

Preliminary survey on the Tetori Group in southern Ishikawa, Japan

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石川県南部に分布する手取層群に対する予備調査

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Abstract

The Lower Cretaceous Itoshiro and overlying Akaiwa subgroups of the Tetori Group are distributed in the Shiramine Area of Hakusan City, Ishikawa Prefecture, Japan. The Kuwajima Formation, the upper division of the lower subgroup, is considered to have been deposited under lacustrine and associated alluvial environments. It has yielded a reasonable number of vertebrate remains that are small, allochthonous, and mostly disarticulated. The Akaiwa Formation, the lower division of the upper subgroup, is suggested to have been formed by fluvial systems with strong currents and rapid deposition. Except for plant fragments, fossils are uncommon. Vertebrates, including dinosaurs, occur in the Kitadani Formation, the upper division of the upper subgroup, in northeastern Fukui Prefecture, and this formation crops out in the Shiramine Area. Therefore, there is a chance that articulated large vertebrate fossils are preserved in the subgroups exposed in the area. However, the indurated nature of the rocks, precipitous topology, thick vegetation cover, and overall poor exposures represent significant challenges to making such a discovery. Further, based on the taphonomy of the observed vertebrates, finding well-preserved large vertebrates in the area will be difficult and require much time and financial support. Organizing a survey group of trained volunteers may be one way to address this problem.

Key words: Tetori Group, Early Cretaceous, Ishikawa

要旨

石川県白山市白峰地域には、石徹白・赤岩亜層群（手取層群：下部白亜系）が分布している。湖や河川で形成された桑島層（石徹白亜層群上部）は、様々な生物の化石を産出する。流れの速い河川で形成された赤岩層（赤岩亜層群下部）は、植物以外の化石をほとんど含まない。福井県勝山市にある北谷層（赤岩亜層群上部）からは、恐竜が発見されており、同地層は白峰地域にも分布している。したがって、関節の繋がった大型脊椎動物化石が、同地域の両亜層群の中に保存されている可能性はある。しかし、硬い母岩や急峻な地形、露頭の少なさと調査の困難さに加え、これまで発見された脊椎動物化石の保存状態を考えると、同地域内で保存状態の良い大型脊椎動物化石を発見するのは容易ではなく、莫大な時間と費用を要する。一つの方策として、ボランティアを中心とした調査団を編成し、調査に臨むことである。

INTRODUCTION

The Tetori Group is a Mesozoic stratum distributed discontinuously across six prefectures of North-central Japan, including northern Gifu, eastern Fukui, southern Ishikawa, central-southern Toyama, northwestern Nagano, and southwestern Niigata (Figure 1). In 1874, the German Rein found plant fossils in Kuwajima of the Shiramine Area, Hakusan City, Ishikawa, after climbing up to Mt. Hakusan. Geiler (1877) described them as Jurassic specimens. This locality (Figure 1, 2) is considered the birthplace of paleontology in Japan because the article was the first, officially published study about fossils from the country. The outcrop, where Rein collected the specimens, became the type locality of the Kuwajima Formation of the Tetori Group and was later designated as a natural monument, “Kuwajima Fossil Bluff”, by the national government in 1957. The Tedorigawa Dam’s reservoir submerged the lower portion in 1979, so that only upper portion is observable now (Figure 3).

The Tetori Group became well known to paleontologists and amateur fossil collectors because of its abundant invertebrate and plant fossils, including standing tree trunks (Ishikawa Prefectural Board of Education, 1978; Shiramine Village Board



Figure 1. Distribution of the Tetori Group in North-central Japan. Star represents the position of Kuwajima Fossil Bluff in the Shiramine Area. Based on Higashino & Hibino (2010).

of Education, 2000; Yabe *et al.*, 2003). In 1986, the discovery of a carnosaur tooth in the Shiramine Area made the group publicly famous. This tooth is known as “Kaga-ryu”. Consequently, subsequent paleontological surveys focused on the Tetori Group, resulting in the discovery of various kinds of vertebrate fossils, representing fish, flogs, synapsids, mammals, turtles, lizards, choristoderes, crocodylians, birds, pterosaurs, and dinosaurs (Azuma, 2003; Hirayama *et al.*, 2003; Isaji *et al.*, 2005; Kusuhashi, 2008; Shiramine Village Board of Education, 2000). Avian and dinosaurian foot prints were also found (Azuma *et al.*, 2002; Hirasawa *et al.*, 2010; Matsukawa *et al.*, 2005; Yasuno, 2008, 2009).

