Magnetostatigraphy of the Yamato Group and the Sendai Group, Northeast Honshu, Japan (I)

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ABSTRACT Magnetostatigraphy of the Late Cenozoic sedimentary sections was studied for correlating the terrestrial sediments in the inland areas of the southern part of Northeast Honshu. In the Aizu Basin, four magnetozones were discriminated in the Yamato Group and the relation of these magnetozones to floral assemblage zones was confirmed in order to establish one of the standard for magnetostatigraphic correlation in the inland areas. The correlation of the magnetozones with the standard polarity time scale was also attempted. Three magnetozones were established for the Sendai Group and their relation to the polarity epoch deduced from the deep-sea sediments was considered. Based on magnetostatigraphy and paleobotany, the correlation between the Yamato Group, Sendai Group and Uonuma Group was attempted. The Sendai Group is approximately correlative with the Izumi Formation and the upper part of the Fujitoge Formation of the Yamato Group. The Uonuma Group is also correlative with the Nanaorizaka Formation of the Yamato Group. Using the magnetostatigraphically derived dates of the Yamato Group and Sendai Group, the rate of sedimentation was estimated in these basins. In the Aizu Basin, two remarkably high sedimentation rates were deduced to have taken place about 4.5 and 1.8 m.y. ago.

INTRODUCTION

In the southern part of the Northeast Honshu, many inland basins are developed in various scales. The Late Cenozoic sections in these basins are characterized by the existence of terrestrial sediments containing the considerable amount of volcanic products, and also characterized by the vertical and lateral changes in lithology.

It has not been established the correlation of these sedimentary sections not only with the global geochronologic units but also with marine sections in Japan, because these mutually exclusive environments of deposition prevent the frequent interdigitation of diagnostic fauna and floras. For the reconstruction of the Late Cenozoic geohistory of the Northeast Honshu, however, it seems to be important to establish the correlation between these terrestrial sedimentary sections developed in the inland area. In the present study, therefore, magnetostatigraphy has been adopted for resolution of the relevant problems.

Recently, many magnetostatigraphic studies have been made on the sedimentary sections of both marine (Nakagawa et al., 1969, 1971, 1977; Kennett and Watkins, 1974; Kimura, 1974; Niitsuma, 1976) and terrestrial (Ishida et al., 1969; Manabe et al., 1970; Johnson et al., 1975; Nitobe, 1977) origin. Magnetostatigraphic correlation is based on the stratigraphic variations...
in magnetic characteristics of rock strata such as polarity and intensity of remanent magnetization. Because of the global contemporaneity of geomagnetic field reversal, the magnetostratigraphy is useful not only in the inter-regional correlation of sedimentary sections but also in the correlation of global extent.

In order to establish the standard for magnetostratigraphic correlation in the inland area and to establish the correlation between the terrestrial sedimentary sections in the southern part of Northeast Honshu, the Aizu Basin, Shirakawa area, Sendai area and Tokamachi Basin were studied (Fig. 1). In the Aizu Basin, which is situated between the Ou Backbone Ranges and the Echigo Ranges, a continuous section of the Late Cenozoic sediments is developed. The Yamato Group conformably overlies the Miocene Yamasato Group, and has been subdivided into the Fujitoge, Izumi, Nanarizaka and Todera Formations in ascending order. The floral assemblages from various horizons of the Yamato Group have been studied in detail, and it has become possible to define several floral assemblage zones (Suzuki, 1961, 1976). The Fujitoge Formation is considered to be a correlative with V stage of Kitamura (1959) on the basis of paleobotanical evidence (Kitamura and Takayanagi, 1971; Suzuki et al., 1972).

In the lowland terrain between the Kitakami Massif and the Ou Backbone Ranges of Miyagi Prefecture, the Sendai Group is well developed. The group consists mainly of terrestrial sediments except the Tatsunokuchi Formation and a part of the Dainenji Formation (Hanzawa et al., 1953). Many plant fossils have been yielded from the group and they have been described as the Sendai Flora by Okustu (1955).

In the Oguni and Tokamachi Basins, southern part of Niigata Prefecture, the Early Pleistocene Uonuma Group is extensively developed (Miyashita et al., 1970). The Uonuma Group consists mainly of terrestrial coarse-grained sediments, from which many plant fossils and pollen fossils have yielded in the Tokamachi area (Yamanoi et al., 1970).

