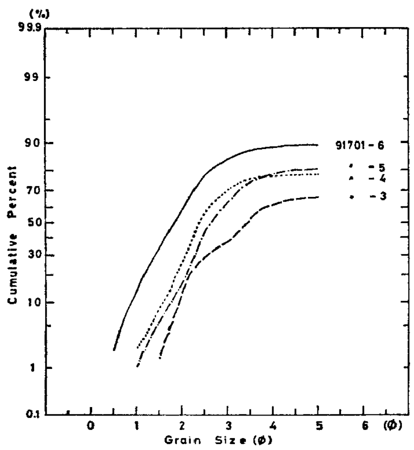


Fig. 19. Change of the cumulative curves in a unit of the cyclothem along the Ishiuchiba route

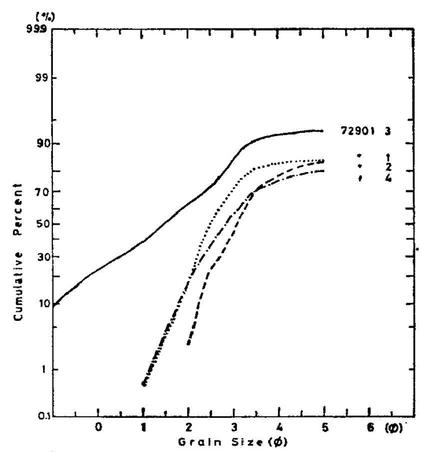


Fig. 20. Change of the cumulative curves in a graded sandstone along the Shiramizu route

developed at the basal part of the cyclothem and graded sandstone. The curve shows a straight line of low angle and the sorting values range from 1.8 to 2.0 (Pl. 9).

c) Type III (Fig. 17): With Type IV, it is a characteristic grain size distribution of the sandstone of the Iwaki Formation. The amount of the matrix is small and the sorting value ranged between 0.7 to 0.8. The curve has a high angle in the coarse grained part (Pl. 10).

d) Type IV (Fig. 17): Compared with Type III, the amount of the matrix increased slightly, the sorting value exceeds 1.0 and the cruve is similar to that of Type III but slightly roundish (Pl. 11).

e) Type V (Fig. 18): This type is recognized in the sandstone of the Asagai Formation and shows uniform distribution. It can be distinguished from the fine grained sandstone of Type IV (Fig. 18). The mean size is over 3.0 ϕ and the sorting value nearly 1.0 (Pl. 11).

Next, an examination was made on the grain size distribution in a sequence of a cyclothem. In the sequence of one unit of a cyclothem as shown by 91701–6,5,4,3 (Fig. 19) chosen from along the Ishiuchiba route in the Taga area, their arrangment is of the Type III and IV, lacking Type II. From the lower to the upper horizon, the grain size distribution changes from Type III to Type IV and at the same time the mean size decreases (as the curve moves from left to right). The amount of the matrix increases progressively and the sorting values tend to change to bad as 0.8 to 1.0. In the graded sandstone in the upper part of the Iwaki Formation, along the Shiramizu route in the Iwaki area, as shown in Fig. 20, 72901–1 to 4 and 3 to 2, the distribution of the former changes from Type III to IV and the latter from Type II to IV.

Visher (1969) studied on the grain size distribution of sandstone of both Recent and ancient sedimentary environments and classified them into size distribution types. The Type III and IV sandstones of the Iwaki Formation coincide with Visher's distribution curve for a natural levee, minor channel, fluvial and deltaic environment.

ii) Grain Size Parameters and Relationships

The graphic method was used to examine the grain size distribution and for calculation many formula have been proposed by Udden (1914), Trask (1930), Krumbein (1936), Inman (1952), Folk (1954), Folk and Ward (1957) and McCommon (1962).

In the present study, Trask's formula (1930) was employed to estimate the parameter of the analyzed samples, and the phi unit was used (Krumbein, 1936) in calculation. The sorting value revised by McCommon's formula (1962) was used. The parameters of the samples were estimated according to Inman's formula (1952). If the sorting is not bad, the characteristics and parameters of the grain size distribution may be calculated as done by Friedman (1962 b) and McCommon (1962). As shown in Figs. 21 and 22, the relationships between Trask's and Inman's formulas calculated on the two parameters of mean size and sorting value are shown. In the present study, the result of the analysis along each route is shown in Figs. 23, 24, 25 and 26. The characters of the grain size distribution of the each route are as follows.

Along the Takinosawa and Seitaro routes (North Futaba area), the sediments mostly consisted of very fine grained sandstone with a mean size value of nearly 3.0 ϕ. The sorting value was nearly 1.0 and no change of the value associated with change of the mean size existed.

Along each route of the South Futaba area, pebbly sediments are well developed and sandstone is scarce. Though the samples are few those from along the Kobisa River, Shiraiwa and Tamayama routes show that the mean size becomes coarse compared to the samples of the North Futaba area though the sorting value does not change and the value was about 1.0 (Fig. 23).

Along the Shiramizu route (Iwaki area), the mean size value dispersed but showed the status of graded bedding. The sorting values ranged from 1.0 to 1.5 in general, and some of the samples from the upper part of this sequence showed the value 0.7 to 0.8 (Fig. 25).

At Takasaki (northern Iwaki area), the sandstone associated with the conglomerate in the lower sequence showed coarse feature, and the value ranged from 0.5 to 0.1 ϕ. In the Gotanda district where the upper part of the Iwaki Formation is developed, the sandstone is very fine grained and the mean size value was 3.0 ϕ.

The sandstone of these two districts in the northern Iwaki area, show change in the mean size and ranged from 0.5 to 3.0 ϕ but the sorting value showed no change and was nearly 0.9 (Fig. 24).

Along the sequence of the Ishiuchiba route (Taga area), the mean size values show graded features and the value ranged from 0.5 to 3.0 ϕ. The sorting value was almost always 0.8 to 1.0 (Fig. 26).

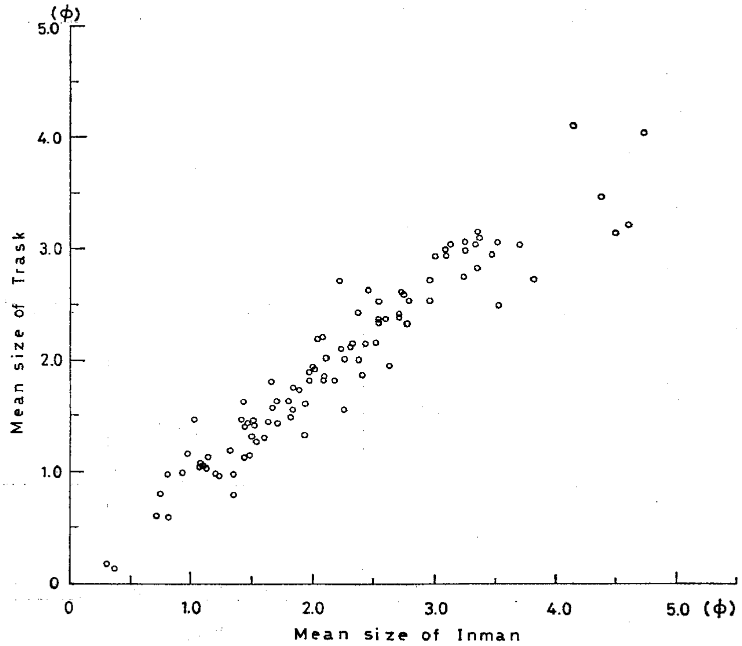


Fig. 21. Relationship between the mean grain size according to Inman and Trask

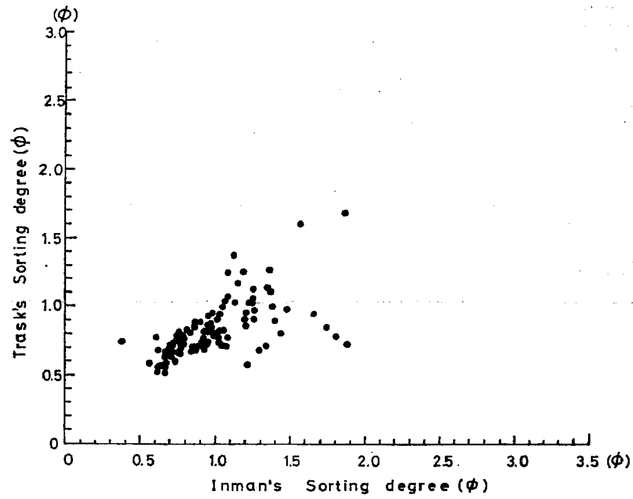


Fig. 22. Relationship between the sorting degree of Inman and Trask

Along the Otani route, fine grained sandstone is distributed and its mean size values are 2.5 to 3.0 ϕ and the sorting value is similar to the above mentioned places.

Along each route as mentioned above the mean size of a sequence of sediments shows cyclothemic arrangement and graded bedding. The sorting value is nearly 1.0 except for the Type III sandstone which has the sorting value of 0.7 to 0.8.

The skewness of the grain size distribution of the sandstone is mostly positive and values are 0.2 to 0.5, so the grain size distribution has a tail in the fine grained part, and it can be interpretated that the sorting did not proceed sufficiently.

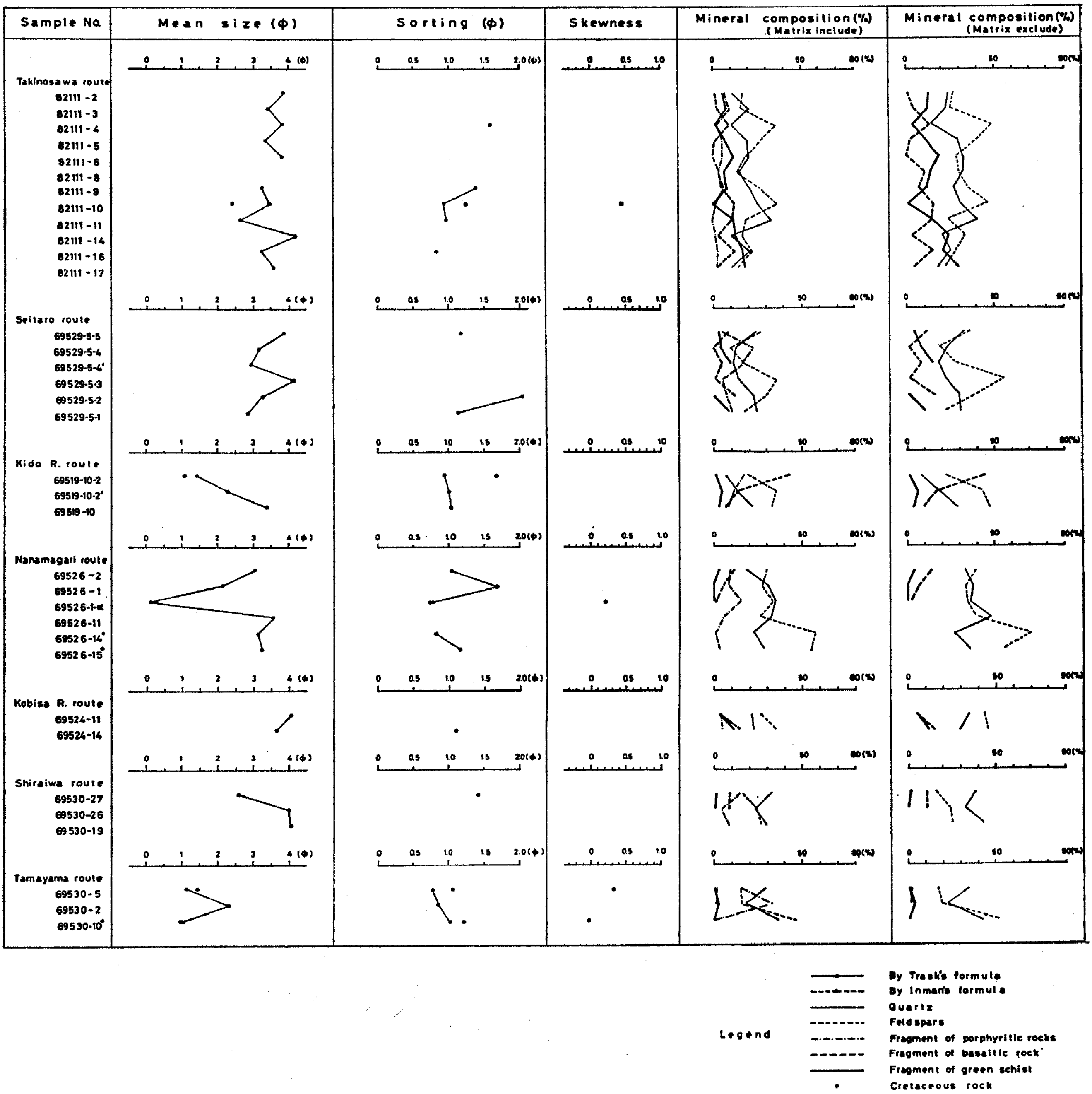


Fig. 23. Sequence of the mineral composition and grain size distribution of sandstone in the Futaba area

The sandstone of the Iwaki Formation change in their grain size but the sorting and skewness values are rather uniform, the former being 0.9 to 1.2 and the latter 0.2 to 0.5, so the sandstone is defined as moderately-poorly sorted and fine skewed sandstone (Friedman, 1962b; Folk, 1965).

The relationship between mean size and sorting value (Fig. 27) indicates positive correlation. In order to interpret the paleoenvironment from the grain size distribution, Inman and Chamberlain (1955) and Friedman (1961, 1962 b) studied the Recent and ancient sediments and classified the characteristics of the grain size distribution. In the

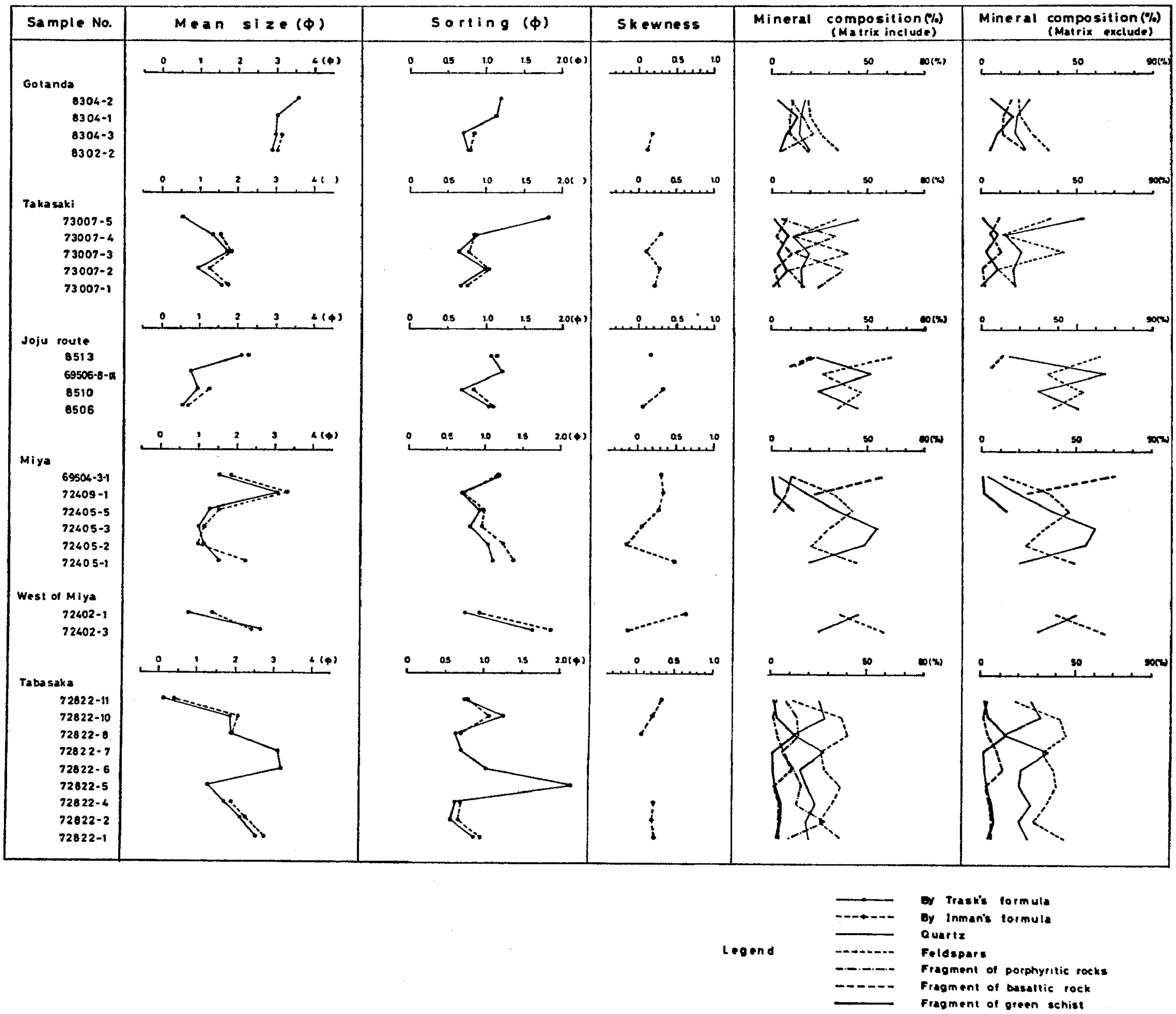


Fig. 24. Sequence of the mineral composition and grain size distribution of sandstone in the Iwaki area

present study, the calculated data according to Inman's formula are plotted to seek the relationship and distribution on a chart of sorting value versus skewness to reconstruct the paleoenvironment (Figs. 28, 29). The result shows that all of the samples fall within the river sand area, and that there are some samples falling near the boundary of marine and river sands.

iii) C-M Pattern Analysis

To study the paleo- and recent sedimentary environment from measurement of the grain size distribution of the coarsest size (1 percentile) and mean size (50 percentile), the C-M pattern was proposed by Passega (1957). Based on this analysis, Bull (1962), Passega (1964), Warner (1966), Royse (1968), Passega and Byranjee (1969) studied and examined many sedimentary environments. In the present study, this method from the data of the present day sediments is incorporated in the paleoenvironment.

