A tooth of *Fukuiraptor* aff. *F. kitadaniensis* from the Lower Cretaceous Sebayashi Formation, Sanchu Cretaceous, Japan

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Abstract

A theropod tooth from Early Cretaceous Sebayashi Formation of the Sanchu Cretaceous in Kanna Town, Japan exhibits low crenulations (or wrinkles) of the enamel along the mesial margin apically on one side. The tooth was found in association with brackish water bivalves. Dinosaurian remains from the Sanchu Cretaceous suggest faunal influences from East and Southeast Asia and Gondwanaland. The Kanna tooth is unique in these features but represents new material similar in form to the teeth of *Fukuiraptor kitadaniensis*, with minor differences, and is thus useful for correlation to the Tetori Group. The Kanna tooth is described as *Fukuiraptor* aff. *F. kitadaniensis* on this paper. From assigning *Fukuiraptor kitadaniensis* and its allied *Fukuiraptor* aff. *F. kitadaniensis* to the Barremian, these forms may show utility as a primary correlation tool. These forms may be derived from the common ancestor of *Fukuiraptor*, and distributed through the fluvio-lacustrine environments. Occurrences of *F. kitadaniensis* and *F.* aff. *F. kitadaniensis* suggest that the Sanchu area bordered on the Tetori area in Barremian.

Key words: Japan, Cretaceous, theropod, Kanna tooth, crenulations, Sebayashi Formation, Sanchu Cretaceous, *Fukuiraptor* aff. *F. kitadaniensis*

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Introduction

Teeth are increasing important structures for dinosaur identification. Although theropod teeth have traditionally been considered not diagnostic for lower taxonomic levels, more recent work (e.g., Currie et al., 1990; Smith, 2005 and others) has shown the usefulness of teeth in identifying at least some theropods. Among genera possessing characteristic teeth is *Carcharodontosaurus*, whose teeth show crenulations or wrinkles in the surface enamel along the mesial and distal margins. A theropod tooth also possessing marginal crenulations in the enamel was found in the Lower Cretaceous Sebayashi Formation of the Sanchu area, Japan (Tanimoto et al., 2003). Since the discovery of

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an ornithomimid vertebra from the Sebayashi Formation (Hasegawa et al., 1984; 1999), probable dinosaur tracks (Matsukawa and Obata, 1985) and a possible spinosaurid tooth (Hasegawa et al., 2003) have also been recovered. This increasing dinosaurian data suggests that the dinosaur fauna of the Sebayashi Formation may have been influenced by those of East Asia, Southeast Asia, Africa and South America.

This paper describes a tooth of *Fukuiraptor* aff. *F. kitadaniensis* from the Sebayashi Formation of the Sanchu area in Japan, and discusses its geological age, palaeozoogeographic and evolutionary significance.

Collection abbreviations: FPDM, Fukui Prefectural Museum, Fukui; NDC, Kanna Town Dinosaur Center, Kanna; MDM, Mifune Dinosaur Museum, Mifune-cho, Kumamoto Prefecture.

Geological setting

This theropod tooth (NDC-P0001) was collected from a block of poorly sorted conglomerate thought to be derived from the lowermost part of the Lower Member of the Sebayashi Formation. This attribution is because of the typical poorly sorted conglomerates in the coarse grained sandstone: the Sebayashi Formation at the Mamonozawa River is represented by the Lower Member consisting of dark gray fine to medium grained sandstone with thin poorly sorted conglomerate layers, and by the Upper Member of alternating beds of sandstone and mudstone (Matsukawa, 1983). The Sanchu Cretaceous is divided into the Shiroi, Ishido, Sebayashi and Sanyama Formations in ascending order. Ammonites from the Ishido, Sebayashi and Sanyama Formations indicate a sequence from the Ishido to Sebayashi formations is Barremian to Aptian in age and the Sanyama Formation is Albian. The Upper Member of the Sebayashi is Upper Barremian to Upper Aptian. Hence, the Shiroi Formation and the Lower Member of the Sebayashi Formation probably may be assigned to the Upper Hauterivian to Lower Barremian and to the Barremian respectively (Obata and Matsukawa, 1984; Matsukawa and Obata, 1988; Matsukawa et al., 2007; Matsukawa and Tomishima, 2009) (Fig. 1)

Consideration of dinosaur occurrences in the Sanchu Cretaceous

The poorly sorted conglomerates of the Lower Member are interbedded with parallel laminated, medium to very coarse grained sandstones that contain molluscan shell fragments. This lithological unit was named as the Lithofacies assemblage 7 (LA 7) (Ito and Matsukawa, 1997). Locally developed conglomerate beds with erosional bases are interpreted to represent lag deposits. This shows the transgressive shoreface erosion of underlying deposits. The theropod tooth was found in a gravel size clast among shell fragments of brackish water bivalves, *Costocyrena radiatostriata*, and sandstone matrix. The tooth is thought to be derived from the underlying deposits that indicate terrestrial influence. Hitherto, one vertebra of an ornithomimid identified as *Gallimimus* sp. by Manabe et al. (1989) and as ornithomimid gen. et sp. indet. (Hasegawa et al. 1999), probable dinosaur tracks (Matsukawa and Obata, 1985) and a possible spinosaurid tooth (Hasegawa et al., 2003) have been reported from the uppermost part of the Lower Member of the Sebayashi Formation. This shows that dinosaurs inhabited the Sanchu embayment (Matsukawa, 1983) during the time of deposition of the Sebayashi Formation, although the sea level regime changed from transgression to regression.