These sections have yielded abundant plant fossils and contain many pyroclastic layers which are useful for tracing the sampling horizons into each area, therefore, they are suitable for the combined magneto- and biostratigraphic investigation.

Moreover, it is substantial problem whether original geomagnetic record has been preserved in sediments, and the areas are also suitable to examine the paleomagnetic stability of sediments.

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LATE CENOZOIC STRATIGRAPHY OF THE STUDIED AREA

1. AIZU BASIN

A continuous section of the Late Cenozoic sediments is distributed in the Aizu Basin. Suzuki (1951) first studied the geology of the western part of the Aizu Basin, and since then stratigraphic investigations have been made extensively on the Late Cenozoic section in the Aizu Basin. The results of these works were summarized in the explanatory notes to geologic maps of the area (Suzuki, 1964; Suzuki et al., 1968, 1972, 1973).

The Late Cenozoic section is divided into the Miocene Yamasato Group and the Mio-Pliocene Yamato Group (Suzuki, 1951). The Yamasato Group consists of marine sediments composed mainly of green tuff, and has been subdivided into the Kagata, Ogino, Urushikubo and Shiotsubo Formations in ascending order. The Yamato Group consists mostly of terrestrial sediments, such as poorly consolidated fluvial and lacustrine deposits, and has been subdivided, in ascending order, into the Fujitoge, Izumi and Nanaorizaka Formations (Suzuki, 1951). Subsequently, stratigraphy of the Nanaorizaka Formation have been revised and subdivided into the Todera Formation above and the Nanaorizaka Formation below (Suzuki et al., 1972).

The stratigraphic succession established in the Aizu Basin is shown in Figure 2. A summary of the stratigraphy of the studied area, including lithology and fossil content, is described below.

a. Yamasato Group

a-1. Shiotsubo Formation

The type locality of the formation is the area along the Aga River, about 500m west of Shiotsubo, Takasato Village (Suzuki, 1951). The Shiotsubo Formation, about 100m thick, consists of three distinct facies; the lower alternation of sandstone and mudstone, the middle alternation of tuffaceous sandstone, siltstone, tuff, and the upper massive medium-grained sandstone. The Shiotsubo Formation conformably overlies the Urushikubo Formation in most of the area, but the formation is unconformable with the Urushikubo Formation in the southern part of the distribution area. The middle part of the formation yielded abundant
marine molluscan fossils, which constitute the so-called "Yama Fauna" (Nomura, 1935; Otuka, 1941).

The upper part of the formation yielded macroscopic plant fossils, and detailed investigations have been made on the floral assemblage (Huizioka and Suzuki, 1954; Suzuki, 1961). The flora is characterized by the warm-temperate ever-green broad-leaved tree elements such as Cinnamomum sp., and the temperate deciduous broad-leaved tree elements such as Fagus palaeocrenata. Most of them are characteristic elements of the Middle Miocene in the Japanese Islands.

b. Yamato Group

b-1. Fujitoge Formation

The Fujitoge Formation, about 300 m in thickness, is widely distributed in the mountainous area to the west of the Aizu Basin and consists of an alternation of conglomerate, sandstone and mudstone with interbedded tuff and lignites. The formation conformably overlies the Shiotsubo Formation in the central part of the distribution area, but it is unconformable with the underlying formations in the marginal part of the area.

The Fujitoge Formation has been subdivided into four parts, the lowermost, lower, middle and upper, based upon the lithology, and they are conformably with one another (Suzuki, 1964). The lowermost part of the Fujitoge Formation has been designated as the Ikenohara Coarse-grained Sandstone Member (Suzuki and Yoshida, 1956). This part is less than 20 m in thickness and consists mainly of white coarse-grained sandstone composed of quartz grains. In the following lines, this member is included in the lower part for descriptive convenience. The lower part of the formation is composed of an alternation of fine tuff, sandstone and mudstone, most of which are characterized by their fairly distinct laminations and intercalated lignites. The lower half of the lower part of the formation seems to have been deposited partly under a brackish condition, because molluscan fossils such as Crassatellites sp. and Natica sp. occurred along with plant fossils. But, most of the lower part excepting the basal part seems to have been deposited under a terrestrial (lacustrine) condition, because molluscan and aquatic plant fossils indicating a fresh water condition occur frequently.