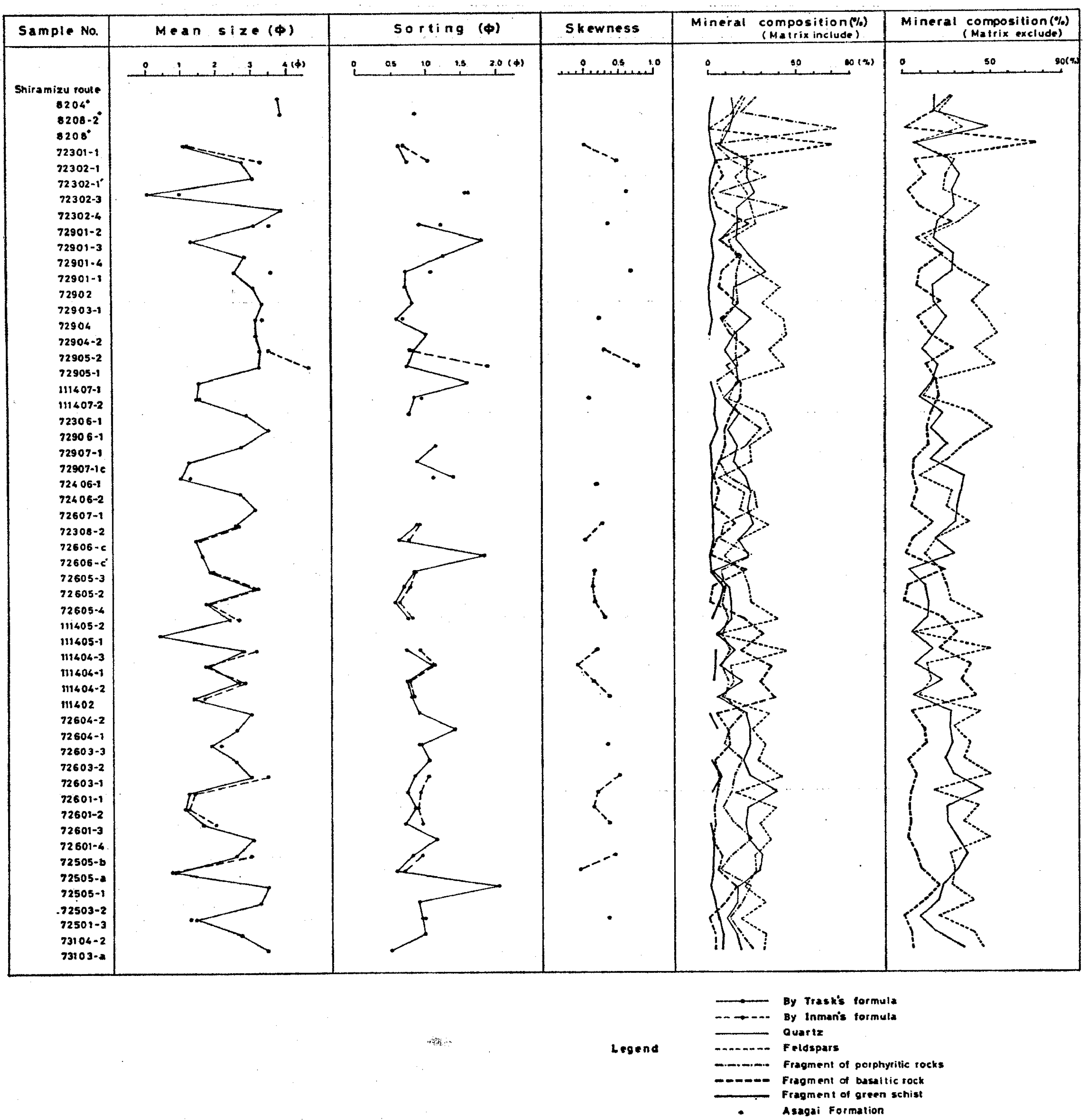


Fig. 25. Sequence of the mineral composition and grain size distribution of sandstone in the Shiramizu route of the Iwaki area

Although the values of authors slightly differ from one another, the feature can be drawn as shown by Passega (Passega, 1964 text-fig. 1), from his study of the Mississippi River (Fig. 30). Each segment in the figure (Fig. 30) is as follows:

T: The sediments formed by pelagic suspension.
SR: The sediments formed by uniform suspension.
RQ: The sediments transported as a graded suspension.
QP: The sediments correspond to those of point Q, to which rolling adds a small

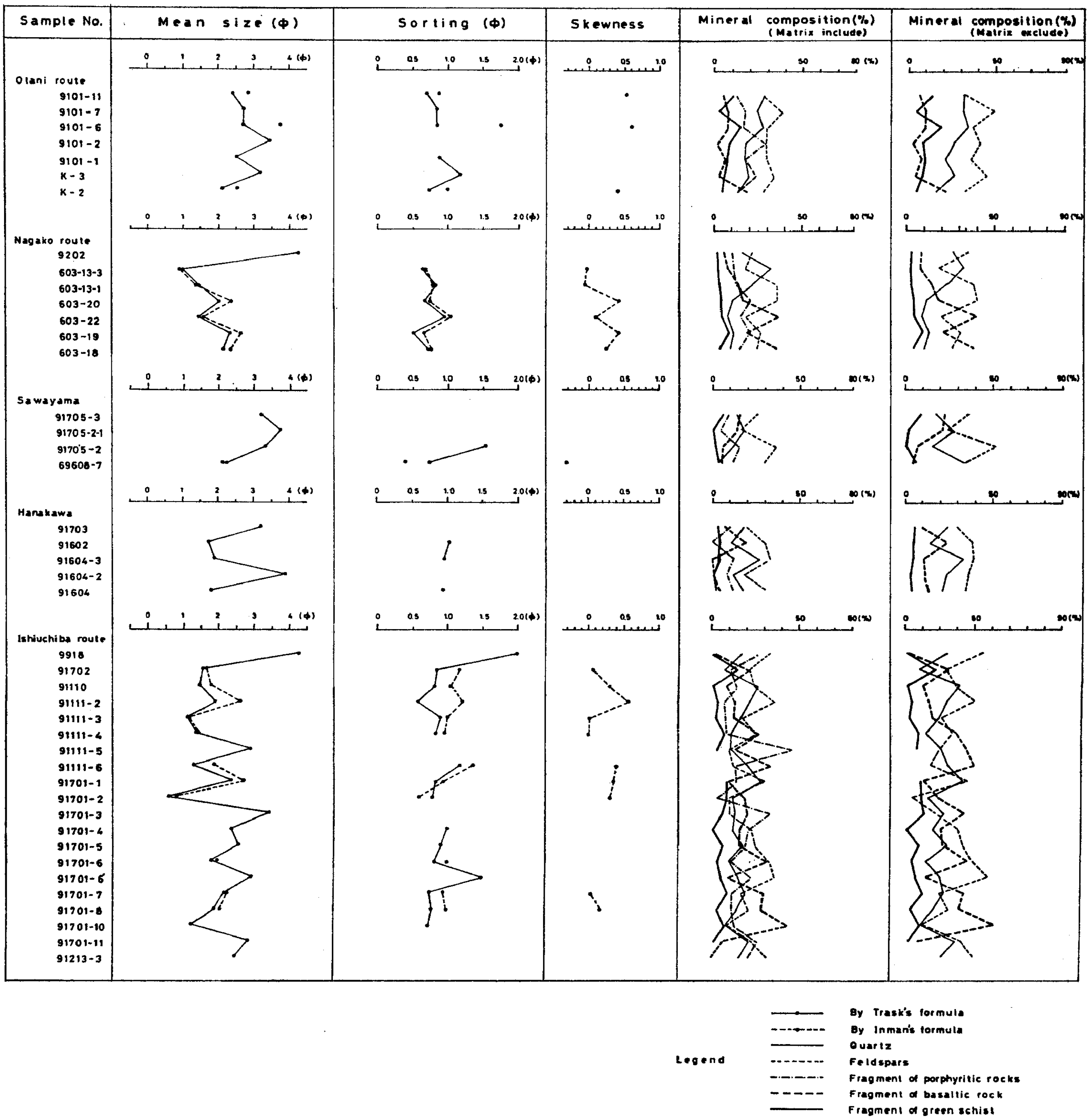


Fig. 26. Sequence of the mineral composition and grain size distribution of sandstone in the Taga area

amount of grains which affect the value of C without change of M.

PO: Reflect the increasing amount of rolled material.

ON: Almost entirely transported by rolling.

Bull (1962) interpreted the segment RQ for the sediments formed by braided stream deposition and the segment QP by stream channel deposition.

The C-M pattern analyses of the sandstone of the Iwaki Formation are shown in Figs. 31 to 36. If it is possible to apply the C-M pattern to the sandstone of the Iwaki

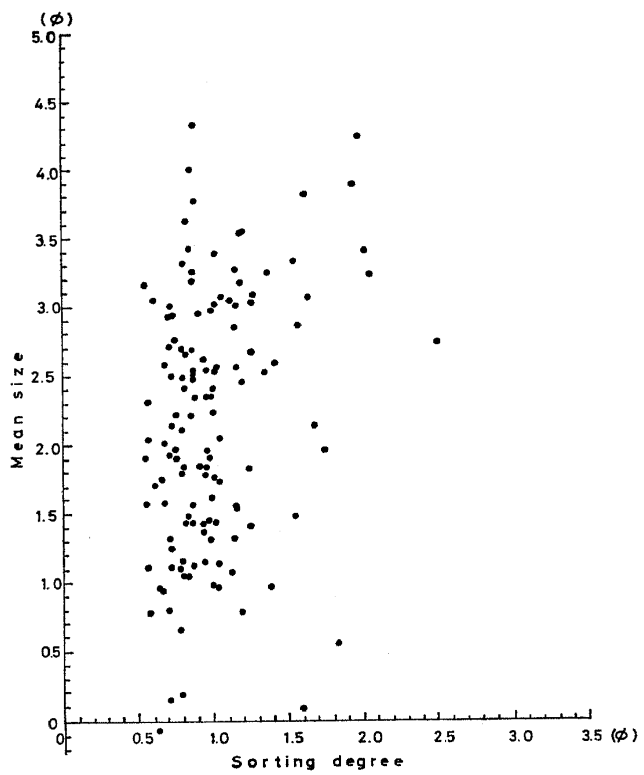


Fig. 27. Relationship between mean size and sorting degree of sandstone

Formation, obviously most of the samples fall in the QR segment parallel to the C=M line, and partly on the QP segment.

The C-M pattern of the sandstone of the Iwaki Formation of the Iwaki area, shows that the samples from the Takasaki district representing the lower horizon in this region are near the point P in the segment PQ and the samples from Gotanda that represent the upper part of this district near the point R in the RQ segment. The sediments have a tendency from the lower to the upper horizon, to change from channel like deposits to suspended load deposits. The sandstone of the Asagai Formation was deposited in a shallow marine environment from the occurrence of its marine molluscan fossils (Hatai and Kamada, 1950) and falls in the middle part of the segment SR to RQ, showing the deposition of suspended load.

The change of the C-M pattern in a cyclothem unit was examined with relation to the samples on which the grain size distribution was studied. The C-M pattern

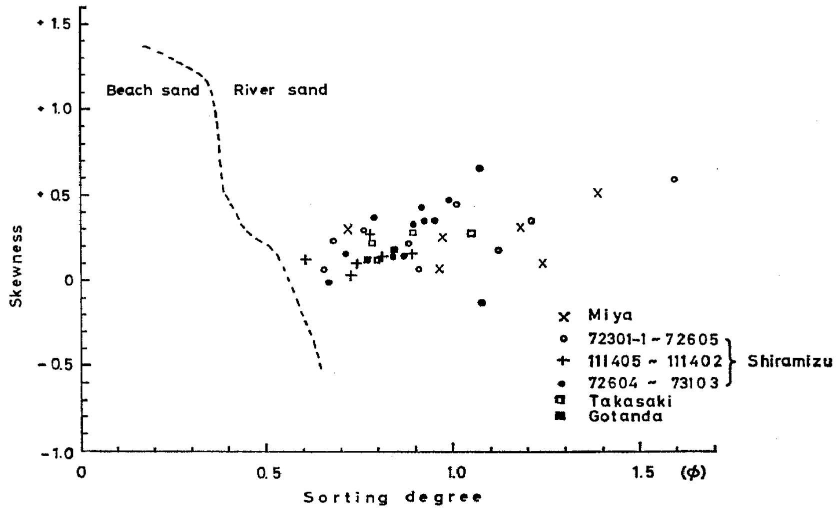


Fig. 28. Relationship between sorting degree and skewness of sandstone in the Iwaki area, and the sedimentary environment as proposed by Friedman (1961).

of it shows that from the lower to the upper part of one unit, the pattern changes from rolling matter in mixing stream channel deposits to the sediments of suspended load (Fig. 36).

If the C-M pattern can be applied to the sandstone of the Iwaki Formation, the interpretation is as follows; almost all of the sandstones of the Iwaki Formation fall in the RQ segment as deposited by graded suspension and by braided stream (Bull, 1962). The coarse grained sediments at the basal part of the cyclothem unit and the graded sandstone, are plotted in QP segment and interpreted to have been supplied by rolling in channel.

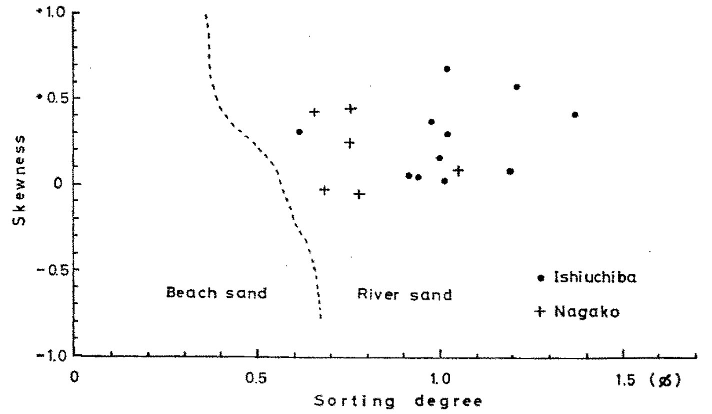


Fig. 29. Relationship between sorting degree and skewness of sandstone in the Taga area, and the sedimentary environment as proposed by Friedman (1961)

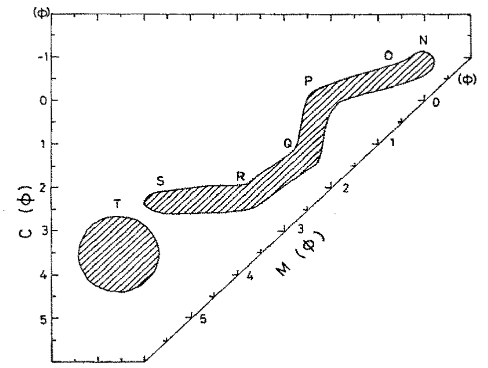


Fig. 30. Typical tractive current deposit according to Passega (1964)

From the grain size analysis, the sandstone of the Iwaki Formation is dominantly of fluvial deposits as is determined from that, the sorting is not progressed and the value ranged from 0.7 to 1.5. Upholding the views are the relationship of sorting value versus skewness (Friedman, 1962), C-M pattern and Visher's grain size distribution type. However, a part of the sediments is thought to be marine sand from that, in the relationship between sorting and skewness there are sediments plotted near the marine sand region and in the C-M pattern there are samples plotted near point P.

3) Mineral Composition (Sand Size Minerals)

i) Mineral Constituents

The sand size minerals of the Iwaki Formation were quartz, feldspar, mica, amphibole, zircon, garnet, apatite and opaque minerals of magnetite, haematite, illmenite and authigenic pyrite, besides fragments of chert, green schist, porphyry, basaltic andesite, slate and other sedimentary rocks. The major constituents are as follows.

a) Quartz: Clastic quartz particle consisted mainly of monocrystalline, straight extinct quartz grain and contained slight undulatory extinct quartz in a small amount, but most of the quartz grains showed non-undulatory extinction. No undulatory extinct streched polycrystalline quartz grain was observed. The polycrystalline quartz is assumed to be derived from chert and vein quartz which probably developed in the schistose rocks, they are distinct from those assumed to be derived directly from metamorphic rocks (Blatt and Christie, 1963). The monocrystalline quartz is a major constituent of the sandstone regardless of the basement rocks as granite and metamorphic rocks, the quartz grains are included in 20 to 30 percent in the entire area.

b) Feldspar: Albite to oligoclase dominated in feldspar and besides microcline and orthoclase were rarely included and presented albite, carlsbad twin, perthite texture and zonal structure. The feldspar identified as andesine, is considered to have originated from the phenocrysts of the basaltic andesite. Feldspar generally suffered weathering and some crystals of feldspar are partly altered to clay minerals. Like the quartz grains the feldspar grain are contained in nearly 30 percent of the whole area.

c) Mica: Mica is represented by biotite, paleochroism is observed under the microscope but decolored ones exist in a small amount. The shape is scale and leaf like and it is common but the amount is small attaining nearly 0.5 to 1.0 percent.

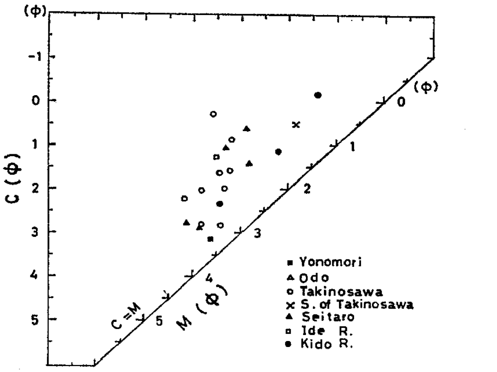


Fig. 31. C-M pattern of sandstone in the Futaba area (part 1)

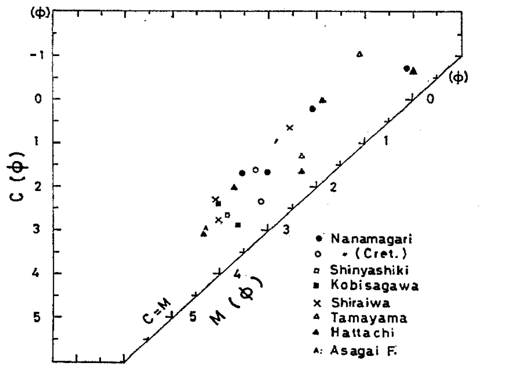


Fig. 32. C-M pattern of sandstone in the Futaba area (part 2)

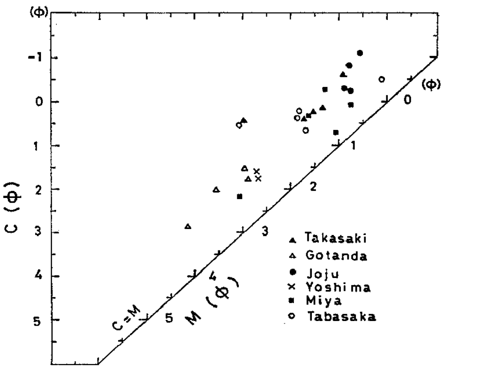


Fig. 33. C-M pattern of sandstone in the Iwaki area

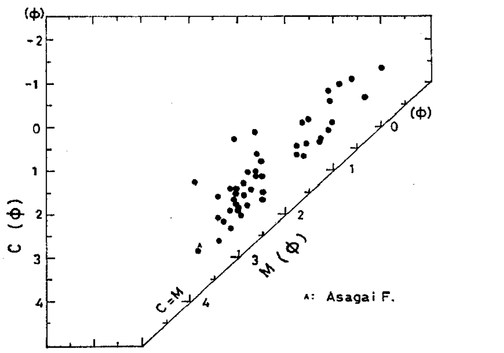


Fig. 34. C-M pattern of sandstone along the Shiramizu route in the Iwaki area

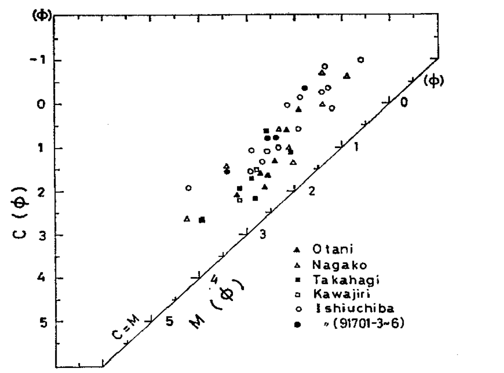


Fig. 35. C-M pattern of sandstone of the Taga area (part 1)

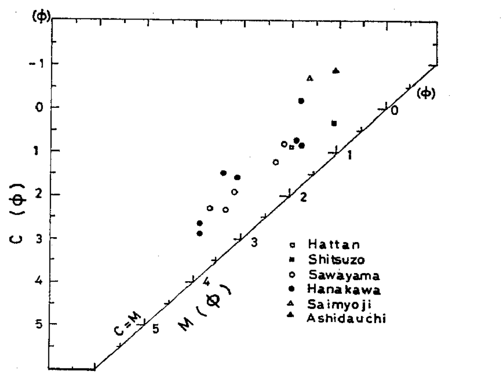


Fig. 36. C-M pattern of sandstone of the Taga area (part 2)

d) Amphibole Group: The amphibole group in the sandstone consisted of hornblende and rarely actinolite. Generally no idiomorphic grains exist. They are rounded, show good development of cleavage and the paleochroic color is green to brown. The content ratio is less than one percent but can be found in most samples like mica fragments.

e) Pyroxene: Pyroxene is of augite and shaped pillar-like. The content ratio is very low and as shown in Pl. 12, there are larger grains at 2ϕ. The source rocks of the pyroxene are thought to be gabbroic rocks and basaltic andesite.

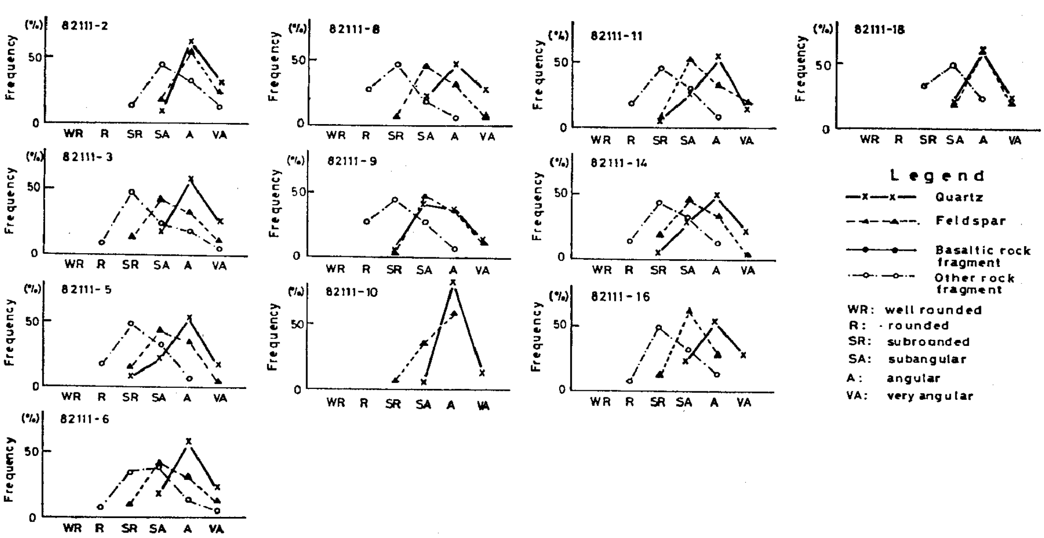


Fig. 37. Grain shape distribution of the sandstone along the Takinosawa route in the Futaba area

f) The opaque minerals as magnetite, illmenite and etc., are of very small amount but commonly contained. Garnet and zircon are very rare.

ii) Grain Shapes

The degree of the abrasion suffered is shown by the transitional change of the grain shapes in the process of transportation and such are varied in each minerals. The analyses of the frequency distribution of the six-grade shapes of Powers' scale are shown in Figs. 37, 38 and 39, their chracters along each route is as follows:

a) Shiramizu route: Quartz grains are generally angular, and subangular in a well sorted sandstone. Feldspar grains are angular like the quartz grains in the lower part of the Iwaki Formation, but in other parts the roundness exceeds that of the quartz grains, and the frequency diagram shows that subangular feldspar grains are most abundant. The fragments of basaltic andesite have a rounded shape according to Powers' scale. No well rounded grain existed. The lithic grains of chert and porphyry as well as of andesite dominated the rounded grains.

b) Along the Ishiuchiba route (Taga area): The top of the frequency distribution of lithic fragments, feldspar and quartz are divided respectively into subrounded, subangular and angular. The roundness distribution of the lithic grains are distinctly different from quartz and feldspar. Along the Otani and Nagako routes (Taga area), the data shown in Fig. 39, are recognized as the same.