Large-scale excavations have been conducted in the Kitadani Dinosaur Quarry, Katsuyama City, Fukui, where the Kitadani Formation, the uppermost division of the group, is exposed. These have resulted in the discovery of dinosaur remains. This paleontological achievement led to establishment of the Fukui Prefectural Dinosaur Museum in the city and has made it the most successful museum in Japan. In contrast, neighboring Ishikawa has not had an actual “natural history museum” for a while. A signature-collecting campaign in the prefecture led to the establishment of the Ishikawa Museum of Natural History in 2006 as the forerunner; it has been categorized as a “museum-like facility” although it is named “museum” in English. Discovery of scientifically relevant specific fossils, such as articulated dinosaurs, in the Tetori Group exposed in the Shiramine Area could facilitate the recognition of this facility as a true museum. Therefore, preliminary fieldwork was undertaken to



Figure 3. Kuwajima Fossil Bluff. The arrow points to the present exposure of the natural monument.

explore the area.

This represented the first exploration of the group in the area for the author. Therefore, several, well-surveyed routes were reinvestigated in order to generate a firm foundation of geologic understanding. Lithological and paleontological data were collected

to determine the depositional environments and to evaluate discuss the chances of finding large, articulated vertebrate fossils, such as dinosaurs, in the group. The localities mentioned in this study were recorded by GPS. However, discrepancies exist in comparison with the topographic map made by the



Figure 2. Map of the Shiramine Area with the Tetori River System. The numbers indicate the surveyed regions. Star represents the position of Kuwajima Fossil Bluff.

Geographical Survey Institute. The localities appear to be inaccurate, and their aberrant position is considered to be off by approximately 10 seconds south in the north latitude and 10 seconds east in the east longitude. Nonetheless, they were mentioned without revision in this study because the accurate position is difficult to verify for many of them with the topographic map.

GEOLOGICAL SETTING

The Tetori Group, which was formed between the Middle Jurassic and Early Cretaceous, is divided into Kuzuryu, Itoshiro, and Akaiwa subgroups in ascending order. The Kuzuryu Subgroup predominantly consists of marine deposits with partial non-marine ones in its lower portion (Fujita, 2003; Kumon & Umezawa, 2001; Matsukawa & Nakada, 1999). The beginning of the subgroup still remains uncertain and is different between the separated areas; the subgroup even does not occur in some areas. Nonetheless, Matsukawa & Nakada (1999) considered that the deposition of the Ushimaru Formation, the lowermost, non-marine formation of this subgroup in the Shokawa Area, northern Gifu, started in the Bathonian, about 167 Mya. The end of the subgroup also appears to be varied between the different areas; the subgroup is considered to be conformably overlain by the Itoshiro Subgroup in areas but unconformably in the others (Fujita, 2003).

The Itoshiro and Akaiwa subgroups are mainly composed of non-marine deposits, and their temporal extent varies across the separate areas. Based on Fujita (2003), the oldest age of the beginning of the lower subgroup is considered the Tithonian, the latest Late Jurassic stage, in the Shokawa Area. The boundary between the two subgroups is obscure and varied in different areas because they are conformable. Nonetheless, it is considered to lie in the Barremian and Hauterivian. The end of the upper subgroup, and therefore the Tetori Group, also varies across the separate areas. Fission-track aging with zircon indicates that the youngest absolute age of the group is Albian, around 110 Mya.

Several factors make correlation within the Tetori Group between prefectures and even within a

given region difficult: structural deformation, lateral discontinuity of strata, lithological variation, and regional variations in the depositional periods and styles. Consequently, different formation names have been applied to the strata of each area. Figure 4 shows the stratigraphy of the group distributed in the Shiramine Area (Fujita, 2002, 2003; Ishikawa Prefectural Board of Education, 1978; Maeda, 1958). The stratum is largely deformed (Maeda, 1961). Volcanic activity, beginning 0.4 Mya and resulting in Mt. Hakusan 0.03-0.04 Mya, contributed to this deformation. The depositional period of the group appears shorter than those in the other areas. For example, the Kuzuryu Subgroup does not exist. The Itoshiro Subgroup is considered to have been formed during the Barremian and Hauterivian, about 127-132 Mya. It is subdivided into the Gomijima and Kuwajima formations in ascending order. The lower formation directly overlies the Hida Metamorphic Rocks. It consists of conglomerate, in which boulders up to 2m in diameter are not rare, and the thickness varies from 50m to 350m. In contrast, the upper formation is characterized by an alternation of sandstone and mudstone yielding abundant plant and molluscan fossils. The thickness is estimated as approximately 100m.