The middle part of the formation consists mainly of conglomerate and many distinct
strata of pyroclastic flows, and partly of an alternation of conglomerate, sandstone and mudstone intercalated with coaly mudstones. Abundant molluscan and aquatic plant fossils indicate lacustrine and fluvial conditions in this part. The biotite-bearing rhyolitic tuff occupying the top of the middle part of the formation is an important marker bed throughout the area studied. The upper part of the Fujitoge Formation consists of conglomerate, sandstone and mudstone interbedded with lignite and tuff beds. This part is thin and contains many fresh water plants.

Several horizons of the Fujitoge Formation have yielded abundant plant fossils at about 90 localities. By a detailed examination of the stratigraphic range of the characteristic species, three fossil assemblage zones, the shiroko, Sudani and Natsui floral assemblage zones in ascending order have been established (Suzuki, 1976).

The characteristics of these floral assemblage zones and lithology of the Fujitoge Formation were described by Manade and Suzuki (1977).

2. Izumi Formation

The Izumi Formation is widely distributed in the mountainous area to the west of the Aizu Basin, and its type locality is the area along the Tadami River, north of Izumi, Aizunbange Town. The formation ranges from 200 to 400m in thickness, and the distribution area is limited in that of Fujitoge Formation. In most area, the Izumi Formation conformably overlies the Fujitoge Formation, but in the southern part of the distribution area it is unconformable with the Fujitoge Formation. The formation consists of an alternation of poorly-consolidated conglomerate, sandstone and mudstone with interbedded tuff and lignites. Five distinctive tuff layers are discriminated in the formation, and are named I₁ to I₅ in ascending order (Manabe et al., 1970).

The formation has been subdivided into three parts, the lower, middle and upper parts whose bottoms are marked by the tuff I₁, I₃ and I₅, respectively. In the mountainous area to the southwest of the Aizu Basin, the thick dacitic tuff which contains a welded part, is interbedded in the lower part of the Izumi Formation and has been named as the Hotokezawa Dacitic Tuff Member (Suzuki, 1964). The welded part of this member is regarded to be equivalent to the I₃ tuff layer, and its K-Ar age is 3.8 m.y. (Suzuki et al., 1976).

Several horizons of the Izumi Formation have yielded plant fossils at about 110 sites. Two fossil assemblage zones, the Fukurohara and Koyanaizu floral assemblage zones, are discriminated in the Izumi Formation (Suzuki, 1976).

The Koyanaizu Floral Assemblage Zone corresponds to the lower part and the lower half of the middle part of the Izumi Formation, and is characterized by Fagus microcarpa, Paliurus nitponicus and Picea koribai. This zone is also characterized by needle-leaved tree elements of older age, such as Metasequoia, Glyptostrobus and Pseudolarix, but an older element Liquidambar has not found. The first appearance of Juglans megacrenerea in this zone is noticeable.

The Fukurohara Floral Assemblage Zone corresponding to the upper half of the middle part and the upper part of the Izumi Formation, is characterized by Juglans megacrenerea, Pterocarya paliurus and associated older elements such as Metasequoia. At the base of this zone, an older element Glyptostrobus disappears and a younger element Menyanthes trifoliata var. minusculus appears first.
Fig. 3. Geological map of the mountainous area to the west of the Aizu Basin (after Suzuki et al., 1968, 1973; Manabe and Suzuki, 1976) and location of the studied sections.
b-3. Nanaorizaka Formation

The type locality of the Nanaorizaka Formation is at Otezawa, along the Tadami River, about 500m north of Izumi, Aizu-Bange Town. The Nanaorizaka Formation has a wide distribution in the mountainous area to the west of the Aizu Basin, and overlies the Izumi Formation with conformity (Fig. 3). But, in the northern and southern parts of the basin, the formation is unconformable with the underlying formations. The Nanaorizaka Formation, about 300m thick, has been subdivided into the lower and upper parts based upon the lithology. The lower part, about 100m thick, consists mainly of poorly-consolidated conglomerate composed of rounded cobbles and pebbles. In the northern part of its distribution, the lower part of the formation is characterized by alternation of conglomerate, sandstone and mudstone.