Along the Takinosawa route (Futaba area) as well as at other places the frequency distribution of the roundness of quartz, feldspar and lithic grains differed from one another (Fig. 37).

Concerning the differences of the roundness, it appears from Klein's description on quartz grains that polycrystalline quartz selectively disappears in the sedimentary cycle rather than monocrystalline quartz grains, because the lithic grain is polycrystalline and tends to be more rounded. But it is difficult to consider that the difference among quartz, feldspar and lithic grain is caused only by the above characteristics because the hardness of the grain, texture, distance from the source rocks and so on, have relation on the rounding process.

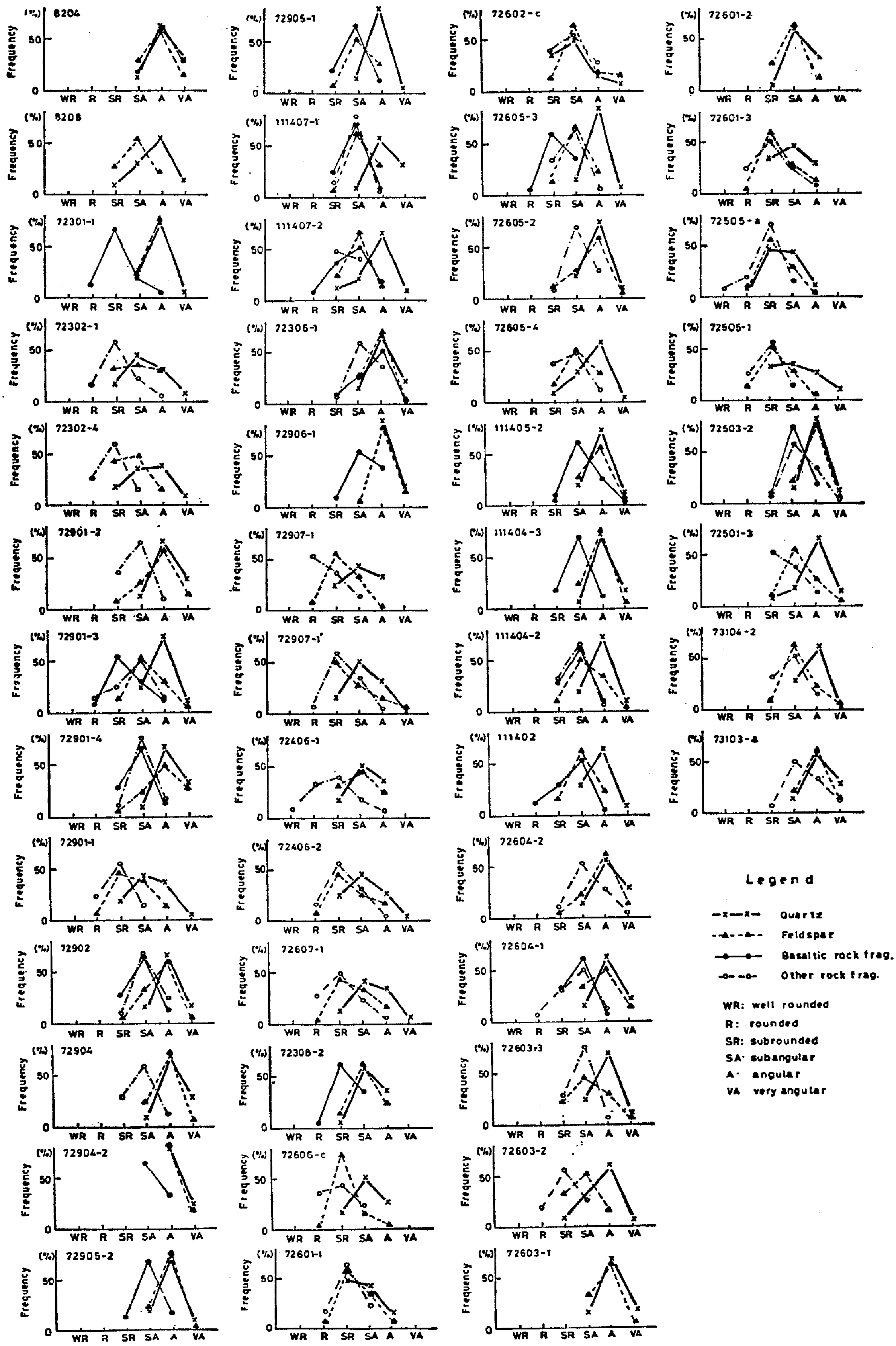


Fig. 38. Grain shape distribution of the sandstone along the Shiramizu route in the Iwaki area

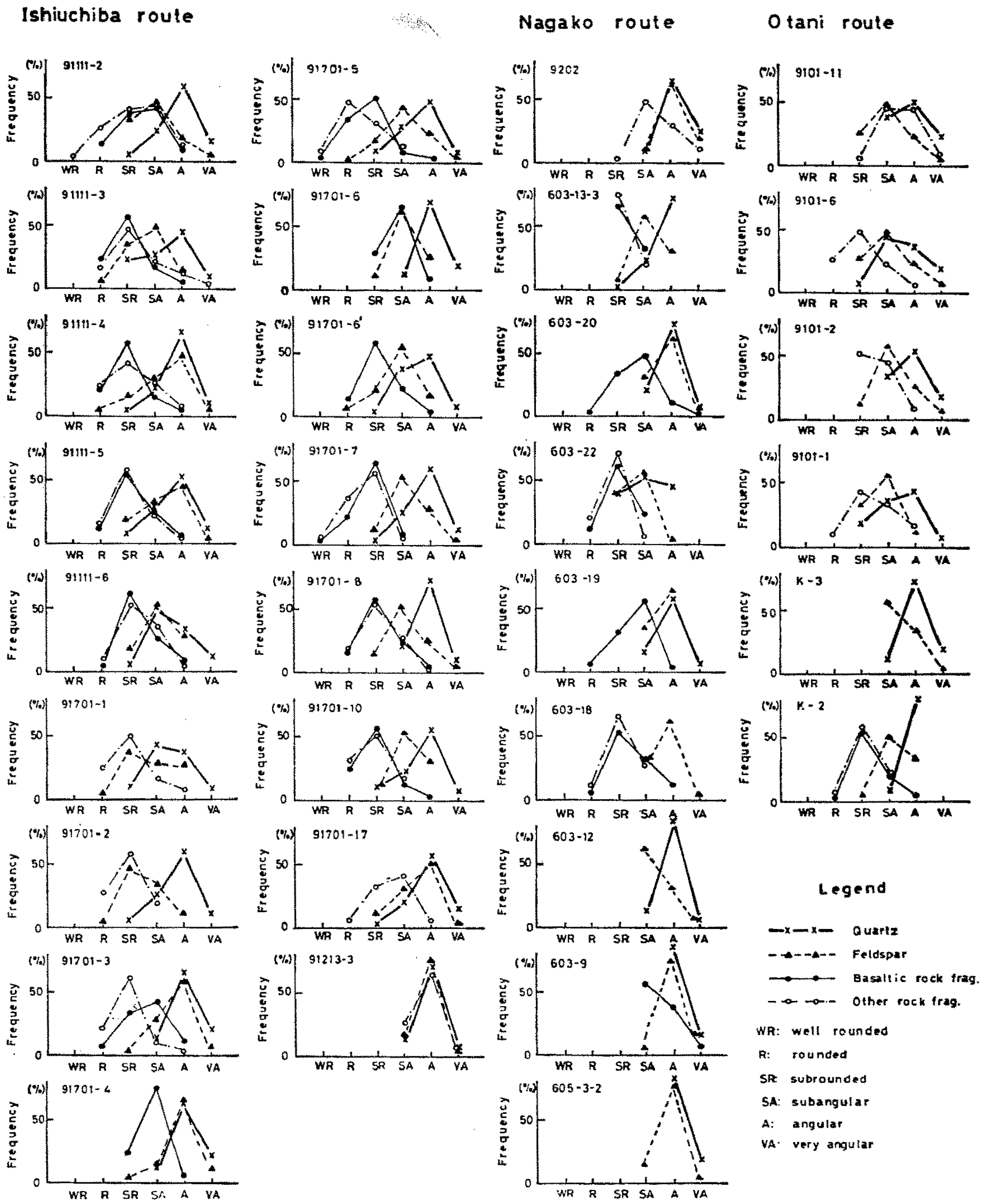


Fig. 39. Grain shape distribution of the sandstone along the Otani, Nagako and Ishiuchiba routes in the Taga area

iii) Change of the Mineral Composition

The composition of the major constituents along each route is represented by the content ratio in Figs. 23 to 26, and the matrix is defined as finer than 5 ϕ grain according to Dott (1964), and Folk (1965). The latter is useful in comparing the sand size mineral composition. The compositional features of the each route are as follows.

a) Shiramizu route: Along this typical route of the Iwaki Formation, the content ratio of quartz varies with horizon being 20–25 percent in the lower part, 15 percent in the middle and 15–20 percent in the upper. The content ratio of feldspar is nearly 30 percent in most of the samples but in the middle part of the formation with the decrease in the quartz content ratio, the content ratio of feldspar is also decreased to nearly 10 percent. The content ratio of mica and green schist fragments is merely a few percent. The other constituents, the fragments of basaltic andesite, porphyry, sandstone, slate and chert are contained in the amount of 5–10 percent and the content ratio of the matrix ranges from nearly 10 to 20 percent. But above mentioned compositions of the sand size minerals vary with the change of the matrix content ratio, so the ratio shown at the right hand of Figs. 23 to 26, calculated for excluding the matrix content shows the mineral composition and is useful for comparison of the composition with other places. The grain size is given in the same diagram. The diagram shows that the tendency of the lithic grain content ratio excluding the basaltic andesite, increases in a coarse grained sandstone (relatively the amount of quartz and feldspar decreased). Noteworthy in the compositional change along the Shiramizu route is that the amount of basaltic andesite grains partially increased obviously after the deposition of the "Honso" (main coal seam), after deposition of the Tochikubo conglomerate bed (Nakamura, 1913) and at the upper most horizon.

b) Along the Takinosawa route (North Futaba area): Quartz and feldspar grains occupied 20–30 percent of the sandstone. In this route the sandstone included green schist fragments in nearly 10 percent and in the lower part its ratio increased to nearly 20 percent. Remarkably the content ratio of the basaltic andesite grains increased partially at above the "Honso", at the middle and at the upper most horizon. Along the Seitaro route, south of the Takinosawa route, the content ratio of the basaltic andesite grains increased at the middle and uppermost horizon and also along the Kido River route in the uppermost horizon of the Iwaki Formation.

The sandstone of the Ashizawa Formation of the Cretaceous System along the Nanamagari route, contained more than 50 percent of feldspar grains and thus belongs to the arkose sandstone clan, it contains no basaltic andesite grains. The sandstone of the Iwaki Formation of this route consists of nearly 30 percent of both quartz and feldspar grains being similar in the contents to the other routes but differs from the northern routes of Takinosawa, Seitaro and Kido River in that the content ratio of green schist fragments are very small. It is thought to reflect the basement rocks. At Tamayama, the sandstone of the Tamayama Formation of the Cretaceous System is remarkably abundant in quartz and feldspar grains. The other constituents are mica and lithic fragments but the amounts are very small and so the sandstone can be classified into arkose sandstone. The sandstone contains no basaltic andesite fragments (Pl. 8).

In the Iwaki area, at Takasaki the lower part of the Iwaki Formation is variable so far as the composition is concerned (Fig. 24). The content ratio of the basaltic andesite is much increased after the deposition of the "Honso", Sample no. 73007–3. The sandstone at Gotanda in the upper part of the Iwaki Formation shows uniform composition of quartz and feldspar in 20–30 percent and the content ratios of the fragments of basaltic andesite and green schist are comparatively high being 10 and 5–10 percent respectively.

Along the Joju and Miya routes, the sediments of lowest part of the formation consist of residual soil and weathered products. The major constituents are quartz and feldspar grains that occupy 30 and 60 percent respectively. Mica fragments are contained in a small amount so the sandstone is very arkosic. The fragments of basaltic andesite appear in the sandstone after the deposition of the first cyclothem. The composition of the sandstone in the middle part of the formation distributed at Tabasaka (southern Iwaki area), consisted of 20 percent quartz, 30 percent feldspar and 10 percent of basaltic andesite.

The samples from the Otani route (Taga area) show quartz and feldspar in 20–30 percent and the content ratio of the basaltic andesite grains increased at the lower part

(Sample no. K–2). Along the Nagako route, the upper part from the middle horizon of the Iwaki Formation, shows that the content ratio of basaltic andesite fragments increases just above the buried hill. The composition of the sandstone along the Ishiuchiba route has the content ratio of, quartz 10–20 percent, feldspar 20–30 percent and green schist grains 3–7 percent. The content ratio of the basaltic andesite fragments increases just above the "Honso" and at the middle part of the formation where the ratios are nearly 40 percent.

The lithic fragments of sandstone, slate and chert are contained in almost all samples but the amount is small. The content of porphyry fragments are abundant in the sandstone of the Iwaki Formation.

As mentioned above, from the vertical compositional change along each route except the residual sediment in the granite region, the sandstone of the Iwaki Formation consists of quartz and feldspar in uniform amount of 20–30 percent. But lateraly the content ratio of the green schist grains increases where the basement rocks of green schist are distributed at the present. This may suggest the resemblance of the distribution of the basement rocks during the time of deposition of the Iwaki Formation as at present.

The importance of partial increase of the basaltic andesite fragment content ratio in three definite horizons are of value in correlation in addition to use of cyclothem. The basaltic andesite fragments are found to increase in definite horizons along the undermentioned routes in the listed areas:

		*	
Futaba Area			
	82111–8	(U)	
	82111–11	(M)	Takinosawa route
	82111–16	(L)	
	529–5–4	(U)	
	529–5–2	(M)	Seitaro route
	519–10–2	(U)	Kido River route
	524–14	(M)	Kobisa River route
Iwaki Area			
	8304–2	(U)	Gotanda
	73007–3	(L)	Takasaki
	72301–1	(U)	
	111404–2, 3	(M)	Shiramizu route
	72505–b	(L)	
Taga Area			
	K–2	(L)	Otani route
	603–22	(M)	Nagako route
	91111–6	(M)	Ishiuchiba route
	91701–10	(L)	

* U: the uppermost horizon, M: middle (after deposition of the Tochikubo conglomerate bed), L: after deposition of the "Honso"

The relationship between sorting and mineral composition shows the progress of the mineralogical maturity corresponding to textural maturity (Folk, 1965; Okada, 1968a, b; Okami, 1969). The relationship between quartz content and sorting degree of the samples along the Takinosawa route (Fig. 40) shows that the progress of sorting advances with the increase of the quartz content ratio. The relationship between feldspar content and sorting degree shows no correlation.

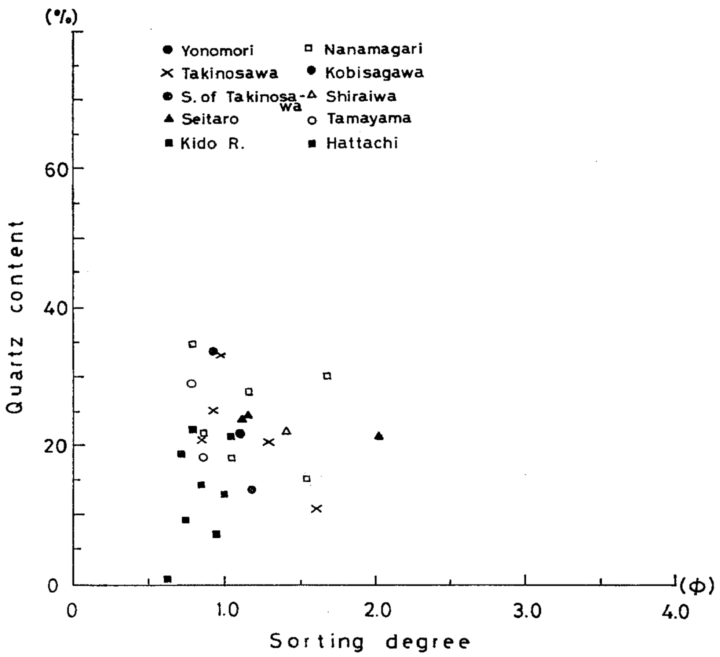


Fig. 40. Relationship between quartz content and sorting degree of sandstone in the Futaba area

iv) The Characteristics of the Iwaki Sandstone

The sandstone of the Iwaki Formation has been examined from the point of view of classification (Klein, 1963; Okada, 1968 a, b) and construction.

The sandstone of the Iwaki Formation includes many different kinds of constituents probably because of the supply was from many provenances. The sandstone is classified to determine whether the characters may suggest the regional source rocks, and for this purpose the classifications of Van Andel (1958), Okada (1968a, b) and Folk (1965) were used and the results were compared.

a) Folk's Classification: Folk used the end members of the triangle in his classification, as Q, quartz and chert; F, all type feldspar and fragment of igneous rocks; M, mica and fragments of metamorphic rocks and quartz derived from metamorphic rocks. From the non-existance of the streched undulatory extinction quartz particle derived from metamorphic rocks, the M end member is mostly of green schist fragments derived from the Gozaisho Series. Most of the sandstones are plotted in the area along Q-F line (Fig. 41 a-r) and classified as subarkose to arkose sandstone. This result shows the small content of M member and also results from the igneous rock fragments belonging to the F member. In the rich F member, the rock contradicts the character of many kinds of fragments and differs from the true arkose sandstone which consists of abundant feldspar and quartz grains as at Nanamagari (d) and Tamayama (f) (Cretaceous samples), Joju (h) and Miya (i). The sandstone of the Iwaki Formation consists commonly of quartz and feldspar with abundant lithic fragments and this kind is very difficult to represent by Folk's classification. Folk's classification is insufficient to represent the nature of the sandstone of the Iwaki Formation. The sandstone with rich M member at 20–30 as at Takinosawa (a), Seitaro (c), Otani (m) and Hakumai (o) are distributed corresponding to the green schist basement area. The characters of the sandstones suggest the paleogeology of the basement rocks at the time of deposition of the Iwaki Formation.

b) Van Andel and Okada's Classification: This classification places the end members as Q, all types of quartz (exluding chert fragments), F, all types of feldspars; RF, lithic fragments. As shown in Fig. 42, the plotted points are concentrated at the central part of the triangle diagram. The arkose sandstones in the Cretaceous System and Iwaki Formation as at Joju (h) and Miya (i) are plotted along the area of Q-F line. The nature of the sandstone of the Iwaki Formation is well represented. The sandstone of the Iwaki Formation is colored dirty and includes abundant lithic fragments which are not expected in the area of the granite basement, but can be interpreted as of mixing of the pyroclastic rocks.

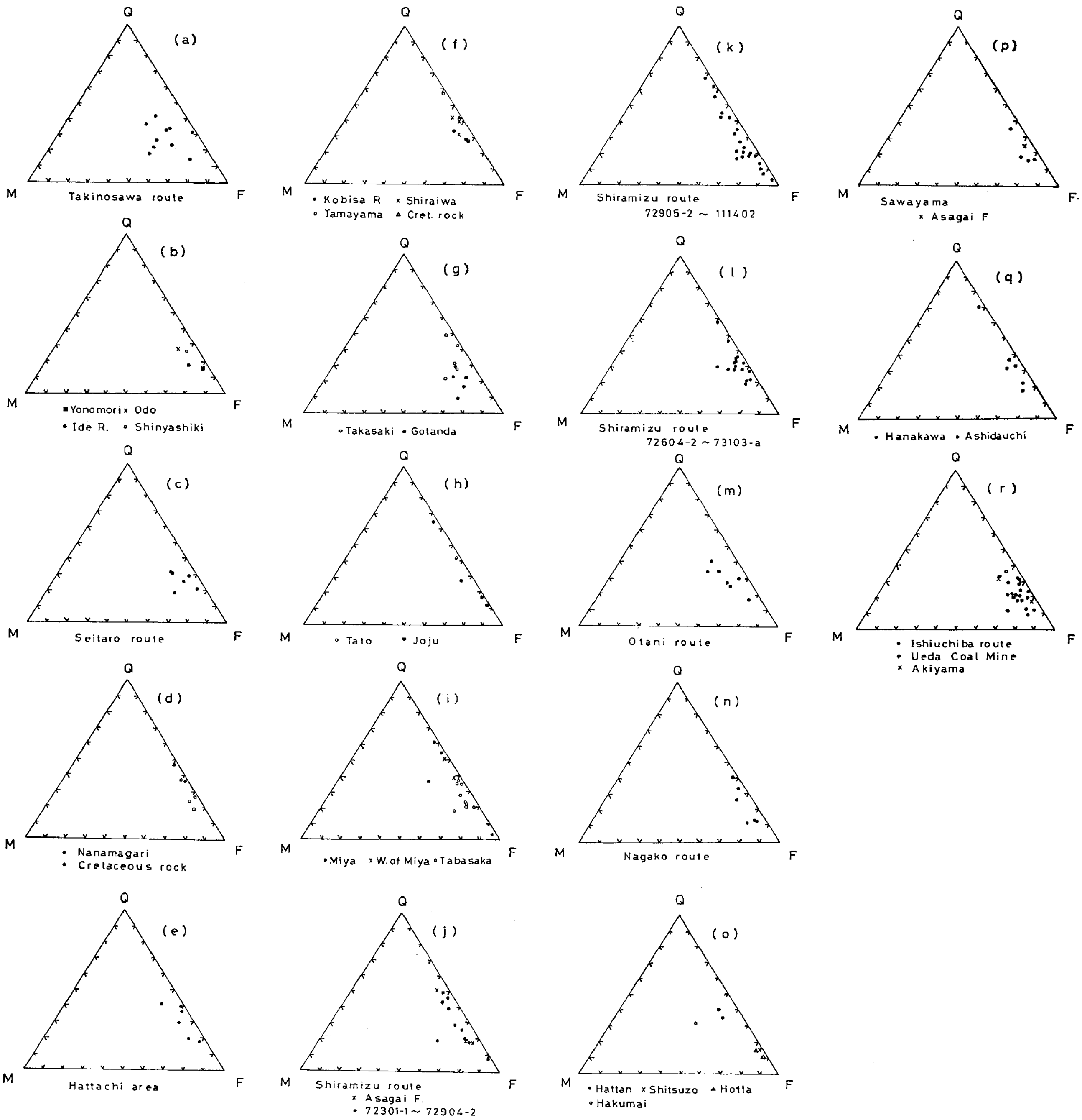


Fig. 41. Classification of the sandstone of the Iwaki Formation based on Folk (1954)

3. CLAY MINERALS

1) Method of Study and Samples

The clay minerals in the matrix of the Iwaki Formation can be used to assume the depositional environment (Sudo *et al.*, 1952; Sudo, 1964; Keller, 1970; Reynolds, 1970). The writer analyzed the clay minerals in the sandstone of the Iwaki Formation by X-ray powder diffraction to know the depositional environments.