The Akaiwa Subgroup is thought to have been deposited in the Aptian-Barremian, about 121-127 Mya. It is subdivided into the Akaiwa and Kitadani formations in ascending order. The lower formation is further subdivided into two portions due to lithological

Mya	Age	Group	Subgroup	Formation
120	Early Cretaceous	Tetori	Akaiwa	Kitadani
				Akaiwa
130			Itoshiro	Kuwajima
				Gomijima

Figure 4. Stratigraphy of the Tetori Group in the Shiramine Area, southern Ishikawa.

differences. The lower portion consists of alternating mudstone, predominant sandstone, and occasional conglomerate, whereas the upper portion is composed of minor mudstone and thick, massive sandstone that partially contains gravels. The thickness of the lower and upper portions is estimated about 600m and 400m respectively. The upper division of the Akaiwa Subgroup in the area was named Myodani Formation in Ishikawa Prefectural Board of Education (1978). In this study, it is referred to as the Kitadani Formation because they are considered to be stratigraphically equivalent. This formation consists of alternating sandstone and mudstone, which is estimated about 350m in thickness. The Late Cretaceous Oomichidani Formation unconformably overlies on it.

FIELDWORK

1 Region along the Ozo and Tedori rivers in the Seto District

The Kuwajima Formation is largely exposed around the junction of the Ozo and Tedori rivers in the Seto District, northern part of the Shiramine Area (Location 1 in Figure 2). The stratum is considered to represent the lower portion of the formation (Maeda, 1958). However, Matsuoka *et al.* (2009) mentioned that the stratigraphic correlation was difficult because of faulting between the area and the type locality of the formation in Kuwajima.

Laterally continuous outcrop along the east side of the Tedori River consists of alternating fine sandstone and mudstone (Figure 5). Planar and cross laminations are developed and ripple marks are visible in parts of sandstone beds. (Figure 6). Ichnofossils of invertebrates occur on a mudstone bed which is overlain by a tuff layer (Figure 7, 36°17'29.2"N, 136°38' 24.8"E). Matsuoka *et al.* (2009) identified them as traces made by snails and horseshoe crabs. The bed strikes N41°E and dips 28°NW. Plants and bivalves frequently occur in rocks on the shore of the river, which are most likely washed out from the outcrop.

Outcrops are well exposed as steep cliffs along the Ozo River. Ripple marks are recognized on a surface of conglomerate bed, which is about 18 cm thick, on



Figure 5. Alternation of fine sandstone and mudstone in the Kuwajima Formation.



Figure 6. Ripple marks in the Kuwajima Formation exposed along the east side of the Tedori River.

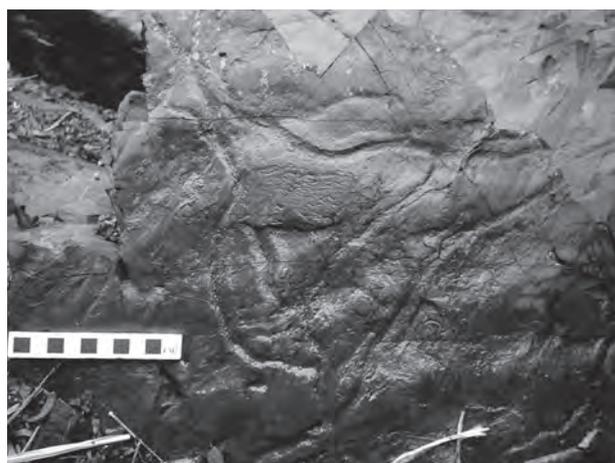


Figure 7. Ichnofossils in the Kuwajima Formation exposed along the east side of the Tedori River. Scale bar subdivided into cm units.

the west side of the river (Figure 8, 36°16'51.3"N, 136°39' 40.6"E). Molluscs, such as abundant bivalves and less common snails, are concentrated

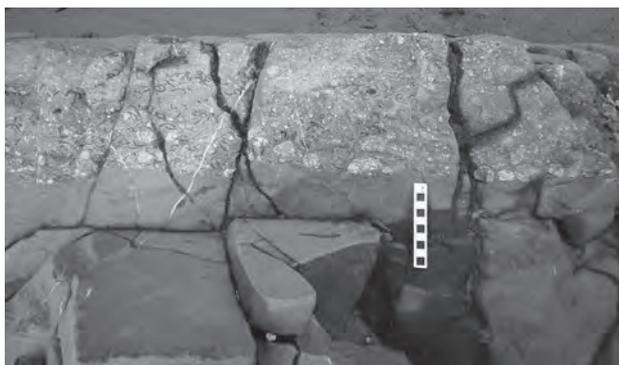


Figure 8. Concentration of molluscs with gravels. Scale bar subdivided into cm units.

within gravels in the unit. It is not sure whether the block is a part of the outcrop in the original position or a big rock fallen from an adjacent cliff.