The upper part, about 190m thick, consists generally of conglomerate and pumiceous tuff layers. Toward the southern part from Nishimura, it is characterized by dominant tuff layers. Four distinctive dacitic tuff layers are discriminated in the upper part, and named T_1 to T_4 in ascending order (Manabe et al., 1970). Abundant macroscopic plant fossils are yielded at about 22 sites from the several horizons of the Nanaorizaka Formation. A detailed study on the stratigraphic ranges of the characteristic species established three fossil assemblage zones, the Otezawa, Osawa and Todera 1-2 floral assemblage zones in ascending order (Suzuki, 1976).

The Otezawa Floral Assemblage Zone coincides with the lower part and lower half of the upper part of the formation, and is characterized by the temperate broad-leaved elements associated with older extinct elements such as Metasequoia, Juglans megacrinerea and Pterocarya paliurus. The zone is also characterized by boreal species such as Picea maximowiczii and Menyanthes trifoliata. Similar character of composition is recognized in the pollen assemblage from the same horizon which is dominantly composed of TCTF (i.e. Taxaceae, Cupressaceae, Taxodiaceae and Fagus).

The Osawa Floral Assemblage Zone coincides with the upper half of the formation excluding the T_3 tuff and above. The zone is characterized by the disappearance of exotic older elements and the appearance of many new subalpine elements such as Pinus koraiensis, Picea maximowiczii, P. jezoensis and Abies veitchii. Juglans mandshurica and many aquatic plants are also found together with them. The pollen assemblage from this zone is characterized by a composition similar to that of macroscopic remains, showing a dominance of APTB (i.e. Abies, Picea, Tsuga and Betula).

The Todera 1-2 Floral Assemblage Subzone corresponding to the interval between the T_3 and T_4 tuff layers in the upper part of the formation, is characterized by temperate species such as Fagus crenata, Styrax japonicus and Trapella primaria.

b-4. Todera Formation

The Todera Formation is typically exposed in the vicinity of Todera, Aizu-bange Town. The formation has a thickness of about 150 m in its type locality, and its distribution is within the Nanaorizaka Formation. This formation conformably overlies the Nanaorizaka Formation and consists of an alternation of gravel, sand, mud and tuff with intercalation of lignites.

According to Suzuki (1976), five floral assemblage subzones have been discriminated in the Todera Formation, which are the Todera 3, 4, 5-6, 7 and 8 Floral Assemblage Subzo-
nes in ascending stratigraphic order. Todera 7 Floral Assemblage Subzone is characterized by broad-leaved arboreal species which are mainly distributed in temperate zone in Japan, such as *Quercus serrata*, *Buxus japonicus* and *Juglans mandshurica* var. *sachalinensis*. This subzone is also dominated by TCTF in the pollen assemblage. Todera 3, 5-6 and 8 Subzones are characterized by Japanese subalpine elements.

b-5. Seaburiyama Formation

The Seaburiyama Formation is widely distributed in the mountainous area to the east of the Aizu Basin. The formation overlies the underlying Miocene and older rocks with unconformity, and its distribution extends from foot of the Mt. Nekoma to south of the Lake Inawashiro (Fig. 4).

The Seaburiyama Formation, 150 to 200 m in thickness, consists mostly of dacitic pyroclastic rocks such as pumiceous tuff and welded tuff. The formation has been subdivided into four parts, the lower, middle, upper and uppermost parts, by interbedded strata of gravel, sand and mud at the bottoms of them. The uppermost part of the formation has a limited distribution in the northern part. The upper and middle parts consist mostly of dacitic welded tuff in the southern area from the Mt. Seaburi, and their distribution extend to the Mt. Aizununobiki, southwest to the Lake Inawashiro. The welded tuff of the upper and middle parts of the formation are correlative with D1 and D2 tuff of the Shirakawa Formation, respectively, on the basis of their distribution and the similarity of lithofacies of each tuff layers. The lower part of the formation consists of densely welded dacitic tuff, which is distributed in the mountainous area to the south of Mt. Seaburi.

On the other hand, the Seaburiyama Formation which is distributed in the hilly lands on the foot of mountains to the east of the Aizu Basin consists mainly of non-welded pumiceous tuff and interbedded strata of gravel, sand and mud. The boring core from the western part of Aizu-wakamatsu City indicates that the Seaburiyama Formation continues to a depth of 150 m from the surface of the basin. Moreover, from lithological similarity this formation is correlative with the Nanaorizaka Formation which is distributed in the mountainous area to the west of Aizu Basin (Suzuki et al., 1972). The result of pollen analysis of samples obtained from other boring core also suggests that the Seaburiyama Formation is correlative with the Nanaorizaka Formation (Suzuki et al., 1977a). Therefore, these three formations are correlative with each other on the evidence mentioned above (Fig. 2). It seems that the compositions of heavy minerals extracted from the tuff layers in these formations support the conclusion.