The diffracting condition is; target: Cu, filter: Ni, scanning speed: 1°/min., time

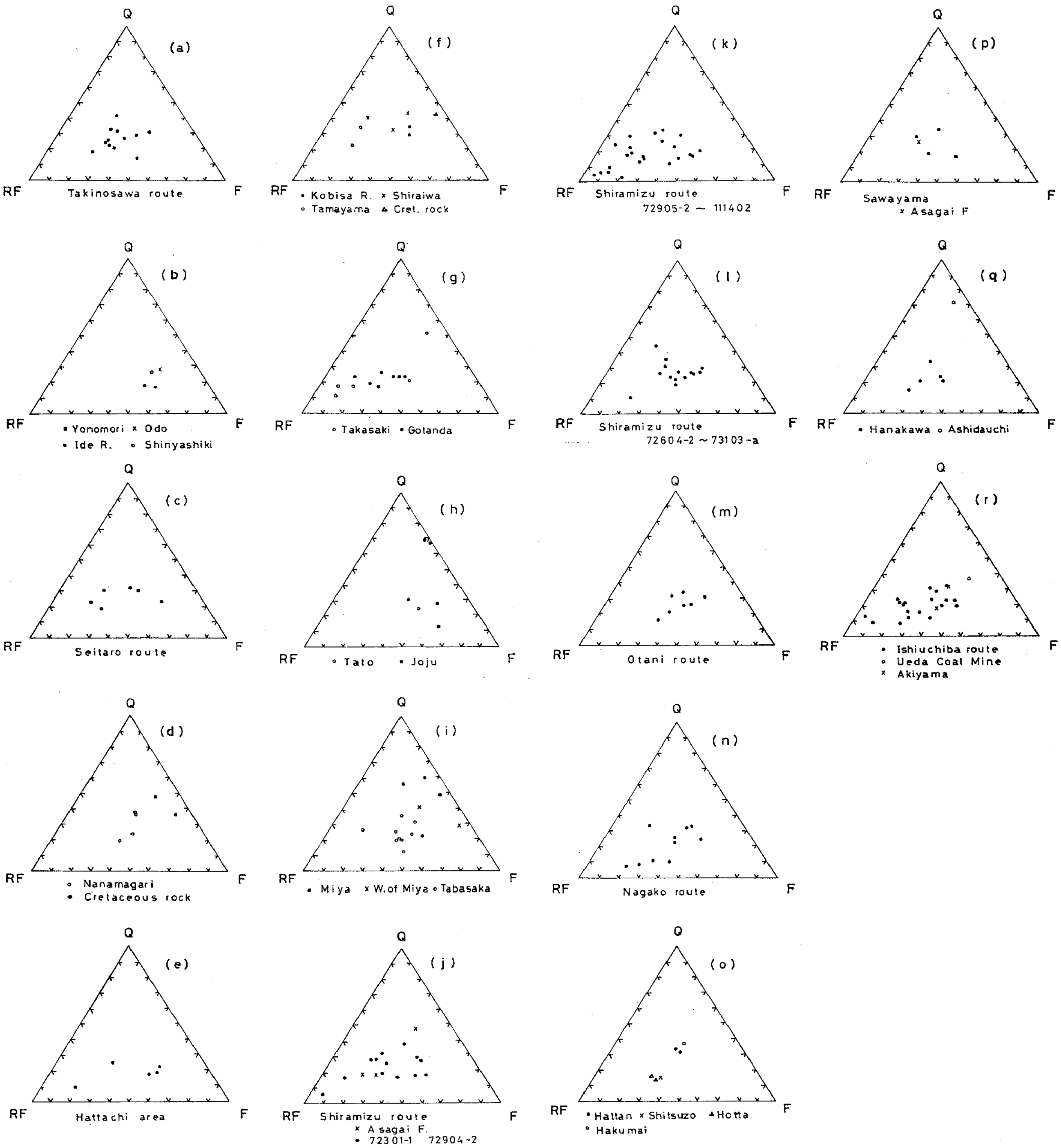


Fig. 42. Classification of the sandstone of the Iwaki Formation based on Van Andel (1958) and Okada (1968)

const.: 2 sec., chert speed: 10 mm/min., full scale: 100 c.p.s., divergency slit: 1.2 mm, receiving slit: 0.2 mm, scanning slit: 0.5 mm, environment: air, and the diffraction obtained is 60–3°.

The samples of the clay minerals were obtained from the crushed sandstone desicated in the oven at 60°C for 24 hours. The upper limit of the temperature is to prevent dehydration of the absorpted water. The samples chosen are from the whole sequence observed along the Takinosawa route (Futaba area), Shiramizu route (Iwaki area), Otani and Ishiuchiba routes (Taga area) to study the change of the assemblage both laterally and vertically. Samples were also selected to study the characters of the clay minerals in the entire area. The horizons of collection are shown in Figs. 5, 6, 7, and the important points are in Fig. 45.

2) X-ray Powder Diffraction

The diffraction peaks are identified by comparison with the data of A.S.T.M.. The identified minerals are montmorillonite, kaolin (kaolinite, halloysite and hydrated halloysite), chlorite of the clay minerals and quartz, feldspar, mica, calcite, dolomite and zeolite (clinoptilolite) (Figs. 43, 44, Tab. 3). The major minerals are as follows.

a) Montmorillonite: The peaks appeared broad, and at low intensity of 15 Å (001) spacing and the diffraction peaks are recognized at 5.25, 4.48, 3.28, 2.56 Å in order. From the low intensity and broad peak, the degree of crystallization is thought to be low. The montmorillonite occurred in almost all of the samples and is the main constituents in the matrix of the sandstone of the Iwaki Formation.

b) Kaolin: Kaolin is determined from the diffraction peak near 7.2 Å (001) spacing and the peaks are recognized at 4.46, 3.56, 2.56 Å (Fig. 43). The kaolin occurred in the

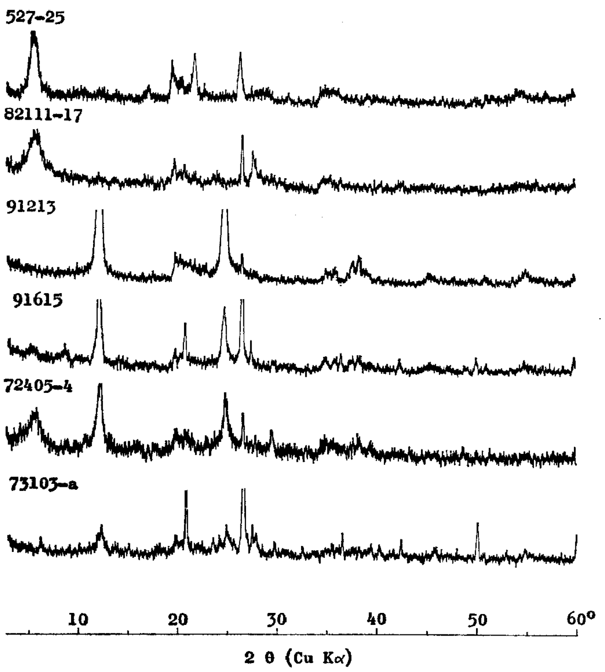


Fig. 43. Chart of the X-ray diffraction of montmorillonite, kaolin and chlorite

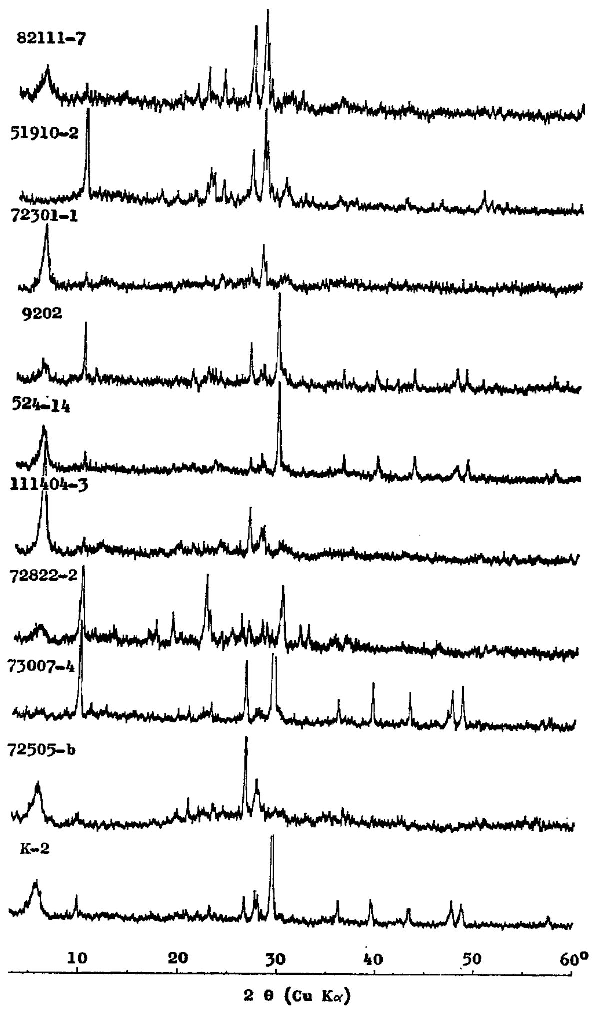


Fig. 44. Chart of the X-ray diffraction of clinoptilolite

residual sediments in the granite area of the basal member of the Iwaki Formation. Their sharp peaks indicated the existence of well crystallized kaolin. The diffraction having the peaks at near 10 Å and near 7.2 Å is considered to be the mixing of the hydrated halloysite and or halloysite.

c) Chlorite: In a few samples, the diffraction peak at 14 Å is recognized and it indicates chlorite. The diffraction peak of the chlorite is shown in Fig. 43; the samples were collected from the basal part of the Shiramizu route, Iwaki area, and this may be due to the alteration of the green schist.

d) Clinoptilolite: Its occurrence was recognized in several samples. The diffraction peak at 9.02 Å (001) and 7.97, 5.15, 3.98 Å coincides with the peak of clinoptilolite, and montmorillonite was found mixed in some samples. The diffraction peak of the clinoptilolite is sharp and had the intensity of 100, so crystallization is considered well (Fig. 44).

e) The other minerals identified by X-ray diffraction are calcite and dolomite, the former has the peaks at 3.03, 2.48, 2.21 Å and the latter at 3.02, 2.89, 2.19 Å (Tab. 3).

From the X-ray diffraction analysis, montmorillonite is recognized in most of the samples as common weathering products and is the main constituents in the matrix of the sandstone of the Iwaki Formation. Kaolin and chlorite are considered to reflect the basement geology at the time of early deposition of the Iwaki Formation.

The result from the X-ray diffraction led to the discovery of clinoptilolite. Clinoptilolite was named by Scheller in 1923 and the chemical formula offered by Mumpton in 1960 is $(Na_2)_{70} \cdot (CaO)_{16} \cdot (K_2O)_{15} \cdot Al_2O_{38.5-10.5}SiO_{226-7}\ H_2O$, and is a most silicate having zeolite in the zeolite group. The study on zeolite has been done by many workers (Sudo, 1964; Iijima, 1961; Iijima and Utada, 1966, 1967; Utada, 1968; Huzioka and Yoshikawa, 1969). The relationship between zoning and buried depth from the occurrence of the zeolite has also been studied by many authors. Recently, Reynolds (1970) and Utada (1970) have attempted to make correlation, and studied the environment from the occurrence of the zeolite group.

The stratigraphic occurrence of clinoptilolite coincides with the horizon of increasing amounts of the volcanic rock fragments. The zeolite group is produced by alteration of pyroclastics during diagenesis, and thus its geochemical condition is important, so the ground water and temperature of the zeolite group have been studied (Iijima, 1961; Iijima and Utada, 1965 a, b). The coincidence of the horizon of zeolite occurrence and increasing amount of the volcanic rock fragments is very important and suggests the existence of volcanic activity during the Iwaki deposition. To date, the existence of volcanic activity during deposition of the Iwaki Formation had not been known. In the present study, for correlation, employed are the cyclothemic arrangement incorporating the increasing amount of the basaltic andesite fragments in the sandstone, the occurrence of the clinoptilolite (Fig. 45), in the key bed and their value for the purpose in correlation throughout the entire area. Volcanic activity occurred three times during the deposition of the Iwaki Formation. These are from the lower: (I) after deposition of the main coal seam ("Honso"), (II) after deposition of the Tochikubo conglomerate bed (Nakamura, 1913), (III) at the uppermost horizon of the Iwaki Formation and aids in the reconstruction of the sedimentary basin. The writer calls this volcanism "**Iwaki Volcanism**" though its activity was weak.

4. THE ORIGIN OF THE EXOTIC SEDIMENTS

Chert and basaltic andesite fragments are included as the exotic sediments in the conglomerate and sandstone of the Iwaki Formation because the original rocks of them

Table 3. Table of X-ray diffraction of clinoptilolite bearing samples of sandstone

K-2 Otani		9202 Nagako		72822-2 Tabasaka		72505-b Shiramizu		111404-3 Shiramizu		72301-1 Shiramizu		73007-4 Takasaki		73007-5 Takasaki		524-14 Kobisagawa		519-10-2 Kido-gawa		82111-7 Takino-sawa		Minerals
dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	dÅ	I/Io	
15.23	29	15.7	22	15.50	11	15.05	21	15.23	100	15.23	100			15.23	100	15.78	46			15.78	34	M
14.48	21	14.7	19																			Chl
				10.5	9																	
9.02	18	9.02	38	9.02	100	9.02	17	9.02	18	9.11	26	9.02	64	9.02	40	9.02	22	9.02	100	9.11	18	Clino.
		8.19	17	7.97	8							8.04	9	8.04	23							Clino.
								7.43	16			7.13	8									K, Chl
				6.89	12									5.60	50							
				5.15	15													5.12	12			M
				4.69	20	4.50	25									4.71	13	4.67	11	4.55	18	M
								4.52	16			4.50	7	4.48	60	4.50	13					
4.33	10																					
4.27	11	4.29	17			4.27	36	4.27	14			4.27	8			4.29	15	4.27	11	4.25	26	Q
4.04	10					4.05	28	4.04	16	4.07	23							4.05	11	4.04	44	F
		4.00	19	4.00	39	3.96	25			3.95	20	4.00	9	4.00	40			4.00	25	4.00	20	Clino.
		3.93	17	3.93	20													3.93	22			
3.85	13	3.86	17			3.83	32					3.86	11			3.86	20					Co
		3.78	15			3.80	30	3.76	18	3.78	26			3.80	50			3.76	17			F
3.75	8			3.72	16	3.64	28											3.66	10	3.64	24	
		3.54	13	3.57	12									3.50	50			3.56	10			F
				3.45	20	3.43	30	3.47	16					3.47	50							
3.35	19	3.36	41	3.36	15	3.35	100	3.35	48	3.35	35	3.36	34	3.36	60	3.35	20	3.35	36	3.35	84	Q
3.22	24	3.25	17			3.22	55			3.23	68			3.22	50	3.22	26	3.22	61	3.22	100	F
								3.20	28	3.19	48	3.20	8									
3.18	21	3.19	11	3.18	16			3.18	30							3.18	17	3.18	41	3.18	68	F
3.14	11			3.14	15	3.13	30	3.15	14									3.14	16	3.14	36	
				3.08	11	3.07	28											3.07	12			
3.03	100	3.04	100									3.03	100	3.03	100	3.03	100					Co
		2.99	19					3.01	18	2.99	26									3.02	20	
				2.97	14			2.98	18									2.98	20			Clino.
						2.94	25	2.95	14	2.96	26							2.95	25	2.94	22	
		2.81	11	2.81	14					2.83	15	2.84	6					2.86	11	2.84	14	Do
		2.75	9	2.74	14																	
						2.60	21					2.58	42									K
				2.53	10	2.54	21							2.56	60			2.53	10	2.52	20	
2.48	16	2.50	19																			Co
				2.46	9					2.50	23	2.50	13			2.49	26					Q
		2.43	11			2.46	28											2.42	9			
								2.42	10													
						2.39	19													2.37	16	
						2.34	17															
2.28	68	2.29	17			2.28	17					2.28	21			2.28	26			2.28	16	Co, Q
		2.24	11																			
		2.18	9																			Q
						2.15	17															Do
				2.14	7	2.13	17													2.14	16	
																						Q
		2.09	19																			
2.08	14											2.09	17	2.09	50	2.09	24					
														2.03	40							Co
												1.91	18					1.98	9			Do
1.91	12	1.91	21																			Co
																1.91	17					
										1.90	20											
		1.88	19																			
1.87	11											1.87	20			1.87	22					Co
		1.82	11			1.82	17											1.82	15			Q

M; montmorillonite
K; kaolin
Chl; chlorite
Clino; chinoptilolite
Q; quartz
F; feldspars
Co; calcite
Do; dolomite

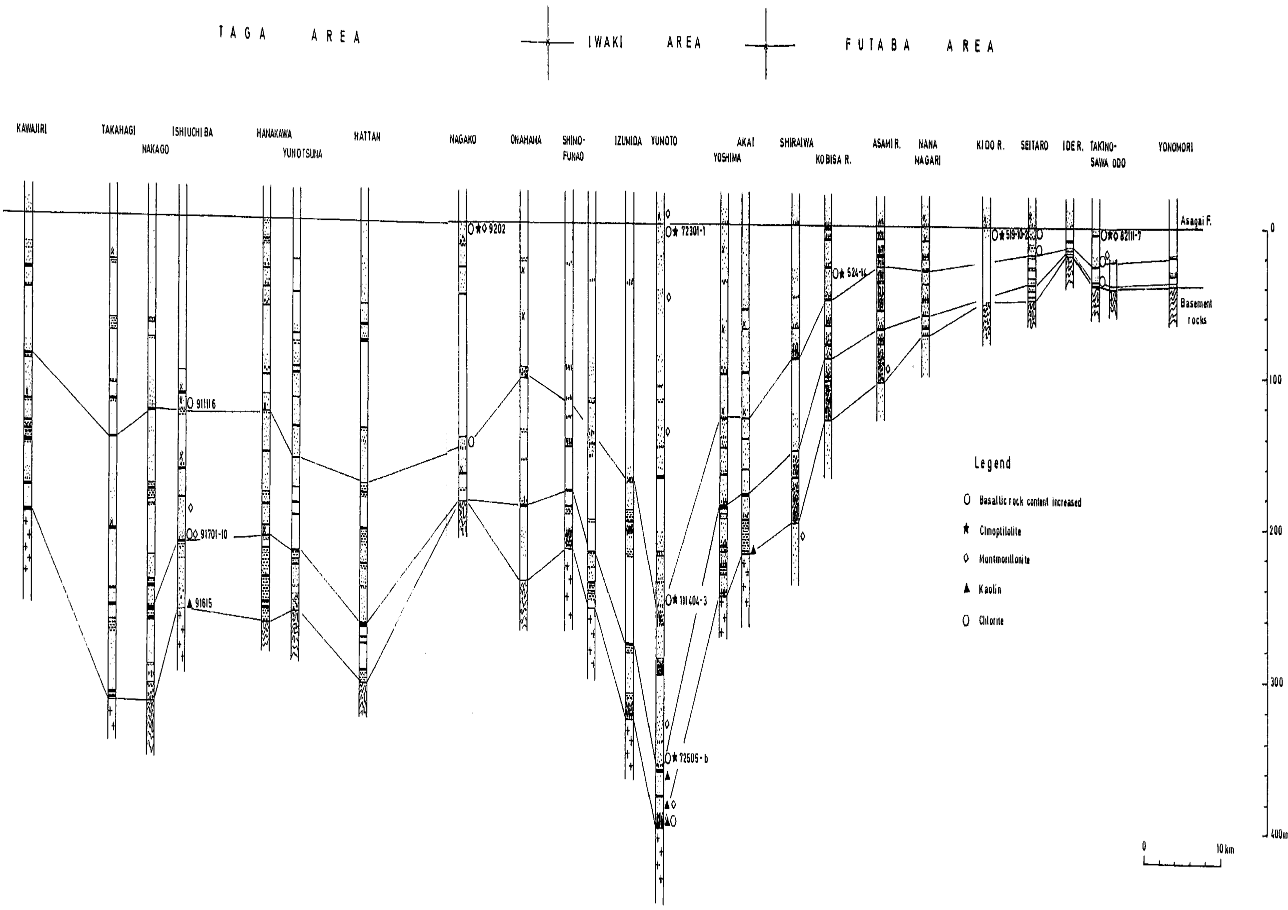


Fig. 45. Occurrence of points of clinoptilolite and other clay minerals, and correlation of the area