Outcrops are rare along a logging road constructed on the east side of the river. One slope is covered with massive, blackish mudstone rocks (36°17'14.8"N, 136°39' 26.1"E). Small brackish water bivalves, *Myrene* (*Mesocorbicula*) *tetoriensis*, are concentrated on the surface of a mudstone piece (Figure 9). This corbiculid typically occurs in the Kuwajima Formation. *Potozamites reini*, the representative fossil plant of the formation, was found in a rock nearby the locality. At another outcrop along the road (36°17'18.1"N, 136°39' 21.3"E), there is a conglomeratic layer on the top. No vertebrate fossils were found along the both rivers in the region during this fieldwork.

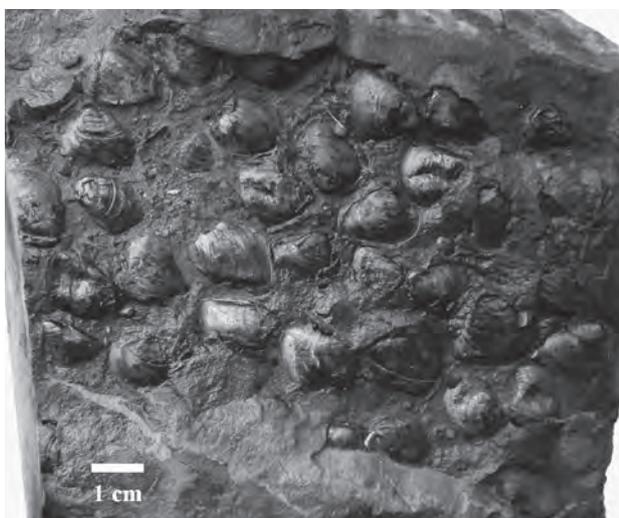


Figure 9. Concentration of *Myrene* (*Mesocorbicula*) *tetoriensis* on mudstone surface.

2 Region along the Akadani River

The Akadani River is one of the tributaries of the Tedoru River and flows from south-southwest to north-northeast (Location 2 in Figure 2). All the formations of the Itoshiro and Akaiwa subgroups are exposed along the river except the lowermost Gomijima Formation (Ishikawa Prefectural Board of Education, 1978). These strike west-northwest and dip south-southwest, so that a lower formation is distributed around the lower branch of the river.

There is the Kuwajima Tunnel near the junction of the river with the Tedoru River, and outcrops are exposed from spot to spot along the logging road running above it. Near to the northern entrance of the tunnel (36°12'42.6"N, 136°37' 47.4"E), a mudstone layer overlies a coarse, well-sorted sandstone. A piece of mudstone, most likely fallen off from the outcrop, contained a corbiculid.

At another locality (36°12'41.7"N, 136°37' 50.9"E), a thick sandstone overlies a mudstone. Planer stratification, which is partially represented by alternation of black and grey colors, is recognized in the mudstone (Figure 10). It strikes N20°W and dips 26°SW. The sandstone is reddish and contains pebbles. No sedimentological structures were recognized within the unit.

A large outcrop of regularly alternating sandstone and mudstone layers crops out at another locality (Figure 11, 36°12'20.7"N, 136°37'43.9"E). The coarse and well-sorted sandstone represents the majority of

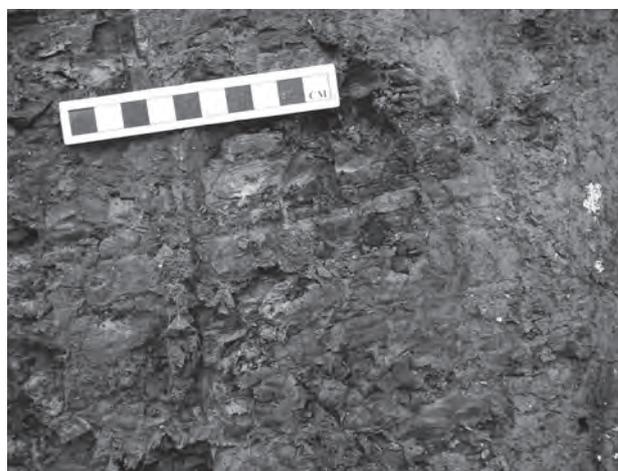


Figure 10. Planar-stratified mudstone. Scale bar subdivided into cm units.



Figure 11. Alternation of sandstone and mudstone.