2. SHIRAKAWA AREA

The dacitic welded tuff, "Shirakawa-ishi" in local name, have a wide distribution in the
hills west of Abukuma lowland terrain from south of the Lake Inawashiro southwards to Shirakawa and Sukagawa Cities. The "Shirakawa-ishi" overlies the Miocene Series and basement rocks with unconformity in the areas mentioned above. The stratigraphic succession in the Shirakawa area is shown in Figure 2.

a. Shirakawa Formation

Manabe et al. (1968) studied the stratigraphy of the so-called "Shirakawa-ishi" corresponding to the Shirakawa Dacitic Tuff (Koizumi, 1963) or the Shirakawa Dacitic Welded Tuff (Kitamura et al., 1965). According to the result of the study, three distinct welded tuff have been discriminated in the "Shirakawa-ishi", and named D1, D2 and D3 respectively in descending order. Subsequently the "Shirakawa-ishi" has been renamed as the Shirakawa Formation (Suzuki et al., 1977b). The distribution of the welded tuff in the vicinity of Shirakawa City is shown in Figure 5.

D1 tuff is characterized by coarse-grained quartz and hornblende contained, and is densely welded in the vicinity of Shirakawa City. The welded tuff attains about 50 m in thickness. D2 tuff has a wide distribution, and is densely welded in most areas. The tuff attains thickness of about 30 to 50 m in the vicinity of Shirakawa, which increases towards the western mountain. The tuff is generally purplish-colored and characterized by lenses of pumice and obsidian, and in most cases, it contains considerable amount of essential dacitic rock fragments derived from the same source in the pyroclastic flow. D3 tuff has a small distribution in the northeastern part of Shirakawa, but its exact thickness is uncertain because of poor exposure. The tuff is weakly welded and somewhat weathered. The lithologic character of D3 is similar to that of D2, but has more basic nature as compared to the other tuff.

The K-Ar age determinations of welded tuff in the Shirakawa Formation have been made by Suzuki et al. (1976). As a result of the study, D2 was dated 1.1 m.y. and overlying D1 was restricted to the age range 1.4 - 1.6 m.y. This inconsistency is considered to be due to weathering effect of measured samples and error in age determination.

3. SENDAI AREA

Since Hanzawa et al. (1953) summarized the geology of Sendai and its environs, numerous studies have been made on the Late Cenozoic section in and around Sendai. Some minor stratigraphic revisions have been also made through these investigations. For example, the Yumoto Formation, which had been considered unconformable with the underlying
Tsunaki Formation, was later thought to be conformable with the latter formation and was treated as a member of the Tsunaki Formation (Shibata, 1962). Shibata (1962) also pointed out the existence of unconformity between the Yumoto Tuff Member and the overlying Shirasawa Formation. In 1967, Niitsuma proposed new stratigraphic unit by the name of Nashino Tuff to the acidic tuff which had been considered previously to be the northwestern extension of the Yumoto Tuff, and revealed that the Nashino Tuff is unconformable with the overlying Shirasawa Formation (Niitsuma, 1967 MS).

Subsequently, a preliminary account on the stratigraphy of Sendai area was given by Nakagawa (1973), and is followed in this study. The succession and lithology of the Late Cenozoic stratigraphic units reported by Nakagawa (1973) are as follows:

Aobayama Formation (10 - 35 m)
Gravel and volcanic ash of its upper part.

Unconformity

(Sendai Group)
Dainenji Formation (50 m)
Blue-gray siltstone and sandstone.

Mukaiyama Formation (40 m)
Consisting of three parts: upper lignite, sandstone, siltstone and tuff, middle massive tuff named the Hirosegawa Tuff Member, lower conglomerate, sandstone and siltstone.

Unconformity

Tatsunokuchi Formation (50 - 60 m)
Blue-gray siltstone, sandstone and tuff.

Kameoka Formation (10 - 30 m)
sandstone, conglomerate, siltstone and tuff.

Unconformity

Mitaki Formation (200 m)
Andesitic basalt lava, agglomerate and tuff.