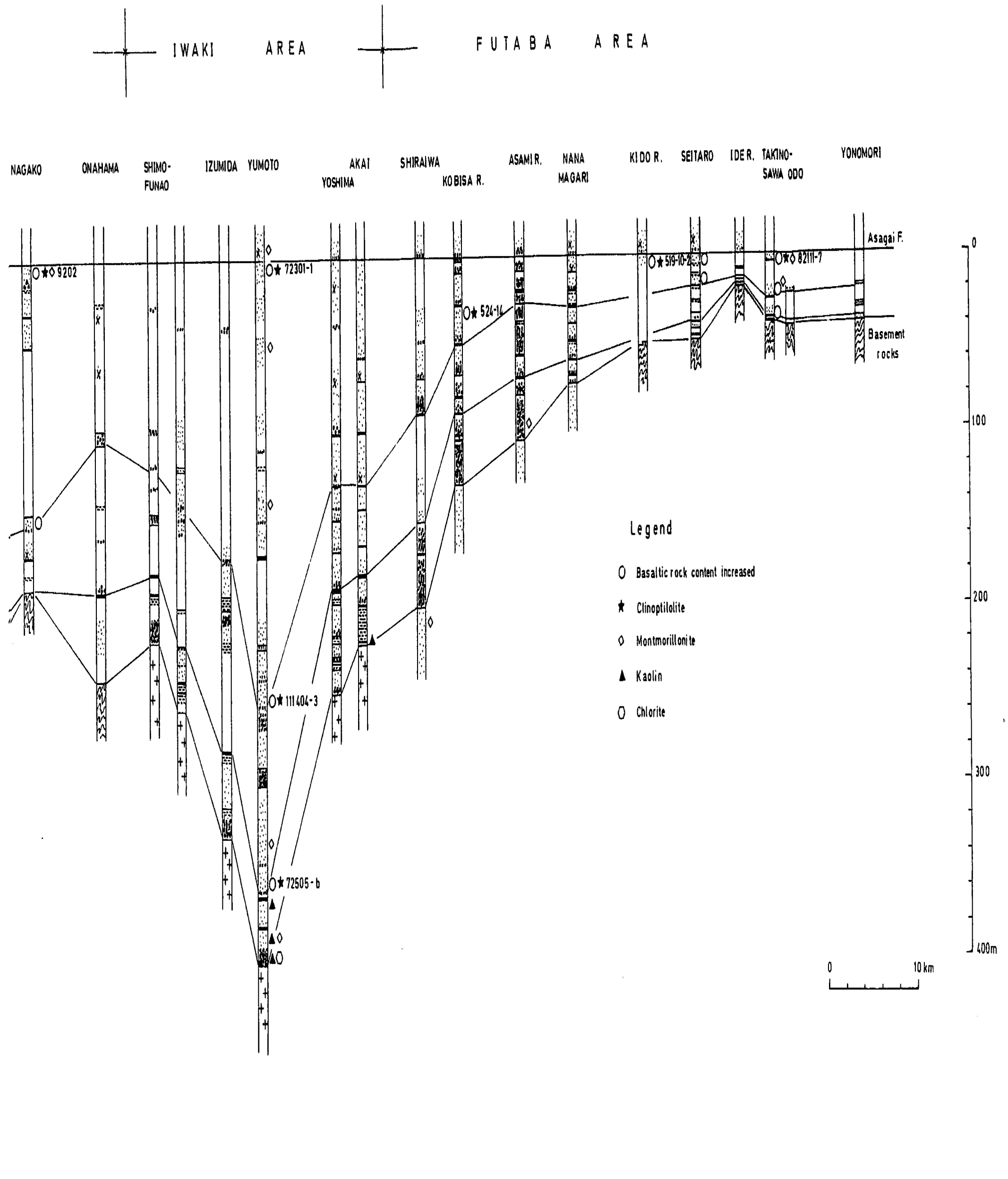
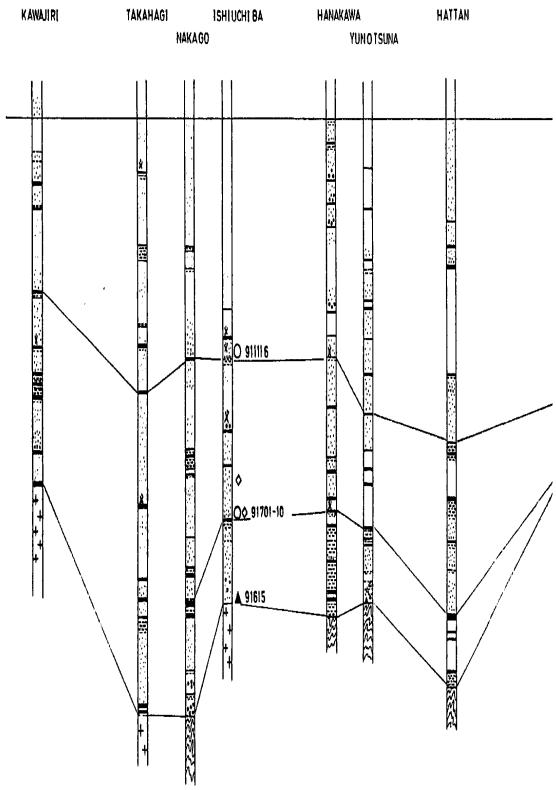


Fig. 45. Occurrence of points of clinoptilolite and other clay minerals, and correlation of the area

TAGA AREA



KAWAJIRI
TAKAHAGI
NAKAGO
ISHIUCHIBA
HANAKAWA
YUNOTSUNA
HATTAN
91116
91701-10
91615

are not distributed in the basement area at present. They may be considered as a part of the original provenance.

1) Basaltic Andesite

The fragments of the basaltic andesite increased at the three horizons of the Iwaki Formation. These three horizons can be traced throughout the entire area, and as described in the paragraph of "Clay Minerals", the three horizons coincide with the occurrence of clinoptilolite. The fragments of the basaltic andesite were derived from the volcanism during the deposition of the Iwaki Formation. The fragments are more rounded than the feldspar grains which tend to be rounded and show evidence of having suffered much abrasion. From the data of the grain size and roundness, the basaltic andesite fragments are considered to have been derived from volcanic breccia and scoria.

The center of the volcanism is obscure, but from the sedimentary structures suggesting the direction of the transportation and directional successive decrease in the grain size, it may be possible to present some assumption as to the center of the volcanism. The only evidence found is that the cross stratification developed in the sandstone of the Iwaki Formation shows eastward dips that point to the sediments supply from the western part of the area studied. The uppermost horizon corresponds to the last stage of volcanism of the Iwaki Formation as is suggested by the basaltic andesite gravel of about 3 centimeter in diameter from Shinyashiki in the Futaba area. From the data of grain size, roundness of basaltic andesite and clinoptilolite determined under the X-ray diffraction, the exact center of volcanism remains in doubt.

2) Chert

Chert is found in the conglomerate in large amounts, the sand grains of chert show small ratio, probably due to the high durability of chert which prevents it from being broken into fine fragments. In the distribution area of the basement rocks, reddish colored cherty rocks interbedded in the green schist are found along the Same River, the environs of Taki, Kadono-machi, in the southwestern part of the Iwaki area. However, lithologically, they differ from the chert gravels of the conglomerate of the Iwaki Formation, the provenance of chert remains unknown. No successive change of the gravel size was observed either laterally or vertically, and the only evidence is the eastward dip of the cross stratification developed in the sandstone, which suggests that the provenance area was probably west of the sedimentary basin of the Iwaki Formation.

Chert is distributed in the mountain range of Yamizo, Toriashi and Torinoko situated southwest of the Abukuma Plateau (Kawada, 1953), but not on the eastern side of the Abukuma Plateau which is the hinterland of the Joban coal field. However in the upper stream of the Natsui River in the granite region at Miharu, rarely crystalline limestone occurs as roof pendant.

The Permian rocks distributed in the Takakurayama hills in the western part of Tamayama, South Futaba area, interbeds conglomerate in which are found chert gravels (Yanagisawa, 1967; Iwai 1932). The sequence of the Soma Paleozoic rocks in the environs of Oashi, Haranomachi City, Soma District, also contain chert and orthoquartzite gravels. The chert gravel is considered to be of secondary origin supplied from the conglomerate of the Permian and Cretaceous rocks. This view is upheld by the high durability and roundness of the chert gravels and the discovery of the orthoquartzite gravels in the Iwaki Formation. Iwai informed the writer (oral communication) that the Cretaceous rocks as gravels occur in the basal conglomerate and contained also chert gravels.

CHAPTER IV

THE RELATIONSHIP BETWEEN DEPOSITION OF THE IWAKI FORMATION, VOLCANIC ACTIVITY AND TECTONIC MOVEMENT

The sedimentary petrographic study proved the existence of pyroclastic fragments of basaltic andesite and clinoptilolite in the three horizons. From the time planes determined by the discovery of the mentioned sediments, the sedimentation and reconstruction of the sedimentary basin of the Iwaki Formation can be classified into three stages as: (I) early period, (II) middle period and (III) late period from the three volcanic activities; they are as follows.

1. EARLY PERIOD OF THE IWAKI DEPOSITION (FIG. 46, STAGE I)

This period extends from the base of the Iwaki Formation up to the first volcanic activity, or to the post-deposition of the main coal seam ("Honso").

During the initial phase of subsidence there was different movement of the basement, and this resulted in the local distribution of different kinds of sediments. Namely, in the South Futaba, Iwaki and Taga areas conglomerate was deposited extensively and the environment from the sediment analysis is thought to have been an alluvial fan to plain area. In the area of distribution of green schist in the North Futaba and Taga areas, fine grained sandstone and shale were deposited. And "Gainome" clay and clayey arkose sandstone were deposited in the hill side area of the granite.

During the deposition of the main coal seam ("Honso"), the relief of the basement is judged to have been flattened by the deposition of the previously laid sediments except for the large buried hills of green schist in the Taga area. The cycle of sedimentation is correlated to the cycles of Komatsu, Toshimo in the Futaba area and Kuroiso in the Taga area. The local characteristics of these sediments are interpreted as the result of being influenced by drainage, the buried hill, and the difference of the weathering products

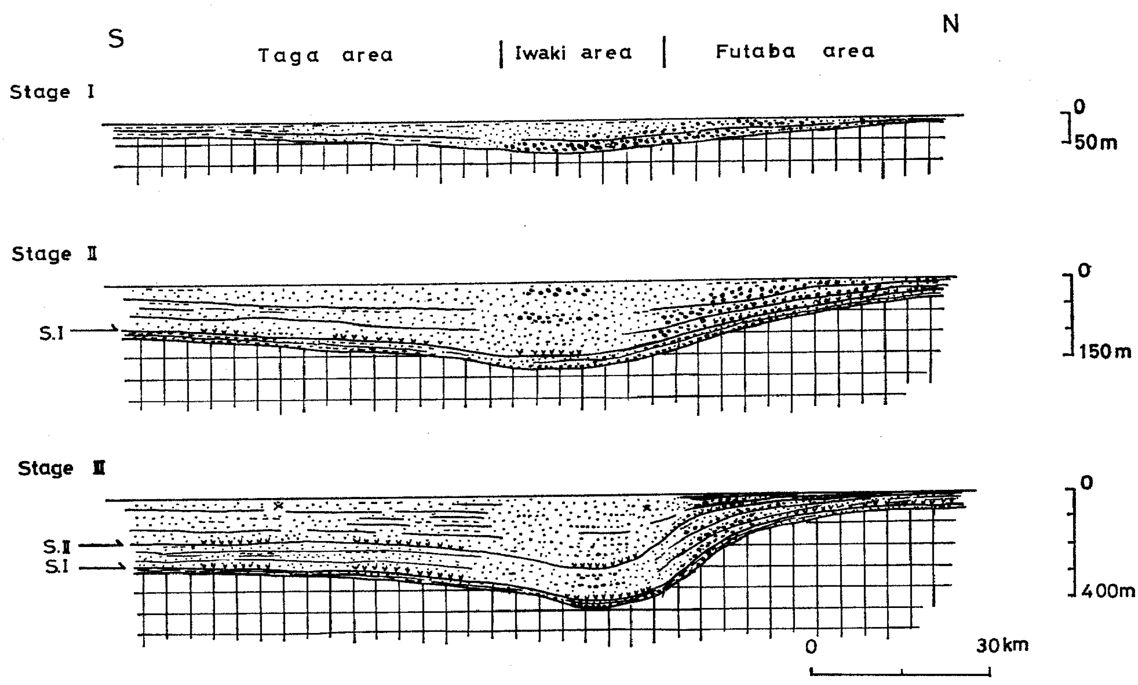


Fig. 46. Compiled sedimentary process of the Iwaki Formation, divided into three stages

resulting from the durability of the basement rocks and also controlled by the basement geology.

The distribution of the sediments of Satge I is shown in Fig. 47. During this stage the faults in the basement rocks and Tertiary rocks do not seem to have influenced the deposition of the Iwaki Formation.

2. MIDDLE PERIOD OF IWAKI DEPOSITION (FIG. 46, STAGE II)

This period or Stage II is from the first to second volcanic activity. The thickness of the sediments of this period attain 120–130 m in the Iwaki area, nearly 100 m at Tamayama in the South Futaba area and about 100 m in the Taga area. The lithofacies throughout the entire area are similar and consist of conglomeratic sediments which developed coal bearing cyclothems, but in the environs of Yumoto (Iwaki area), there is no coal deposition. In the Iwaki area, conglomeratic sediments are dominant and have been named the Nametsu and Tochikubo conglomerate beds (Nakamura, 1913). Such lithofacies are representative of the middle part of the Iwaki Formation.

In the Futaba area, conglomeratic sediments were deposited continuously from the initial stage, and in the North Futaba area the coarser grained sediments changed from fine grained sediments of the lower part, and conglomerate is distributed along the Seitaro route.

In the Taga area, as described by Watanabe (1939), conglomerate is developed in a restricted area (Ishiuchiba-Sekihira route).

In the North Futaba area, the thickness of the sediments decreased as they are the marginal part of the sedimentary basin. The entire area excluding the North Futaba shows similar thickness and lithofacies, therefore, the sedimentary environment may have been uniform since the initial stage.

3. LATE PERIOD OF IWAKI DEPOSITION (FIG. 46, STAGE III)

This period extends from the second to the third volcanism (the uppermost horizon). The sediments deposited during this period show areal change in lithofacies and thickness. The thickness is less than 100 m in the Futaba area, especially in the North Futaba area the thickness diminishes to nearly 20 m. In the Iwaki area, the thickness is 150–200 m. The kind of sediments also changes with the thickness, namely, in the North Futaba area the rocks make a cyclothemic arrangement dominated fine grained sandstone, the South Futaba shows cyclothemic sediments mainly of conglomeratic sediments. The Iwaki area resembles the South Futaba area, but in the southern part of the Yumoto district, the sediments are dominantly of sandstone intercalated with a thin conglomerate bed, and is called the "Iwaki Sandstone" by Nakamura (1913). The Taga area resembles the North Futaba area in having dominant sandstone cyclothemic arrangement.

In this period as shown by Stage III (Fig. 46), the sedimentary basin began downwarping in the Iwaki area, and because of the different paleogeology the sediments deposited in each area began to show considerable difference. The sediments deposited in the Iwaki area show estuary to deltaic facies and the large cross stratification points to a deltaic environment (Pl. 6), perhaps the large paleo-river of the Natsui and Yoshima might have existed during the Iwaki deposition in the Iwaki area. It is considered that these ancient rivers may have been responsible for the transportation of sand size sediments in the Iwaki area then situated at the mouth of these rivers.

In the Futaba area, the sediments are characteristic and consist of coal bearing conglomeratic cyclothemic sediments. That may be result from minor subsiding, intermittent subsidence of the basin and to the supply of the sediments. Consequently in the Iwaki area, the boundary between the Iwaki and Asagai formations is gradual whereas the boundary between those formations in the Futaba area is a disconformity (Pl. 3). In this district, the basal conglomerate of the Asagai Formation covers with disconformity the coal bed of the uppermost part of the Iwaki Formation. The basal conglomerate of the Asagai Formation becomes thinner northwards. From the uppermost cycle of the Iwaki Formation along the Nanamagari route of the Futaba area, marine molluscan fossils occurred, thus suggesting the northward tilting of the Futaba Block (Sugai and Matsui, 1957). In the Taga area, the subsidence of the sedimentary basin and the supply of the sediments was not so large as in the Iwaki area, and the sequence consists dominantly of sandstone showing cyclothemic deposition. The thickness is slightly less than in the Iwaki area.

The deposition of the Iwaki Formation might have been influenced by volcanism though weak. After the third volcanic activity, the major transgression occurred and

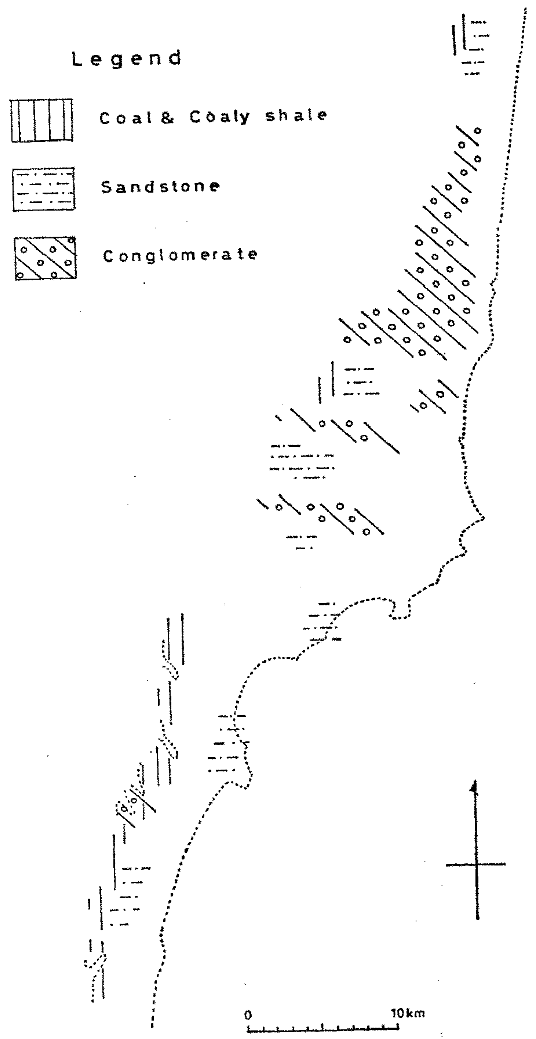


Fig. 47. Distribution of the sediments during the early period of deposition of the Iwaki Formation

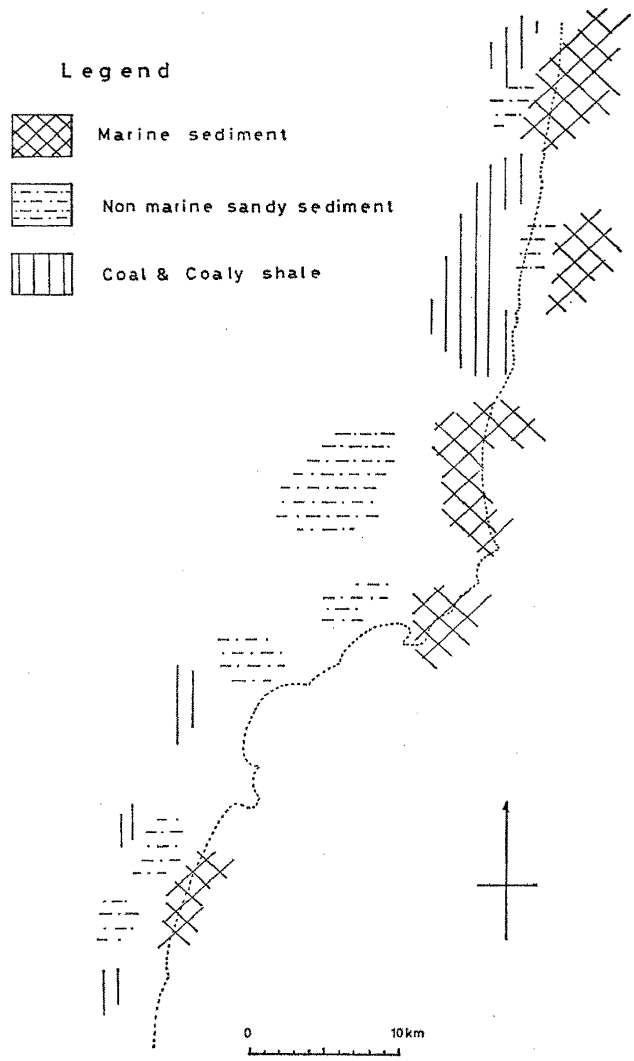


Fig. 48. Distribution of the sediments during the later period of deposition of the Iwaki Formation

deposited the Asagai Formation. The Asagai Formation is lithologically uniform in lateral and vertical sequences, and the areal difference of the thickness is little.