Figure 12. Sandstone interbedded with mudstone.

the outcrop by volume. The layers strike $N38^{\circ}W$ and dip $32^{\circ}NW$. Based on Ishikawa Prefectural Board of Education (1978), all the outcrops from the beginning of the logging road to the last locality are considered to belong to the Kuwajima Formation. However, the southern outcrops consist predominantly of sandstone or alternating sandstone and mudstone (Figure 11). The lithologies resemble those of the lower portion of the Akaiwa Formation. Therefore, it remains unclear whether these outcrops are actually the Kuwajima Formation. The surfaces of the outcrops could not be examined in many localities due to the steepness of the slope. Nonetheless, no fossils were found during this survey except a corbiculid in a mudstone and probable rootlets in sandstone.

In the middle reach of the river, coarse sandstone is predominant and interbedded with dark-gray mudstone at a locality (Figure 12; $36^{\circ}11'18-30''N$, $136^{\circ}36'34-37''E$). The boundary between the upper sandstone and underlying mudstone shows $N20^{\circ}-30^{\circ}W$ in strike and $12^{\circ}W$ in dip. At another locality ($36^{\circ}11'17.9''N$, $136^{\circ}36'33.7''E$), massive sandstone is exposed with large-scale cross-beddings recognizable by alignment of gravels (Figure 13). Gravels are partially concentrated in it (Figure 14). These clasts are fairly rounded but do not appear to be well sorted. These two outcrops are considered to belong to the Akaiwa Formation (Ishikawa Prefectural Board of Education, 1978). No fossils were found in them during this survey although the rock surfaces could not be examined in detail due to the steepness.



Figure 13. Cross-beddings in sandstone.



Figure 14. Concentration of gravels in sandstone.

3 Region on the north-west hillside of Mt.Ooarashi

Outcrops occur sporadically along a logging road running around the north-west hillside of Mt. Ooarashi (Location 3 in Figure 2). Because the road is located above the Kuwajima Fossil Bluff (Figure 3) and the

outcrops predominantly consist of sandstone, they are considered a lower portion of the Akaiwa Formation.

A relatively large outcrop consists of a thick, coarse sandstone bed between blackish mudstone beds with a fine conglomerate lying upon the upper mudstone layer (Figure 15; 36°11'37.7"N, 136°38'29.9"E). The sandstone contains intraclastic mudstone chips and plant fragments. Some of the fossils are coalified. Ferns fragments occur in a small piece of fine sandstone nearby the outcrop (Figure 16).

Plant fragments are concentrated on the surface of a rock considered to be fallen off from an adjacent cliff (36°12'14.5"N, 136°38'40.0"E). They are coalified,



Figure 15. Outcrop of the Akaiwa Formation.

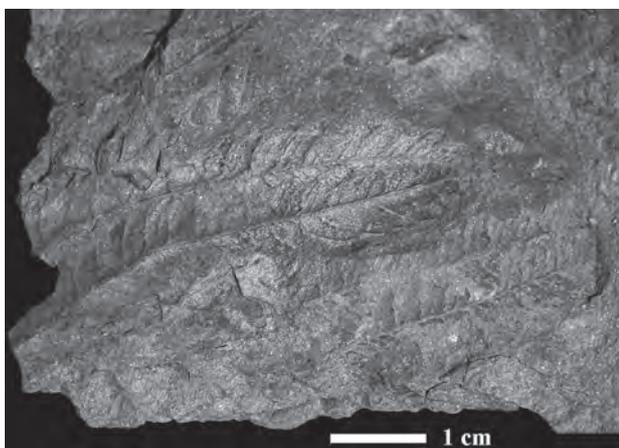


Figure 16. Fern in very fine sandstone.

and larger fragments appear to align in the same direction (Figure 17). A turtle fragment was found in a rock that was supposedly removed around this spot during the construction of the logging road. No other vertebrate fossils have been reported in the outcrops along the road. Animal fossils were not found in this survey route during the fieldwork.

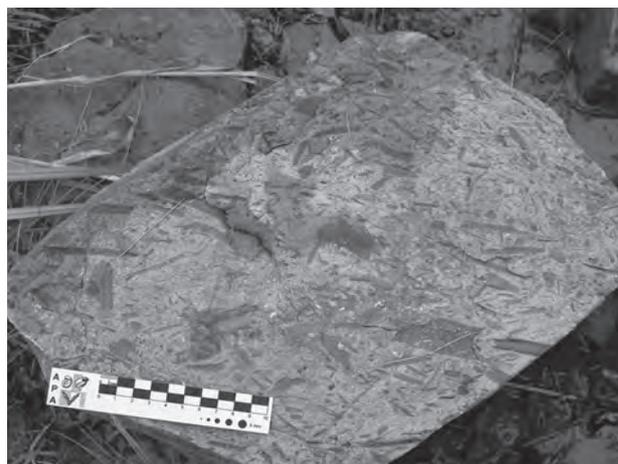


Figure 17. Plant fragments lining up on rock surface. Scale bar subdivided into cm units.