Shirasawa Formation (300 m)
Tuff, tuffaceous siltstone and sandstone.

Nashino Tuff (80 m)
Massive tuff with interbedded siltstone.

Unconformity

(Monoiwa Formation (20 - 60 m)
Sandstone, conglomerate and calcareous sandstone; basal part interfingering with the Takadate Formation.

Takadate Formation (60 - 250 m)
Andesite, basalt and agglomerate.
Tsukinoki Formation (20 - 150 m) 
Conglomerate and sandstone.

Many paleontological studies on the Sendai Group have been published (Nomura, 1938; Takayanagi, 1950; Hanzawa et al., 1953; Okutsu, 1955; Hatai and Masuda, 1966; Koizumi, 1972, 1973). Okutsu (1955) reported abundant plant fossils from the Shirasawa Formation which is overlain by the Sendai Group with unconformity, and established the floral assemblage as the Nenoshiroishi Flora. The Nenoshiroishi Flora is characterized by such species as Fagus palaecrenata, Betula miomaximovicziiana and Liriodendron honsonis. Okutsu (1955) also reported many plant fossils from the Sendai Group and are described later. In the present study, many additional plant fossils have been obtained from the Sendai Group at 8 sites (Table 7, Fig. 8). In the following lines, based on the previous works, the every stratigraphic unit of the Sendai Group is summarized.

a. Sendai Group
   a-1. Kameoka Formation

   The Kameoka Formation is typically exposed along the Hirose River in Kameoka (the type locality), and has a thickness of about 30 m. The formation overlies the Mitaki Formation and the underlying formations with unconformity. The formation consists mainly of an alternation of conglomerate, sandstone, tuff and siltstone with interbedded lignites. The paleontological evidence and lithology of the formation indicate that most of the formation seems to have been deposited under terrestrial and lagoonal conditions.

   From the type locality, macroscopic plant fossils such as Glyptostrobus europeus, Sequoia sempervirens, Fagus crenata and Cinnamomum scheuchzeri have been reported (Okutsu, 1955). In the present study, in addition to the above species, many fossil plants including such species as Quercus crispula, Fagus microcarpa and F. palaecrenata have been obtained from the vicinity of Sakuragaoka (Table 7, Fig. 8).

   a-2. Tatsunokuchi Formation

   The type locality is the Tatsunokuchi Gorge in the southwestern part of Sendai City. The Tatsunokuchi Formation which is conformable with the Kameoka Formation consists of tuffaceous sandstone, siltstone and tuff. The formation, about 50 to 60 m in thickness, has a wide distribution on the east of Abukuma Massif and in the Kitakami lowland from the northern part of Ibaraki Prefecture to the environs of Ichinoseki, where it is called by the name of Yushima Formation, and further north.

   The Tatsunokuchi Formation is characterized by many kinds of marine fossils. Molluscan species such as Anadara tatunokutiensis (Nomura and Hatai), Dosinia tatunokutiensis Nomura, Fortipeten takahashii (Yokoyama) and thick-shelled shallow water forms are characteristic fossils (Nomura, 1938). The molar teeth of Triophodon sendaiicus Matsumoto were reported from the formation at Kitayama and Aramaki, Sendai City (Matsumoto, 1924; Hatai and Masuda, 1966). The formation has also yielded some plant fossils such as Juglans cinerea, Pseudosassa purpurascens, Fagus crenata and Quercus crispula (Okutsu, 1955).

   Recently, the diatom assemblage from the Tatsunokuchi Formation distributed in Fukushima and Miyagi Prefectures, have been examined by Koizumi (1972, 1973). According
to Koizumi (1972); the diatom flora of this formation in Fukushima Prefecture, is dominated by *Denticula kamtschatica*, *D. seminae* and some species of the genus *Thalassiosira*.

a-3. Mukaiyama Formation

The Mukaiyama Formation was defined by Nakagawa (1973). The formation comprises three previously defined units, the Kitayama Formation, Hirosegawa Tuff and Yagiyama Formation of Hanzawa *et al.* (1953). The Mukaiyama Formation, about 40 m in thickness, is unconformable with the underlying Tatsunokuchi Formation. The basal part below the Hirosegawa Tuff, which has been called the Kitayama Formation, consists mainly of basal conglomerate and sandstone, intercalating siltstone and coaly beds. The upper part above the Hirosegawa Tuff consists of massive tuff, sandstone, tuffaceous siltstone and lignitic beds, and has been called previously the Yagiyama Formation. The Hirosegawa Tuff Member, about 10 m thick, is typically exposed along the Hirose River in the City. It consists mainly of massive pumiceous tuff and contains wood stems and natural charcoals.