During the time of post-Shiramizu Group and pre-Yunagaya Group (Kitamura, 1963), both the north and south sides of the downwarped sedimentary basin of the Stage III were influenced by activation of the Futatsuya and Yunotake faults both of NW-SE trend. The distribution of the sediments during the late period of Iwaki deposition is shown in Fig. 48.

CONCLUSION

1. From the composition of the conglomerate, the basal conglomerate shows local characteristic aspects, and from the distribution of the green schist, granite and pyroxinite gravel, the basement geology during the initial stage of Iwaki deposition is thought to have been similar to that at the present.

2. The sandstone of the Iwaki Formation contained much matrix, so the sorting was not good and regardless of the variation of the grain size of the sandstone, the distribution is represented as moderate-poor sorted and fine skewed. The type of the grain size distribution of the Iwaki Formation can be divided into four types of which Type III and IV are characteristic (representative) of the sandstone of the Iwaki Formation. The grain size distribution shows the depositional environments to be from alluvial to deltaic. The result of the C-M pattern analysis and characteristic feature of the cross stratification supports the above mentioned inferred environment.

3. The sandstone of the Iwaki Formation consists of various kinds of minerals and rock fragments, and suggests that the supply was from different provenances. The sandstone classification by use of the triangle diagram of Van Andel (1958), resulted in the concentration to the central part of RF pole (rock fragment area), and represents the characters of the sandstone but does not present the difference of the provenance. On the other hand, according to Folk's classification (1965), the difference of the provenance is reflected in the triangle diagram but recognition of the nature of the sandstone is impossible. It is necessary that the classification of the sandstone by use of the triangle diagram, the end members must be chosen according to the purpose of the study.

4. In the compositional change of the sandstone, the increasing the ratio of the basaltic andesite fragments is recognized in three horizons that can be traced over the entire area, and this is proved to be very useful and to form important key beds for correlation of the Iwaki Formation.

5. The deduction that the constituents of the Iwaki Formation were supplied from the same parent rocks as now distributed in the back ground as basement rocks is considerable, but the exotic sediments as chert and andesite fragments present some problems. Chert is considered to have been originated from a chert bed in the pre-Tertiary rocks on the granite as roof pendant during Iwaki deposition. The chert bed may have been eroded away and be preserved as sediments. There is also a possibility of secondary supply from the conglomerate beds of the Permian and Cretaceous rocks, but there is no evidence to uphold this view.

6. X-ray powder diffraction analysis of the clay minerals and the matrix of the sandstone, shows that the clay minerals are mainly of montmorillonite and the sediments near the basement rocks are of kaolin and chlorite, thus reflecting the basement geology at the early period of Iwaki deposition. And X-ray analysis clarified the occurrence of clinoptilolite (zeolite group) for the first time.

7. The relationship between the basaltic andesite fragments, and clinoptilolite, and their horizons of occurrence is closely related to the three horizons of volcanic activities

during Iwaki deposition (Iwaki Volcanism). This volcanic activity during Iwaki deposition occurred three times as is shown by the ratio of the basaltic andesite fragments and zeolite. The pyroclastics are important key beds for correlation of the formation throughout the whole area studied.

8. During Iwaki deposition three volcanic activities are confirmed, one after the deposition of the main coal seam ("Honso"), one after deposition of the Tochikubo conglomerate bed (Nakamura, 1913) and the third at the uppermost horizon of the Iwaki Formation. From the volcanism the deposition and reconstruction of the sedimentary environment became possible, and three stages were recognized as follows;

A). At the early stage (Stage I), from the base to after deposition of the main coal seam to the first volcanism, the basement subsided and characteristic sediments were deposited locally corresponding to the geology and relief. At the final part of this stage the coal seam was deposited over the whole area, this coal seam is called "Honso" in this coal field. The thickness of the sediments in this period attained about 40 m.

B). At the middle stage (Stage II), from the after deposition of the main coal seam to after deposition of the Tochikubo conglomerate bed to the second volcanism, the sediments consisted almost only of conglomeratic material and the thickness attained about 100 m. Cyclothemic deposition occurred in each area.

C). At the late stage (Stage III), from after the deposition of the Tochikubo conglomerate bed to the uppermost horizon of the formation, the place of deposition seems to have been adjacent of the mouth of large drainage from the hinterland and large quantities of sandy sediments were deposited in the downwarped sedimentary basin. The subsidence in the Taga and Futaba areas were less than in the Iwaki area, where the sediments are characterized by coal bearing cyclothemic deposits.

The downwarping in the Iwaki area in this period may be closely related to the activation of the Futatsuya and Yunotake faults of NW-SE trend.

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Plate 1

(All cross nicols, $\times 30$)

Figs. 1–6. Microphotographs of the thin section of the basement rocks of the Iwaki Formation

Fig. 1. Amphibolite-chlorite quartz schist, Locality: Yoshima, Iwaki City.

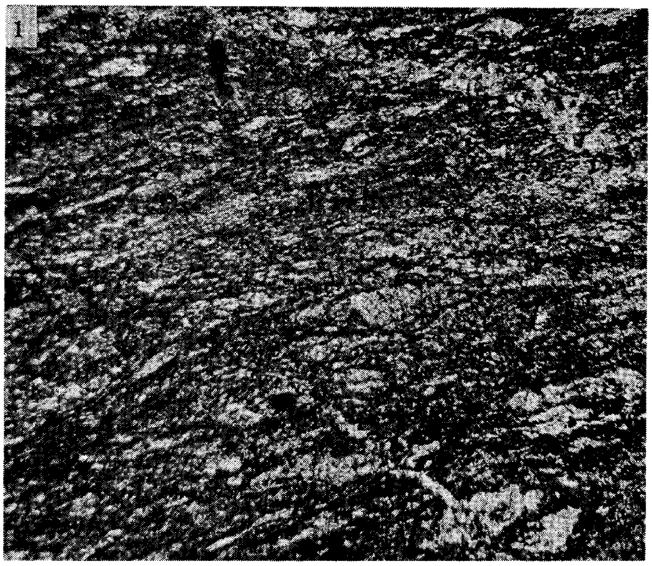
Fig. 2. Hornblende biotite granite, Locality: Yunotake, Joban Yumoto, Iwaki City.

Fig. 3. Biotite granite, Locality: Isohara-machi, Kitaibaraki City.

Fig. 4. Pyroxenite, Locality: Nakane, west of Shiota.

Fig. 5. Quartz porphyry, Locality: Yunotake, Joban Yumoto, Iwaki City.

Fig. 6. Arkose sandstone (530–10) of the Tamayama Formation of the Futaba Group, Locality: Tamayama, Yotsukura-machi.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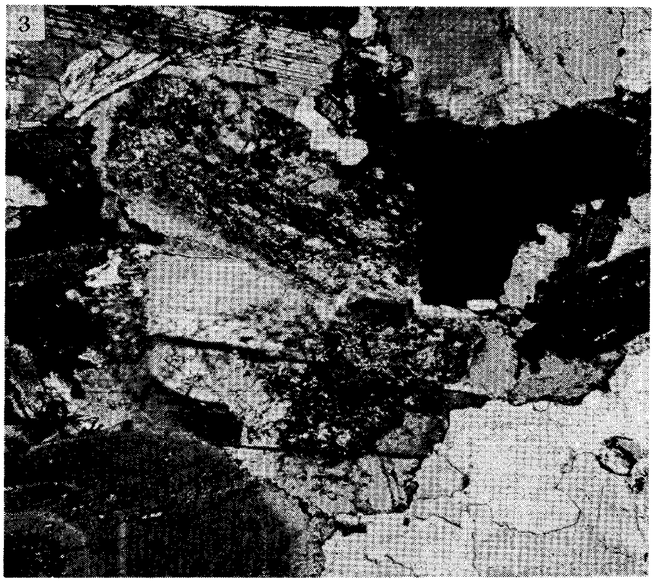
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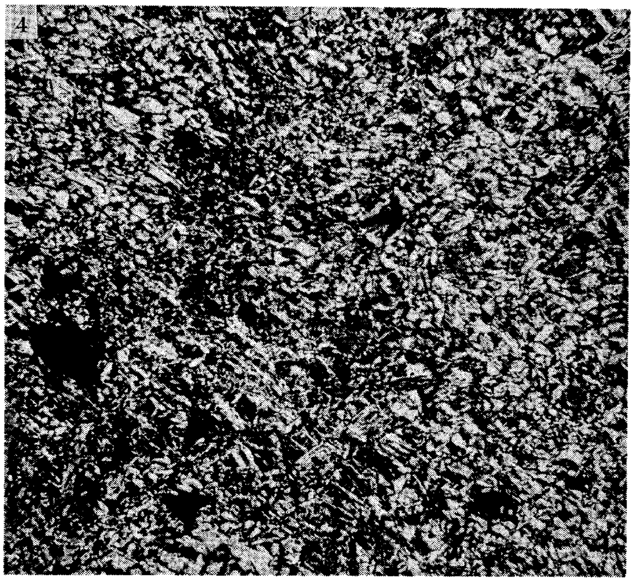
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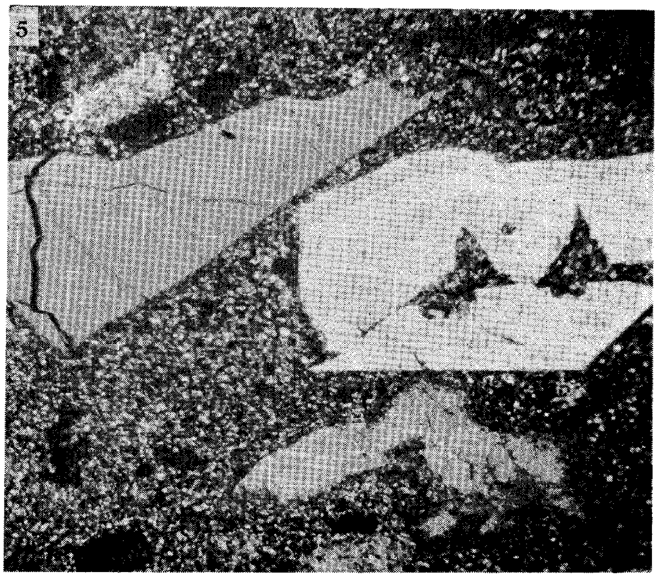
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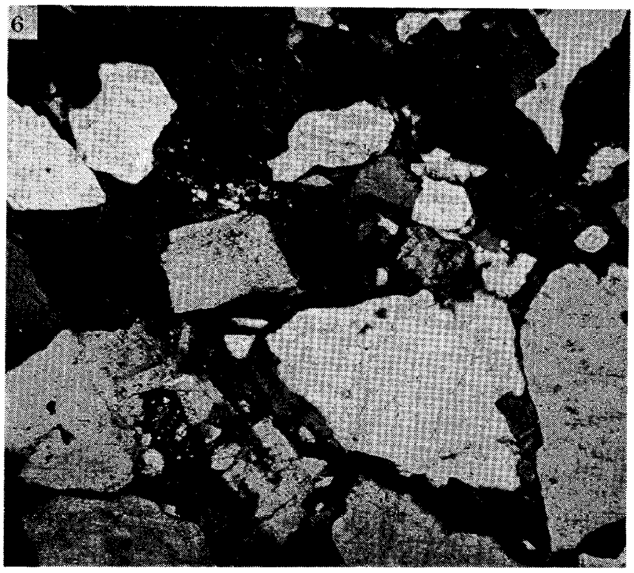
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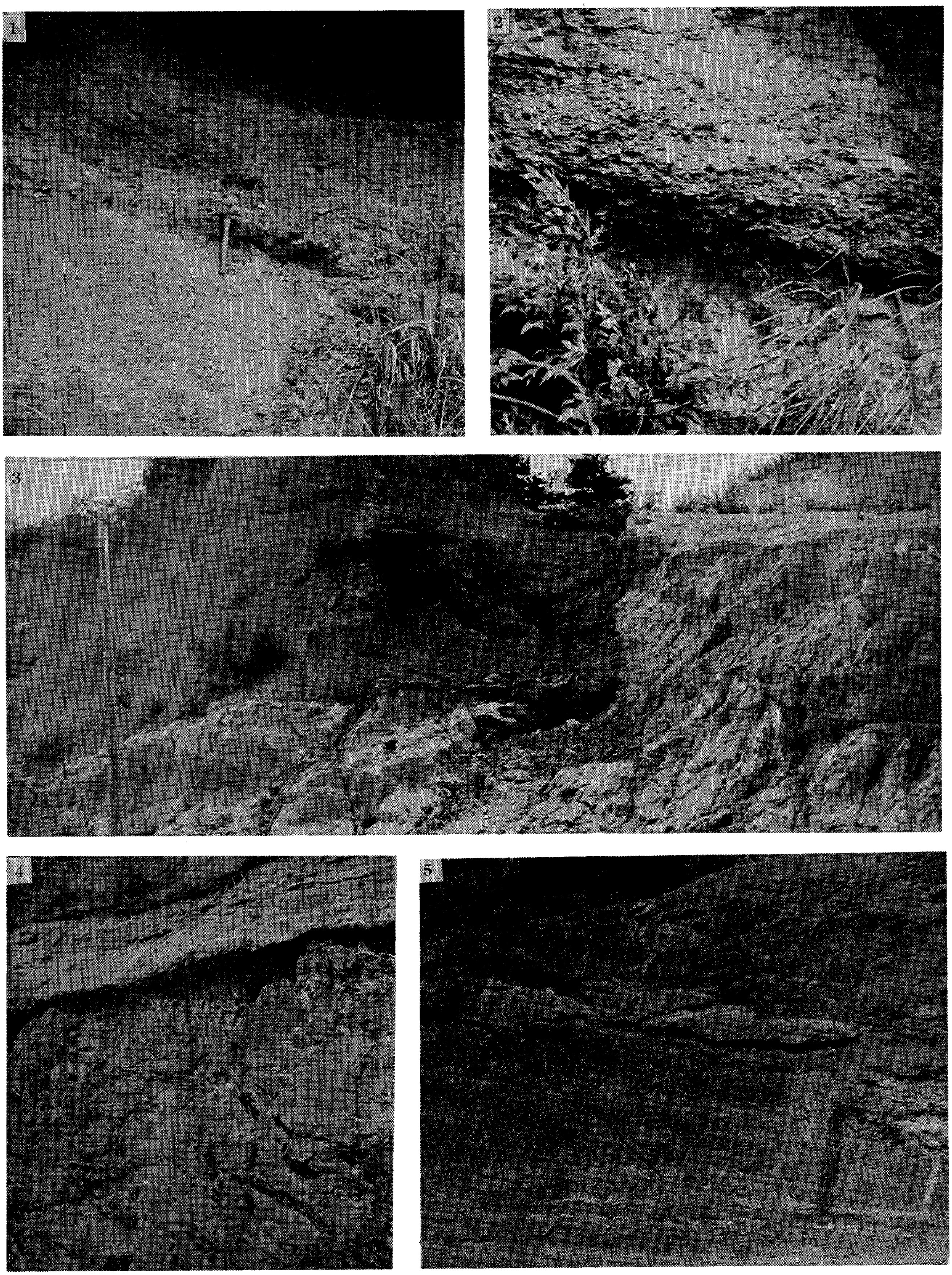
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Plate 2

Figs. 1–5. Outcrops showing the unconformity between the Iwaki Formation and basement rocks.

Fig. 1. The Iwaki Formation superposed on the granite with basal conglomerate, Locality: at the foot of Yunotake, Iwaki City.

Fig. 2. The Iwaki Formation covers the Cretaceous rock with basal conglomerate, Locality: Tamayama, Yotsukura-machi.

Fig. 3. The Iwaki Formation lies on the granite with basal sandstone. At the boundary there is developed Gainome clay, Locality: Joju, Iwaki City.

Fig. 4. The Iwaki Formation lying on the green schist with basal sandstone. The main coal seam is situated above the green schist, Locality: Shiramizu, Iwaki City.

Fig. 5. The Iwaki Formation covers with basal sandstone on the granite, Locality: Miya, Iwaki City.

Plate 3

Figs. 1–4. Outcrops showing the boundary between the Iwaki and Asagai formations in the Futaba area.

Fig. 1. Outcrop showing the Asagai Formation lying above the Iwaki Formation with basal conglomerate, Locality: Hattachi beach, Yotsukura-machi.

Fig. 2. The outcrop at the beach side opposite the outcrop shown in Fig. 1.

Fig. 3. Outcrop of the basal conglomerate of the Asagai Formation, Locality: Nanamagari, Naraha-machi.

Fig. 4. Outcrop of the basal conglomerate of the Asagai Formation, Locality: Seitaro.