4 Region around the Myodani and Kazaarashidani rivers

The Myodani and Kazaarashidani rivers are two tributaries of the Tadori River, which run from south to north parallel to each other (Location 4 in Figure 2). The Itoshiro Subgroup largely crops out in this region, and a syncline and an anticline run WSW-ENE in the lower and middle reaches of the rivers respectively (Ishikawa Prefectural Board of Education, 1978). Consequently, the underlying Akaiwa Formation is exposed in the lowermost and middle reaches of the Myodani River and the whole lower-middle reach of the Kazaarashidani River, and the Kitadani Formation crops out in the upper reaches of the two rivers and around the junction of the Myodani River with the Komatadani River, a tributary diverged to the east in the lower reach.

White, coarse sandstone is exposed at a locality on the logging road along the Komatadani River (36°08'50.5"N, 136°38'05.2"E). Well-rounded gravels are included in the bed. One of them is about 12 cm in diameter (Figure 18). Exposures on the logging

road along the Myodani River include alternating beds of sandstone and mudstone (36°08'34.2"N, 136°37'48.1"E). Intraclastic mudstone chips are observed at the bottom of a coarse sandstone unit (Figure 19). The bed strikes N53°E and dips 19°NW. Sandstone in another outcrop (36°08'30.4"N, 136°37'50.6"E) contains pebbles. Plant fragments are included in fine sandstone that is interbedded with mudstone at a more southern locality (36°07'43.9"N, 136°37'50.6"E). They appear to be coalified and show a three-dimensional random orientation (Figure 20). The layer strikes N88°W and dips 12°S. The gentle dip of the stratum switches to the opposite direction between the first and last localities mentioned above along the Myodani River, reflecting the presence of the anticline between them. Based on Ishikawa Prefectural Board of Education (1978), the first

two outcrops (Figure 18, 19) belong to the Akaiwa Formation and the last one (Figure 20) to the Kitadani Formation.

A thick sandstone body with occasional gravels is exposed along the Kazaarashidani River (Figure 21; 36°08'48.8"N, 136°38'50.7"E). Coarse, mature sandstone of another outcrop also contains gravels that are well rounded but only moderately sorted (Figure 22). Based on surface observation, gravel



Figure 18. Sandstone including gravels.

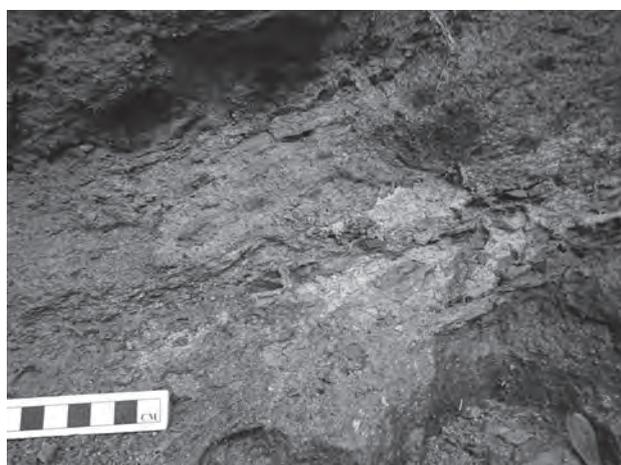


Figure 19. Intraclastic mudstone chips in sandstone. Scale bar subdivided into cm units.

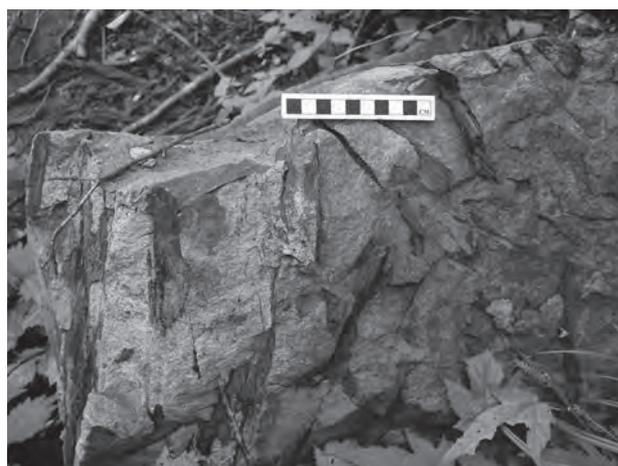


Figure 20. Plant fragments in fine sandstone. Scale bar subdivided into cm units.