The Mukaiyama Formation has yielded abundant plant fossils such as *Glyptostrobus*, *Metasequoia*, *Sequoia*, *Alnus* and *Fagus* (Okutsu, 1955). In the present study, additional fossil plants such as *Salix* and *Cornus* are reported (Table 7).

a-4. Dainenji Formation

The Dainenji Formation, about 50 m in thickness, conformably overlies the Mukaiyama Formation, and is overlain unconformably by the Aobayama Formation. The formation consists mainly of siltstone and sandstone, and its distribution is limited to Sendai and its southern environs.

The formation has yielded many molluscan fossils such as *Callithaca adamsi*, *Anadara cf. amicula* and *Dosinia japonica* (Hanzawa *et al.*, 1953). Plant fossils such as *Glyptostrobus* and *Liquidambar* have also been reported from this formation (Okutsu, 1955). In addition, in the present study, many plant fossils such as *Fagus microcarpa*, *Nyssa sylvatica* and *Paliurus nipponicus* have been obtained from the lower part of the formation.

**METHODS AND MATERIALS OF MAGNETIC STUDIES**

1. FIELD METHODS

a. Sampling

The samples for paleomagnetic study were obtained, by using a gasoline powered portable core-drill, at about 190 sites in the western part of the Aizu Basin, 11 sites in the Shirakawa area and 21 sites in the Sendai area.

Generally, the sediments ranging the grain size from silt to fine sand provide the best paleomagnetic records, and hence, in most cases tuffaceous siltstone and fine-grained sandstone were sampled (Manabe, 1977).

The outcrop was cleaned to a depth of 20 - 30 cm before drilling, and two or three cores of 3.3 cm in diameter and average 10 cm length were taken at each sampling site. The cores were oriented by compass, and the precision of core orientation is estimated to be ± 5°. In most cases, the stratigraphic interval of the sampling sites was less than 10 m except in the case of conglomerate.
b. Description of the sections studied

b-1. Aizu Basin

Location of the sections from which paleomagnetic samples have been collected are shown in Figure 3.

**Shiotsubo Formation**: The paleomagnetic samples of the Shiotsubo Formation were obtained at 10 sites in the Shiotsubo section and 2 sites in the Fujitoge section. The Shiotsubo section is well exposed along the Aga River with homoclinal structure. The lithology of the formation is characterized by massive sandstone and siltstone with intercalation of tuff.

**Fujitoge Formation**: The samples for paleomagnetic study were obtained at 47 sites in the five separate sections; the Kamifujisawa, Miyako-gawa, Ohbayashi, Fujitoge and Yasakano sections (Fig. 3). The detailed lithology of these sections were described by Manabe and Suzuki (1977).

The Kamifujisawa, Miyako-gawa and Ohbayashi sections are located in the northwestern part of the Aizu Basin. At most sites, tuffaceous siltstone and fine-grained sandstone were sampled. The Fujitoge section is situated near the type locality of the Fujitoge Formation, about 10 km southwest of the Ohbayashi section. The dip of the strata is generally steep in this area and the strata have a homoclinal structure.

The Yasakano section is located along the Yasakano River about 2 km east of Yanaizu and running almost normal to the trend of the strata. The strata in this section have been subdivided into the Fujitoge, Izumi and Nanaorizaka Formations in ascending order. In this section, paleomagnetic samples were collected at 6 sites from the upper part of the Fujitoge Formation.

**Izumi Formation**: Paleomagnetic samples of the Izumi Formation were obtained at 20 sites in the Yasakano section and 19 sites in the Hara-gawa section about 2 km east of Yamato. In these sections, the Izumi Formation is characterized by an alternation of sandstone, siltstone, conglomerate and tuff. In the Hara-gawa section, the basal part of the formation is not exposed.

**Nanaorizaka and Todera Formations**: In the Hara-gawa section, paleomagnetic samples were collected at 12 sites from the lower part of the Nanaorizaka Formation.