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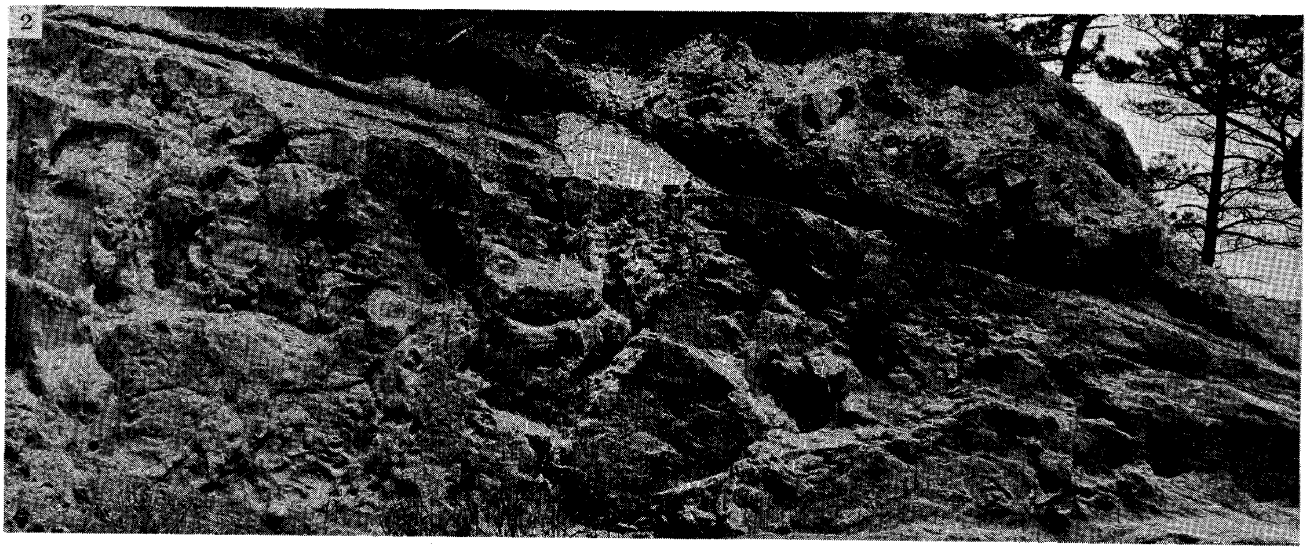
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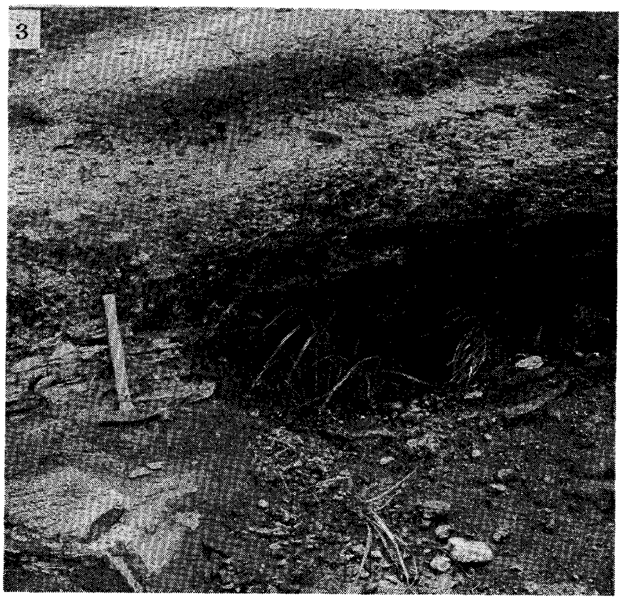
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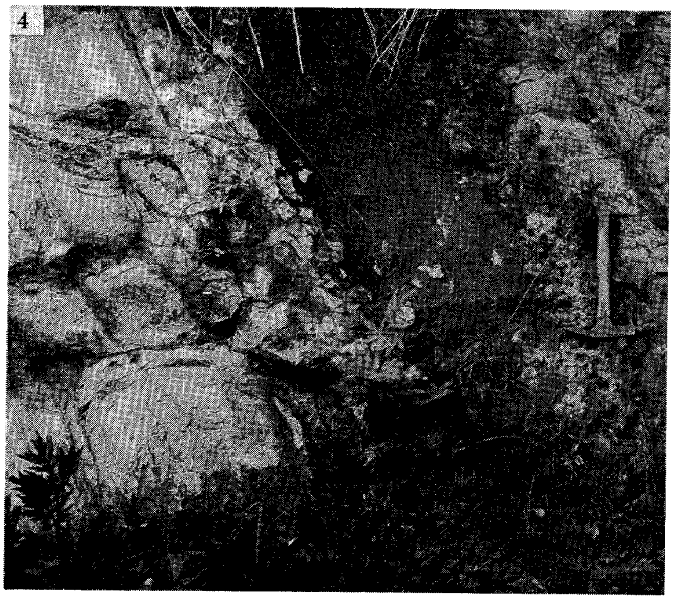
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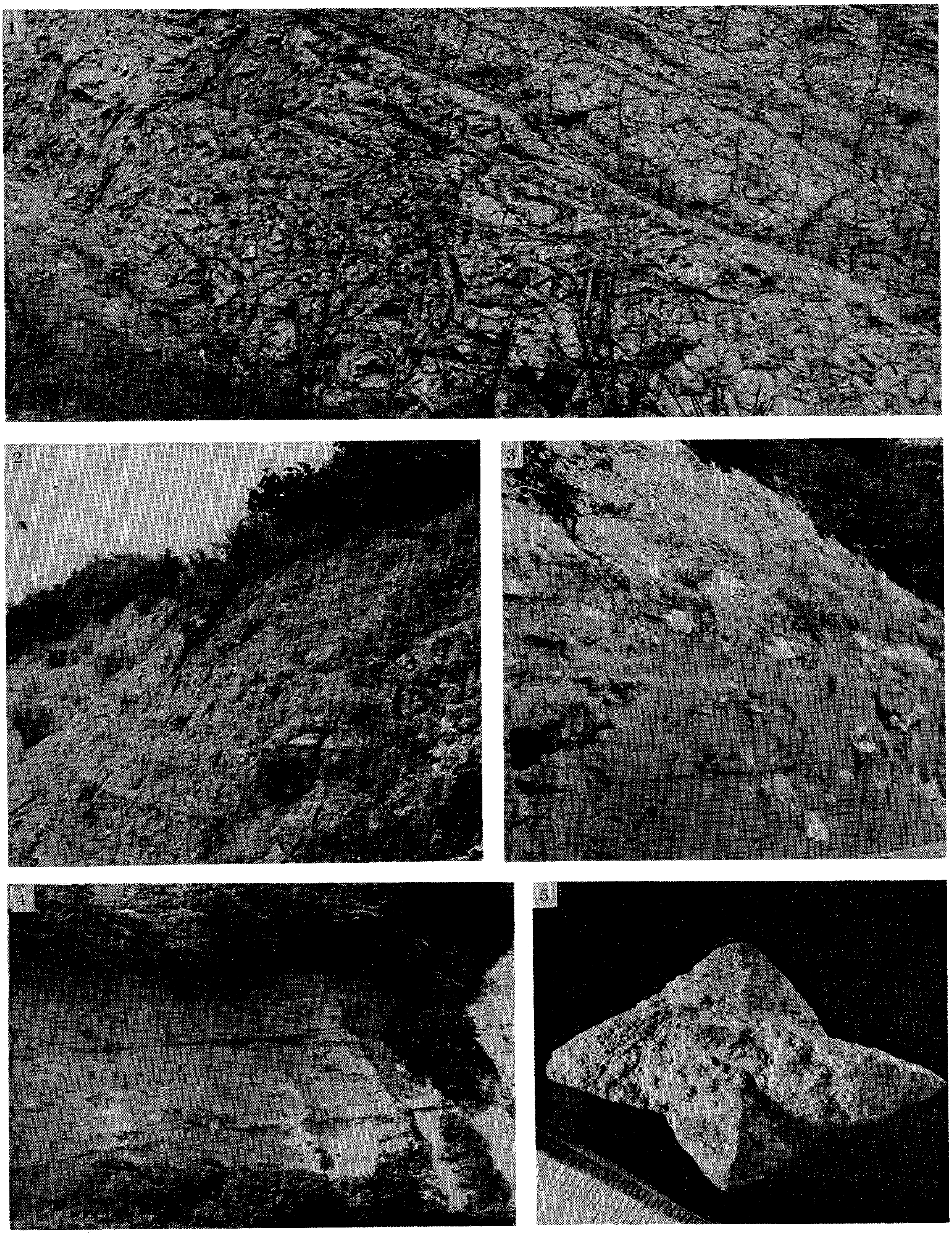
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Plate 4

Fig. 1. Outcrop of the Asagai Formation, showing the development of stratification and onion structure, Locality: Nanamagari, Naraha-machi.

Fig. 2. Outcrop showing the boundary between the Asagai and Shirasaka formations, Locality: Uchigo, Iwaki City.

Fig. 3. Outcrop showing the boundary between the Asagai and Shirasaka formations, Locality: a road side cutting in Isohara-machi, Kitaibaraki City.

Fig. 4. Outcrop showing the boundary between the Asagai and Shirasaka formations, Locality: Tabasaka, Joban Yumoto.

Fig. 5. Gen-no-ishi (hammer stone) collected from the Shirasaka Formation, Locality, Uchigo, Iwaki City.

Plate 5

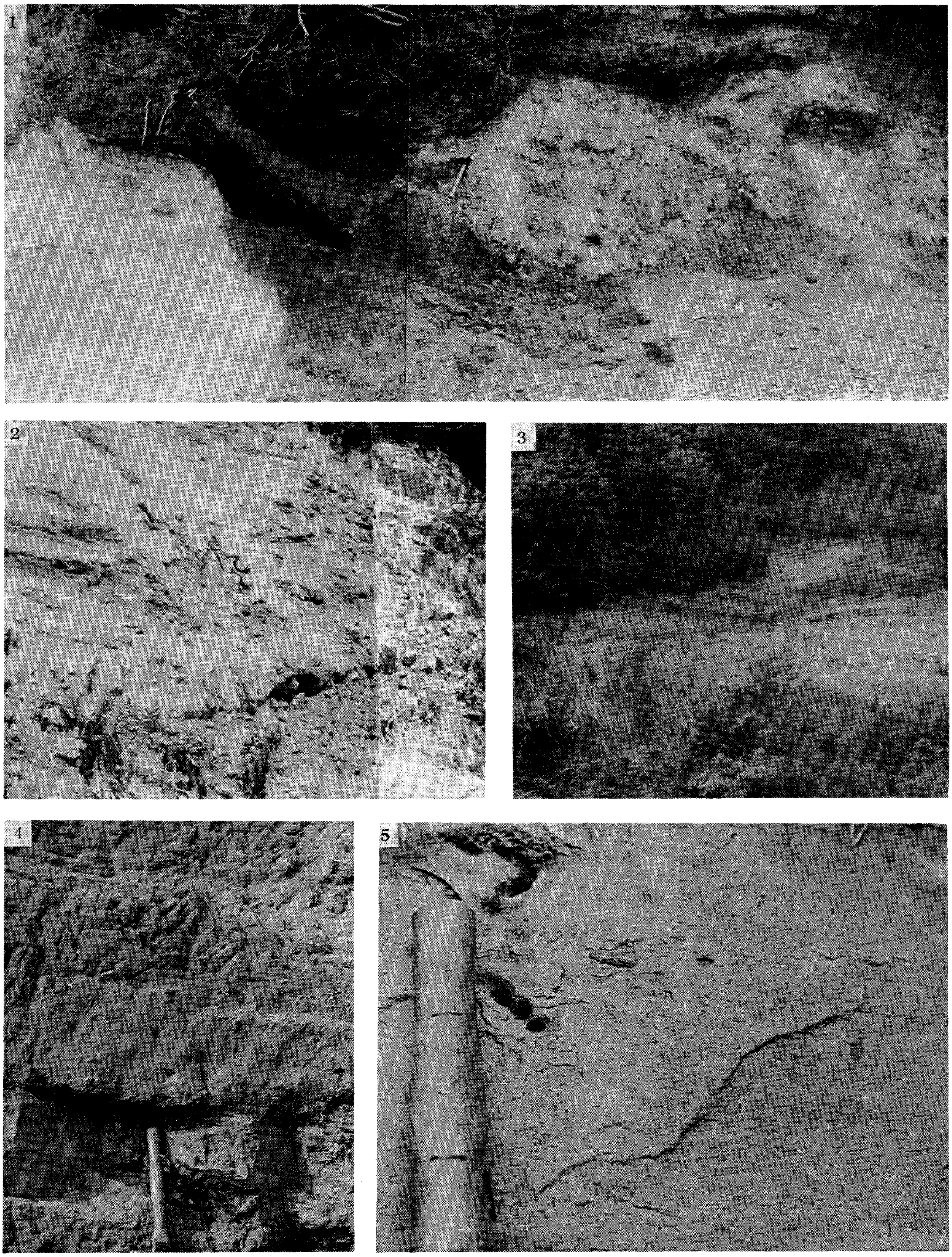
Fig. 1. Outcrop of a buried hill of granite at Keishin, showing the coal seam abuting against the buried hill.

Fig. 2. Outcrop showing the unconformity between the Iwaki Formation and granite of the buried hill, Locality: Joju, Iwaki City.

Fig. 3. Outcrop showing the second cyclothem that covers the first cyclothem at Keishin with diastem.

Fig. 4. Graded bedding in the upper part of the Iwaki Formation, Locality: Shiramizu, Iwaki City.

Fig. 5. Stratified sandstone in the upper part of the Iwaki Formation, Locality: Miya, Iwaki City.



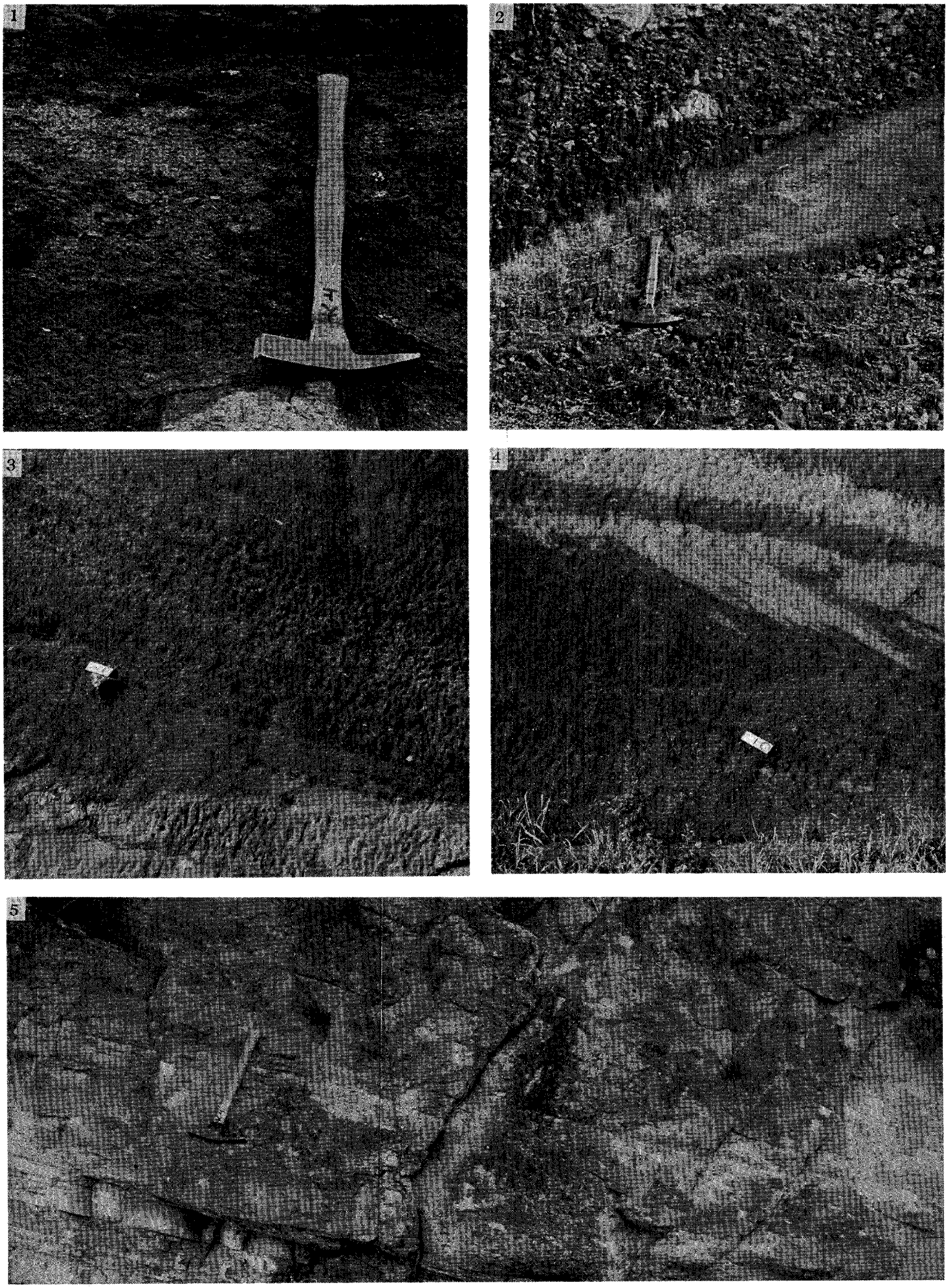

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Plate 6

Fig. 1. Outcrop showing the occurrence of molluscs in the uppermost part of the Iwaki Formation, Locality: Nanamagari, Naraha-machi.

Fig. 2. Outcrop of the Iwaki Formation showing the cross stratification in the sandstone intercalated with conglomerate; Locality: Ishiuchiba.

Fig. 3. Cross stratification in the middle part of the Iwaki Formation, Locality: Yoshima, Iwaki City.

Fig. 4. Cross stratification in the middle part of the Iwaki Formation, Locality: Nagako, Nakoso, Iwaki City.

Fig. 5. Cross stratification in the upper part of the Iwaki Formation, Locality: Miya, Iwaki City.

Plate 7

Figs. 1–3. Outcrops showing the boundary of the cyclothems.

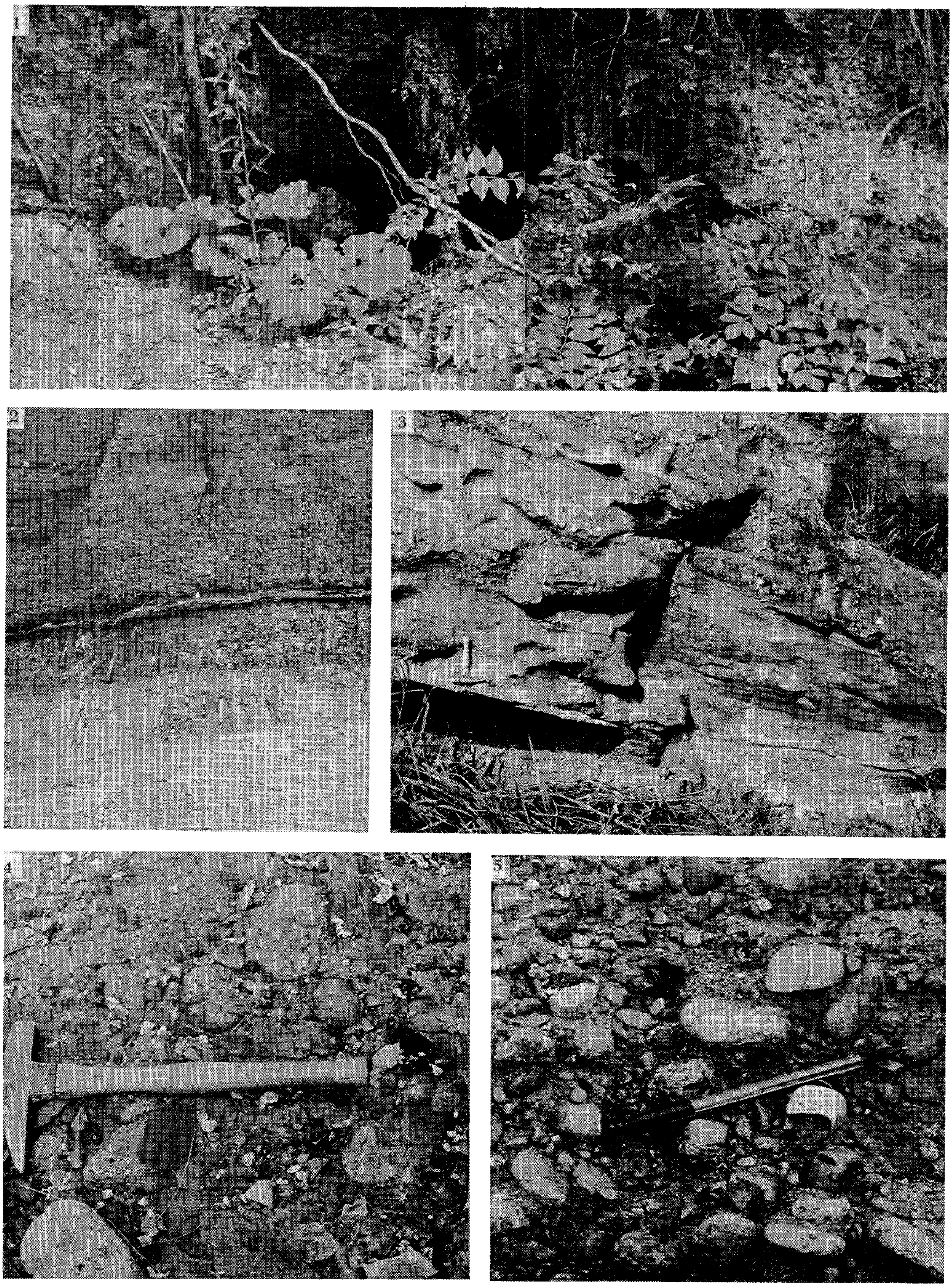
Fig. 1. Outcrop showing the conglomerate at the base of the fourth cyclothem with slight erosion surface, Locality: west of Obisa, Hisanohama-machi.

Fig. 2. Outcrop showing the conglomerate at the base of the third cyclothem covers the coal seam of the second cyclothem, Locality: Kobisa River, Hisanohama-machi.

Fig. 3. Outcrop showing the coarse grained sandstone at the base of the seventh cyclothem covers the coaly shale of the sixth cyclothem, Locality: Nagako, Nakoso, Iwaki City.

Fig. 4. The basal conglomerate of the Iwaki Formation, Locality: Shinyashiki, Obisa River.

Fig. 5. The basal conglomerate of the Iwaki Formation, Locality: Tamayama, Yotsukura-machi.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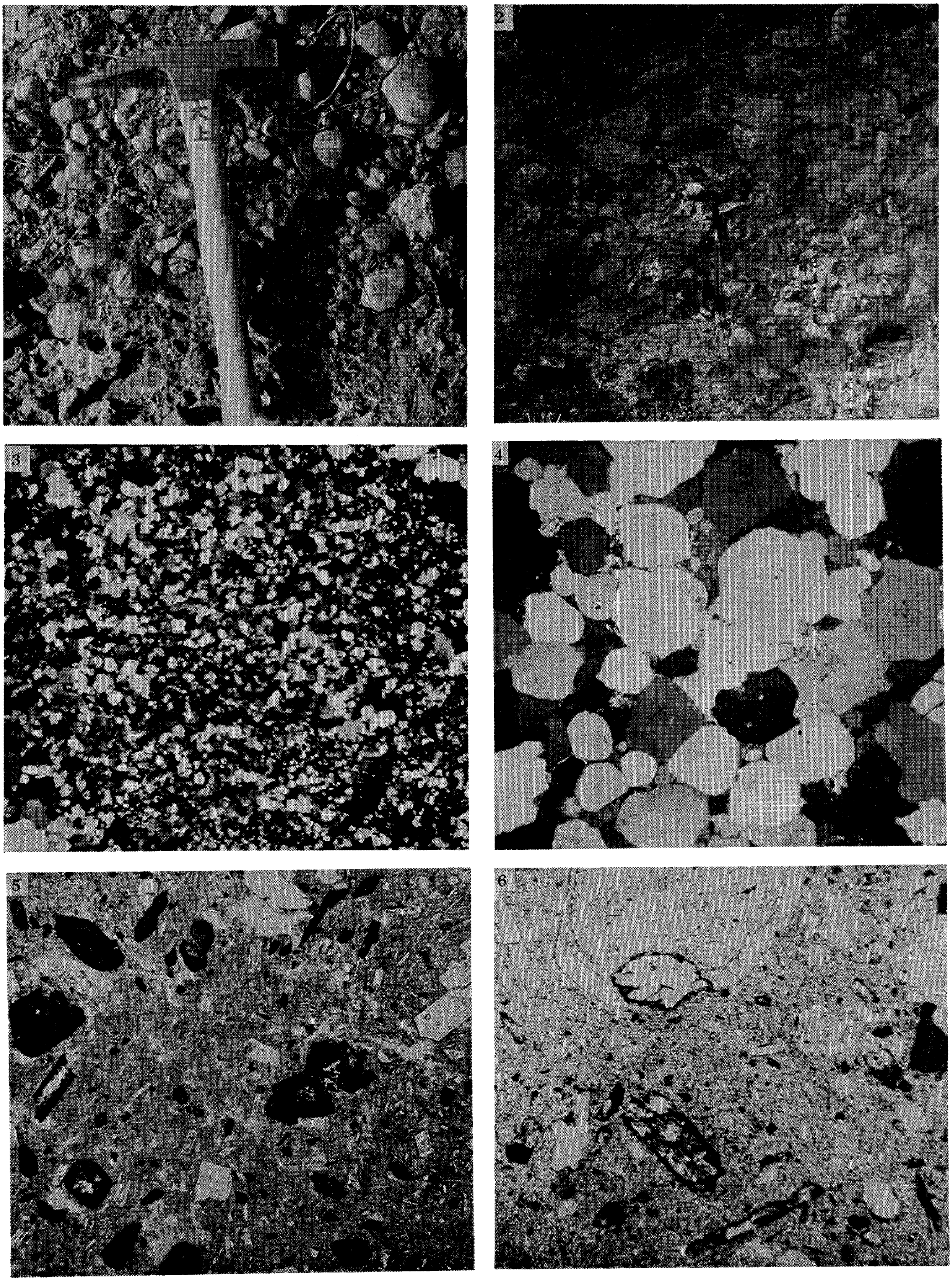


Plate 8

Fig. 1. The basal conglomerate of the second cyclothem of the Iwaki Formation, Locality: Keishin, Iwaki City.