Figure 21. Massive sandstone.



Figure 22. Gravels in sandstone. Scale bar subdivided into cm units.



Figure 23. Plant fragments in sandstone block. Scale bar subdivided into cm units.

clasts appear to be distributed randomly in the unit. No other sedimentological structures are visible. At another locality (36°08'48.3"N, 136°38'54.9"E), a massive sandstone unit includes coalified plant fragments. Coarse sandstone blocks on a bank of the river, likely removed from this outcrop during construction of the logging road, also contain plant fragments that show three-dimensionally random orientation in them (Figure 23). Reddish mudstone intercalates with sandstone at another locality (36°08'03.2"N, 136°39'05.0"E). The fieldwork of this survey could not be extended to the upper reach of the river, where the Kitadani Formation is exposed. All the examined outcrops along the described route are, therefore, considered to belong to the Akaiwa Formation.

Steep topology along the Myodani and

Kazaarashidani rivers prevented observation of most of the outcrop surfaces. Nevertheless, unidentified plant fragments were the only fossils recognized in them during this fieldwork.

DISCUSSION

Dynamic geological changes occurred to the sedimentary basin where the Tetori Group formed in the eastern margin of the present Eurasian Continent. Based on the paleomagnetic analysis, Hirooka *et al.* (2002) suggested swift migration of the basin. It was located in a low-latitude area, about 24°N, prior to the deposition of the Kuwajima Formation, the upper division of the Itoshiro Subgroup, and then, rapidly shifted to north, about 40°N. Both this formation and the overlying Akaiwa Subgroup were deposited in the high-latitude area. Hirooka *et al.* (2003) suggested that the more than 40 degree difference in paleomagnetic declination between the stratigraphically equivalent Fukui-Ishikawa and Toyama areas resulted from differential rotation within the sedimentary basin during its northward migration. The basin was transferred to the present position, within 35°-36°N (Figure 1), with 80° clockwise rotation during the Early Miocene in association with the opening of the Japan Sea (Hirooka *et al.*, 2002).

The tectonic shift resulted in a change in sedimentary sources occurred between the two subgroups. The gravels contained in the conglomeratic Gomijima Formation, the lower section of the Itoshiro Subgroup, consists predominantly of granitic and metamorphic rocks likely representing the underlying the Hida Metamorphic Rocks (Ishikawa Prefectural Board of Education, 1978; Maeda, 1958). Kunigiza *et al.* (2002) suggested that sediments, including cherts, were supplied to the basin from the Mino Terrane, a Jurassic accretionary complex consisting of Paleozoic thru Mesozoic marine sedimentary and igneous rocks. A mountain range was formed as a result of collision of the northward moving Yangtze Plate and the Sino-Korean Plate. Then, sediments were shed southward to an ocean basin. The accretion prism, the Mino Terrane, was formed there as a result of the northward subduction of the Izanagi Plate and/or Farallon Plate

underneath the collided plates. Later, the accretion prism was uplifted, and sediments were carried from it to the basin.

The Itoshiro Subgroup basically consists of terrestrial deposits, but the fossil record indicates that neritic sedimentation also occurred in it (Fujita, 2003; Matsuoka *et al.*, 2009). Taira & Matsuo (1983) considered that meandering river-delta systems were developed around a large lake. Based on sedimentological and paleontological analyses in addition to the taphonomy of the discovered fossils, Isaji *et al.* (2005) suggested three facies in the fossil-bearing beds of the formation at the “Ku wajima Fossil Bluff”, depositions in a peat marsh, a shallow lake, and a vegetated swamp.

In contrast, Taira & Matsuo (1984) described the sandstone of the Akaiwa Formation, the lower division of the Akaiwa Subgroup, as containing an appreciable proportion of alkaline feldspars and therefore, as highly arkostic. Further, the included gravels consisted mainly of orthoquartzites with rare granitic rocks. The analysis of the paleocurrents in the formation shows that the water flow was generally directed from northwest to southeast. Therefore, the sands with gravels are considered to have been supplied from a continent lying to the north-northwest of the sedimentary basin. Taira & Matsuo (1983) suggested that anastomosing rivers were developed during the sedimentary stage and well-rounded, large orthoquartzite gravels were secondarily deposited. Considering three-dimensionally random orientation of plant fragments and large-scaled cross beddings expressed by gravels (Figure 13, 23) in the sandstones of the formation, the sediments were very likely carried and deposited rapidly by strong water currents. The existence of intraclastic mudstone rip-ups within sandstones (Figure 19) further supports this idea.