The Todera section is situated at the type locality of the Nanaorizaka and Todera Formations. The strata in this section are generally trending in northeast and dipping to southeast direction with homoclinal structure. In most cases, fine-grained tuffaceous sediments, and in some cases pumiceous tuff were collected at 26 sites.

**Seaburiyama Formation**: The Seaburiyama Formation is well exposed along a road to the north of Mt. Seaburi. Paleomagnetic samples were collected from dacitic welded tuff of the upper and middle parts of the formation at 3 sites along this road (Fig. 4). In the vicinity
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b-2. Shirakawa area

For paleomagnetic measurement, the samples were collected from three welded tuff layers of the Shirakawa Formation at the four sampling sites situated in the northwestern part of Shirakawa City (Fig. 5). Columnar sections at the sampling locality and the stratigraphic positions of the samples are schematically shown in Figure 6.

The Shirakawa Formation is typically exposed along the cliff located in the northern part of Kutano. The samples were taken from three welded tuff layers, D1, D2 and D3, in this section. In the Mukaidera section the samples were taken from the D1 tuff which has been densely welded. The samples from D2 and D3 tuff were also taken at 3 sites in the Izumida and Kodagawa section, where the D1 tuff is not distributed.

b-3. Sendai area

Location and lithology of the sections from which paleomagnetic samples and plant fossils have been collected are shown in Figures 7, 8. The Sozenji and Hyojogawara sections are well exposed on cliffs on roadside along the Hirose River, running almost normal to the general strike of the strata. In these sections, strata are in generally striking in northeast and dipping to the south.

In these sections, two or three cores were taken at each of the 6 sites in the Dainenji Formation and 4 sites representing the upper half of the Mukaiyama Formation (Fig. 8). As a rule, siltstone and tuffaceous fine-grained sandstone were sampled for paleomagnetic measurement. The samples from the Tatsunokuchi Formation and the Hirosegawa Tuff Member of the Mukaiyama Formation are taken on the wall of the Tatsunokuchi Gorge.

In the Sakuragaoka section, tuffaceous siltstone and fine-grained sandstone of Kameoka Formation were sampled at 4 sites. Abundant plant fossils were also collected from the section.

2. MEASUREMENT

a. Measurement of remanent magnetism

For the paleomagnetic analysis, a segment of 3.3 cm in length was cut from each core. The natural remanent magnetization (NRM) was measured with an astatic magnetometer placed within a two-layered shield case. The sensitivity of the magnetometer was about $1 \times 10^{-7}$ Gauss/division. Special attention was paid to simple and rapid operation in measurement, which was achieved by using an automatic system of specimen presentation and rotation. Direction and intensity of remanent magnetization and position of virtual geomagnetic north pole were computed with TOSBAC-3400 of the Computer Center of Fukushima
b. Paleomagnetic stability

For the purpose of confirmation of the stability of remanent magnetism, two kinds of test have been applied to rocks, laboratory tests such as demagnetization experiment and field tests.

In the laboratory, the unstable component of remanent magnetization was examined by a progressive demagnetization experiment in an alternating magnetic field as high as 400 Oe using 3-axis turning specimen tumbler. The experiment was performed carefully in a fieldfree space. Changes in NRM intensity and direction during the progressive stepwise demagnetization of the pilot specimens from various sites indicate that the significantly large normal component with about 200 Oe coercivity had superposed on a more stable original component, and that an alternating field of 200 Oe in demagnetization lead to concentration of directions of the samples taken at every site. On the basis of demagnetization experiments on pilot specimens, a field of 200 Oe was chosen for magnetic cleaning treatment of all specimens.

Two kinds of field test, the fold test and the consistency check, has been applied to the samples from the Aizu Basin. The field tests are capable of learning information on stability over geological time interval while laboratory tests are concerned with physical properties in shorter interval of time. When the direction of the layer is corrected for the deformation, all directions of magnetization will be equal, if this direction was acquired before folding and has been kept stable since that time (Graham, 1949). This fold test has been applied to the T1 tuff layer of the Nanaorizaka Formation, and the results indicate that the magnetization of the tuff is considered to have been preserved stable (Manabe, 1977).

On the other hand, the reversed polarity magnetozone including the paired normal subzones was traced into four separate sections in the Fujitoge Formation (Manabe and Suzuki, 1976). The great similarity in the magnetic polarity successions between the sections with different sedimentation rate and lithology is a convincing support for the validity of the magnetostratigraphy.

(to be continued)