Fig. 2. The basal conglomerate of the Iwaki Formation, Locality: Natsui No. 3 Power Plant.

Fig. 3. Microphotograph of the chert collected from the basal conglomerate of the Iwaki Formation, Locality; Yunotake. Cross nicols; ×30.

Fig. 4. Microphotograph of the orthoquartzite collected from the basal conglomerate of the Iwaki Formation, Locality: Shinyashiki, Obisa River. Cross nicols; ×30.

Fig. 5. Microphotograph of the basaltic andesite collected from the uppermost conglomerate of the Iwaki Formation, Locality: Shinyashiki. Cross nicols; ×30.

Fig. 6. The same as Fig. 5. Open nicols; ×30.

Plate 9

Figs. 1–6. Microphotographs of the thin sections of the sandstone of the Iwaki Formation (Type I and Type II). Cross nicols; ×30

Fig. 1. Type I, sample no. 72405–3, lower part of the Iwaki Formation, Locality: Miya, Iwaki City.

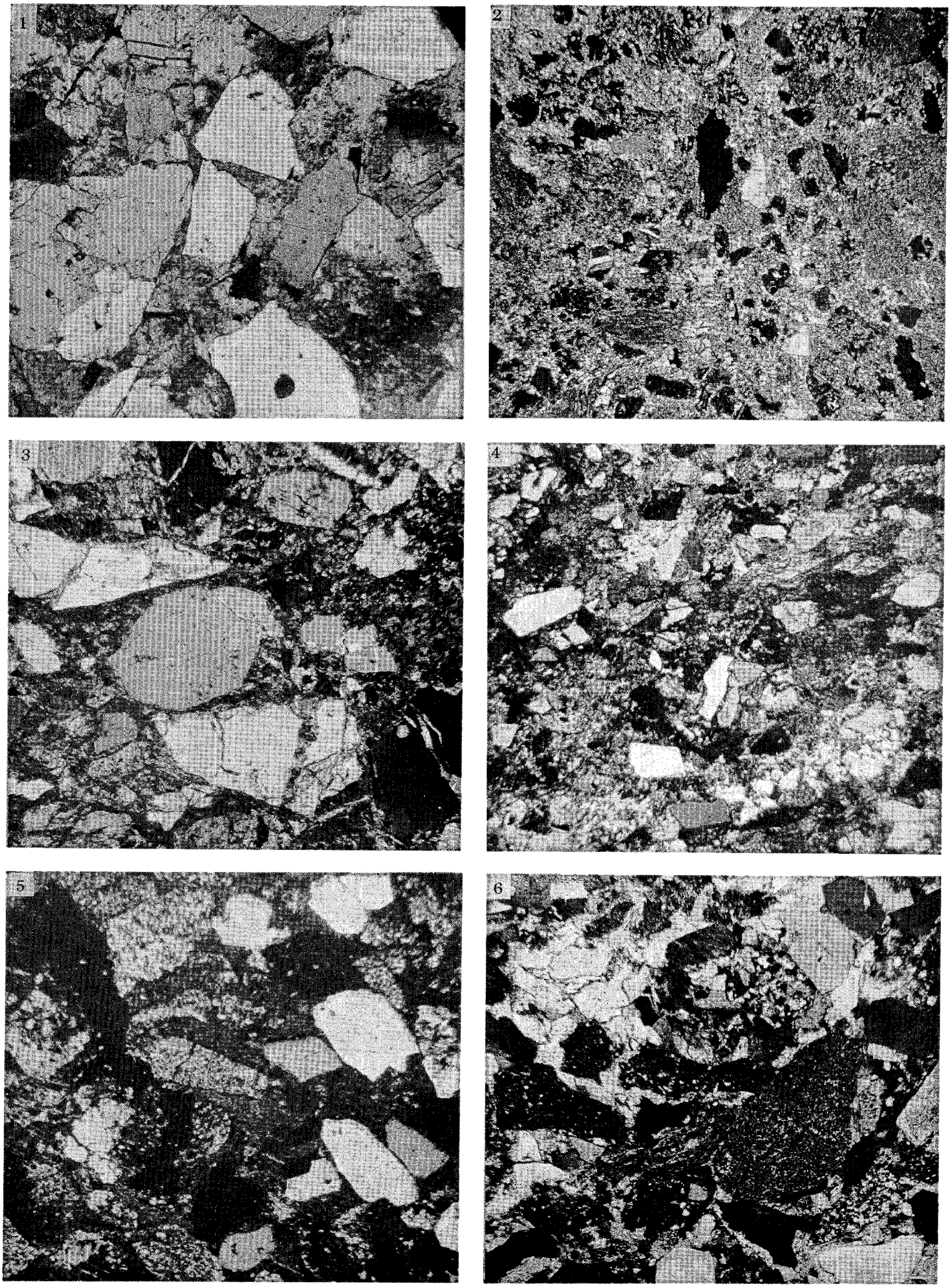
Fig. 2. Type I, sample no. 605–3, lowest part of the Iwaki Formation, Locality: Hakumai, Nakoso, Iwaki City.

Fig. 3. Type I, sample no. 506–3, lower part of the Iwaki Formation, Locality: Joju, Iwaki City.

Fig. 4. Type I, sample no. 91213–3, lowest part of the Iwaki Formation, Locality: Ishiuchiba.

Fig. 5. Type II, sample no. 73007–5, lower part of the Iwaki Formation, Locality: Takasaki.

Fig. 6. Type II, sample no. 91604, lower part of the Iwaki Formation, Locality: Hanakawa, Isohara-machi, Kitaibaraki City.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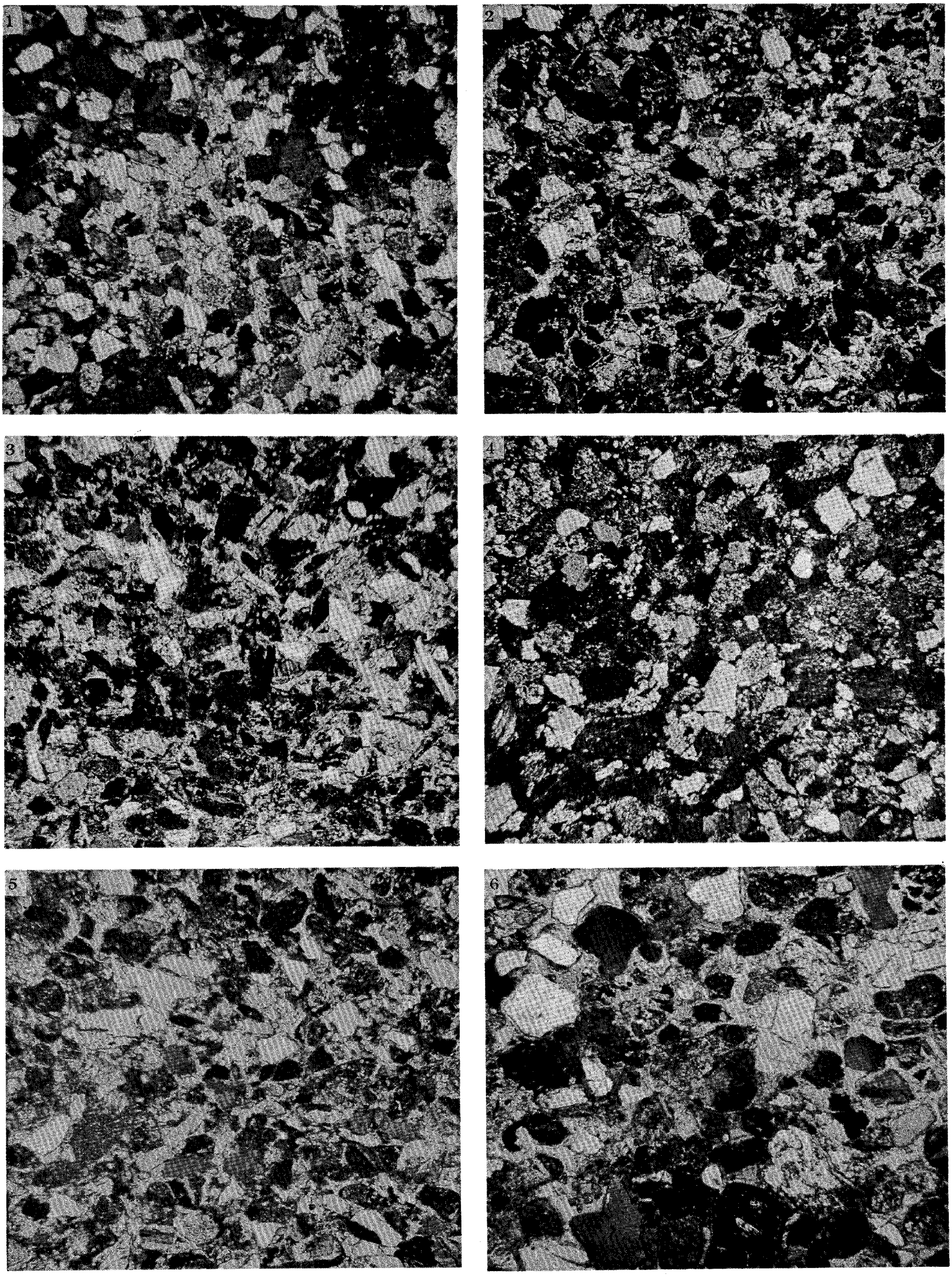
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Plate 10

Figs. 1–6. Microphotographs of the thin sections of the Type III sandstone of the Iwaki Formation. Cross nicols; ×30.

Fig. 1. Sample no. 72302–1, upper part of the Iwaki Formation along the Shiramizu route, Iwaki City.

Fig. 2. Sample no. 72901–2, upper part of the Iwaki Formation along the Shiramizu route, Iwaki City.

Fig. 3. Sample no. 72904–2, middle upper part of the Iwaki Formation along the Shiramizu route, Iwaki City.

Fig. 4. Sample no. 72605–2, middle part of the Iwaki Formation along the Shiramizu route, Iwaki City.

Fig. 5. Sample no. 603–20, middle part of the Iwaki Formation along the Nagako route, Iwaki City.

Fig. 6. Sample no. 91211, middle part of the Iwaki Formation at Saimyoji, Isohara-machi, Kita-ibaraki City.

Plate 11

Figs. 1–4. Microphotographs of the thin sections of the Type IV sandstone of the Iwaki Formation. Cross nicols; ×30.

Fig. 1. Sample no. 8304–1, upper part of the Iwaki Formation at Gotanda, northern part of the Iwaki area.

Fig. 2. Sample no. 91701–8, lower part of the Iwaki Formation along the Ishiuchiba route.

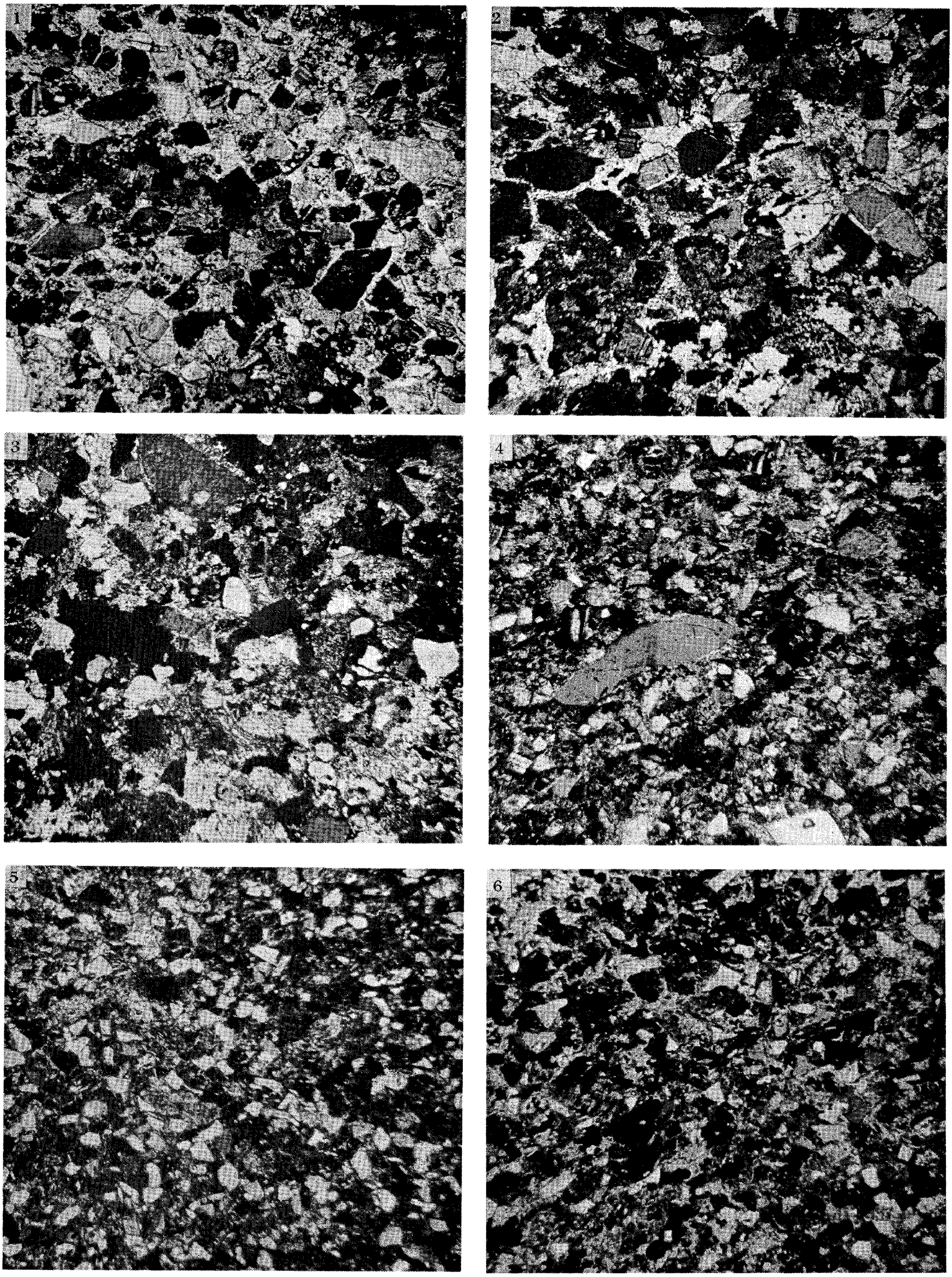
Fig. 3. Sample no. 91701–11, lower part of the Iwaki Formation along the Ishiuchiba route.

Fig. 4. Sample no. 82111–9, upper part of the Iwaki Formation along the Takinosawa route.

Figs. 5, 6. Microphotograph of the thin sections of the Type V sandstone of the Asagai Formation. Cross nicols; ×30.

Fig. 5. Sample no. 82111–5, lowest part of the Asagai Formation along the Takinosawa route.

Fig. 6. Sample no. 8208, lowest part of the Asagai Formation along the Shiramizu route.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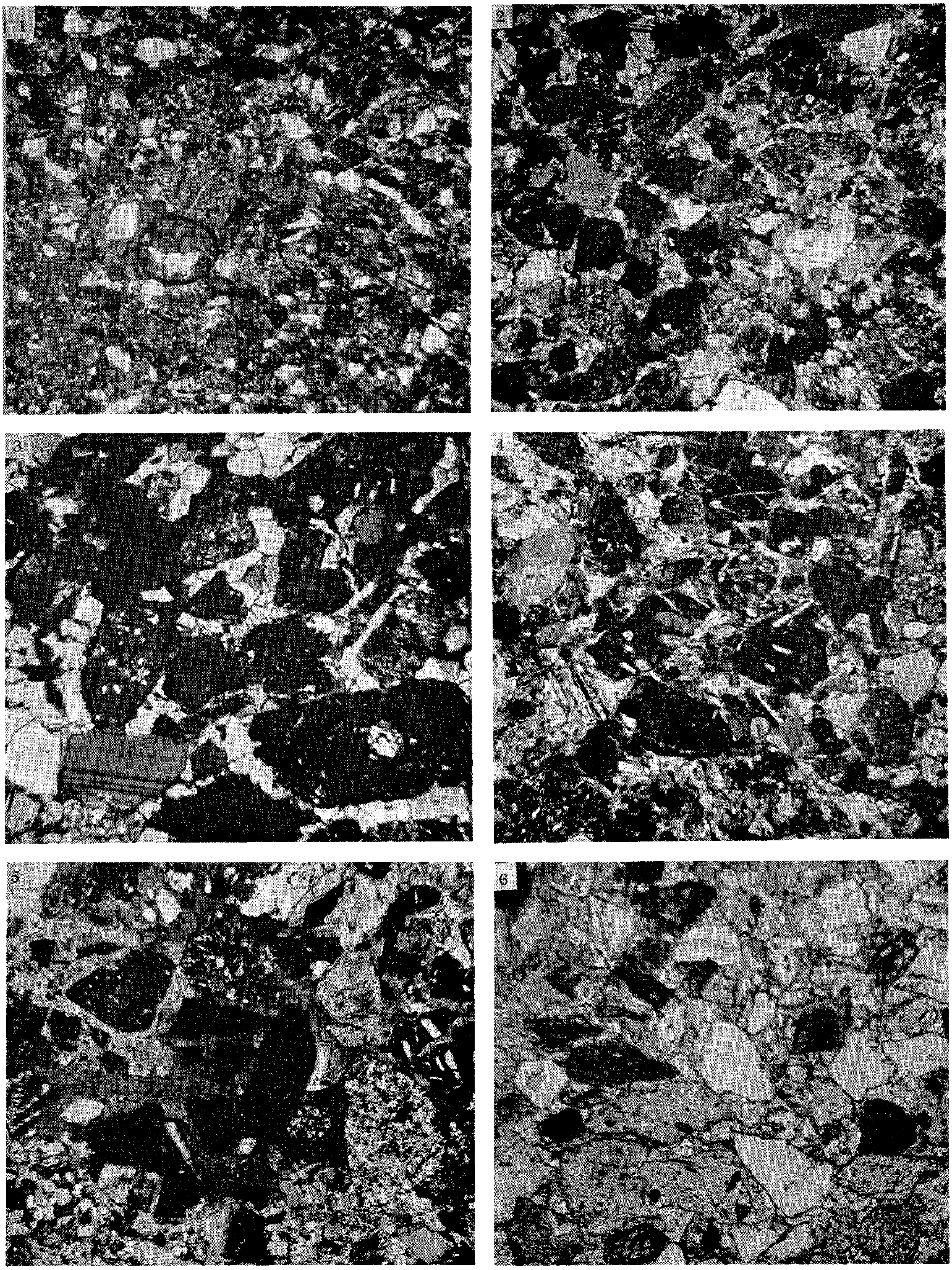
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Plate 12

Figs. 1–6. Microphotographs of the thin sections of three horizons of the Iwaki Formation showing the increase in quantity of the basaltic rock fragments. Fig. 1–5, cross nicols and Fig. 6, open nicols. All enlarged $\times 30$.

Fig. 1. Lower part, sample no. 72505–b, of the Iwaki Formation along the Shiramizu route.

Fig. 2. Lower part, sample no. K–2, of the Iwaki Formation along the Otani route.

Fig. 3. Lower part, sample no. 91701–10, of the Iwaki Formation along the Ishiuchiba route.

Fig. 4. Middle part, sample no. 603–12, of the Iwaki Formation along the Nagako route.

Fig. 5. Middle part, sample no. 91111–6, of the Iwaki Formation along the Ishiuchiba route.

Fig. 6. Upper part, sample no. 72301–1, of the Iwaki Formation along the Shiramizu route. Large grains of pyroxene as seen at the lower left hand.