The Kitadani Formation was only briefly examined in this study. The fine sandstone at the Myodani River locality preserves plant fragments dispersed in a three-dimensionally random orientation (Figure 20). This pattern suggests swift transportation and deposition by relatively strong water currents, as in a flood or possibly within a debris flow. Azuma

(2003) suggested that the formation was deposited by meandering rivers.

During the complicated geological changes, a large lake, named Tetori Lake, is considered to have consistently existed and consequently, supported a rich aquatic and terrestrial fauna and flora were flourished in the basin (Ishikawa Prefectural Board of Education, 1978; Shiramine Village Board of Education, 2000). The Itoshiro and Akaiwa subgroups are the most vertebrate-productive, non-marine Mesozoic strata in Japan. Vertebrate fossils have been found in the Ku wajima Formation in the Shiramine Area. The Kitadani Formation has yielded a reasonable number of vertebrate fossils, including dinosaurs, in the Kitadani Dinosaur Quarry, northeastern Fukui. The same formation also crops out in the Shiramine Area. Therefore, large articulated vertebrate fossils may potentially be found in the subgroups exposed in the area.

However, it is considerably hard to find such fossils because of the following difficulties. The most productive quarry in the Shiramine Area is the “Ku wajima Fossil Bluff” consisting of the Ku wajima Formation. A tunnel was constructed behind the natural monument, and the rocks removed from it have been surveyed in detail, resulting in discovery of many vertebrate fossils. For example, Shiramine Village Board of Education (2000) reported that 1277 vertebrate remains were found in them during 1997-1999. However, the specimens, including 268 fish scales and 547 turtle shells, are mostly fragmentary and isolated elements. Because of their small size and preservational state, they are considered to be allochthonous. Although rare, partially articulated or associated specimens have been discovered, the overall taphonomic pattern appears generally unsuitable for fossils with better preservation.

As discussed above, the Akaiwa Formation was likely deposited primarily by rapid and strong water currents. Drowned or carcasses of terrestrial vertebrates can be buried without being torn apart in a river. Articulated vertebrate fossils are occasionally preserved in a channel-fill sandstone body. However, it is still considered that the Akaiwa Formation, which

were deposited by fluvial systems that are strong enough to carry coarse sands with large gravels, only rarely preserves articulated vertebrate remains. Fujita (2003) mentioned that fossils were rarely found in the lower position of the Akaiwa Subgroup except some dinosaur footprints. As mentioned in the fieldwork, no vertebrate fossils were found in the subgroups during this investigation although the period was short.

To begin with, problems fundamentally lie in paleontological survey to the group in the Shiramine Area. Geological fieldwork itself is strictly limited in a large part of the area because it is designated as Hakusan National Park; it is basically prohibited to hammer rocks, remove plants to expose outcrop surfaces, take small amounts of samples, and even just prospect freely in the park. The outcrop exposure is poor, which is mostly due to thick vegetation, in comparison with those of fossil-bearing strata in other countries, such as USA, Canada, and China. Therefore, searching fossils is hard. Additionally, precipitous topology hinders prospecting. The Kitadani Formation is mostly distributed around the upper regions in the area. Therefore, even reaching outcrops of the formation is not easy. Although outcrops are well exposed along the rivers and roads, the deep and steep incursion prevents checking rock surfaces and chasing the strata vertically and laterally. Therefore, finding fossils under the conditions is challenging.

The rocks consisting of the subgroups are so solid that preserved fossils are not easily weathered out from host rocks and excavation itself is very tough. Heavy equipment has been used to cut off the hill until reaching bone beds for the excavation in the Kitadani Dinosaur Quarry conducted by the Fukui Prefectural Dinosaur Museum. Even in the case, an intense use of manual labor is the basic way. Removed solid rocks from the site are hammered one by one to discover fossils. A similar process has been used for finding fossils in the rocks removed from the tunnel behind the "Kuwajima Fossil Bluff". This is a time-consuming method but may be the only way to locate uncommon fossils. The discovery of many vertebrate fossils from the place in contrast to other localities within the same formation is considered to result

simply from the intense concentration of work.

Considering the whole difficult situations and conditions mentioned above, discovery of well-preserved large vertebrates in the subgroups exposed in the Shiramine Area is hardly optimistic. Otherwise, it requires much money and time. Even if these fossils are actually found, further financial supports and efforts are indispensable for excavation, transportation, and preparation. One way to solve this dilemma is to create a survey group consisting mainly of trained volunteers at the Ishikawa Museum of Natural History.

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