Based on the only Asian ornithomimid occurrences, from the Sanchu Cretaceous (Hasegawa et al., 1999; Manabe et al. 1989), southern Mongolia and northeastern China (Kobayashi & Lu, 2003; Ji et al., 2003), a continental connection between both areas during Cretaceous time, allowing dinosaur migration, is inferred by Matsukawa and Obata (1994) and Matsukawa et al. (1995). The occurrence of a possible spinosaurid tooth suggests a continental connection between Thailand and the Sanchu Cretaceous. This means there were possibly two routes into what is now Japan in Cretaceous time. The theropod tooth described here suggests the possibility that the Sanchu region also had *Fukuiraptor* in common with the Tetori area, Fukui Prefecture.

Materials and Methods

The single specimen (NDC-P0001) of a theropod tooth was collected by Y. Watanabe from a block of poorly sorted conglomerate along the right branch of a mountain stream flowing into the Mamonozawa River, north of Sebayashi Hamlet, Kanna Town, Gunma Prefecture (Fig. 2).

The specimen was found in a boulder identified as belonging to the Sebayashi Formation on lithological features, and dated by interpolation from ammonite dates

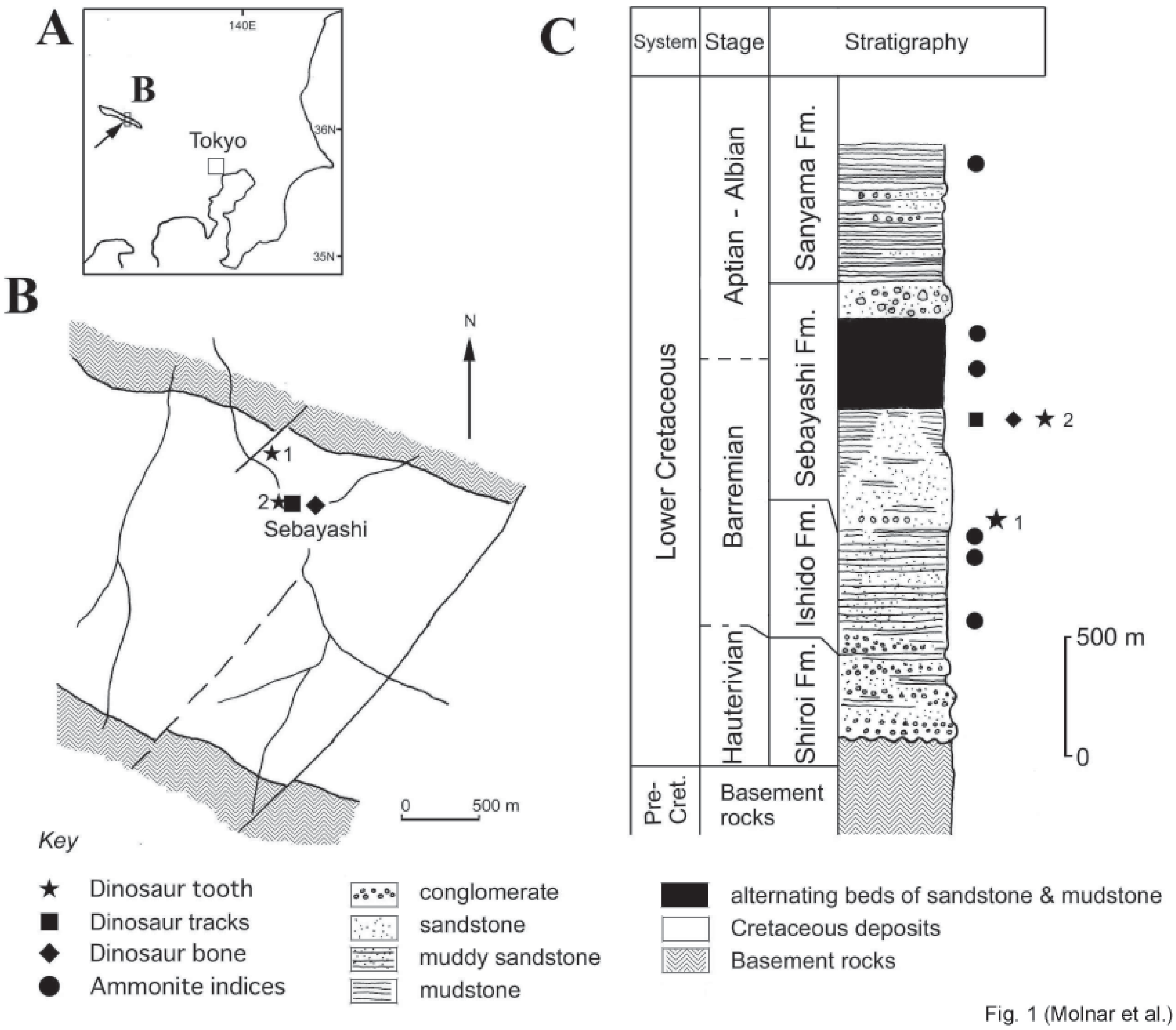

Fig. 1. Dinosaur localities in the Sanchu Area. A. Index map of the Sanchu area; B. Geological map and fossil localities. 1. The Kanna tooth (NDC-P0001), 2. A possible spinosaurid tooth; C. Stratigraphic section showing dinosaur remains. Geological map and stratigraphy based on Matsukawa (1983) and Matsukawa and Obata (1994).

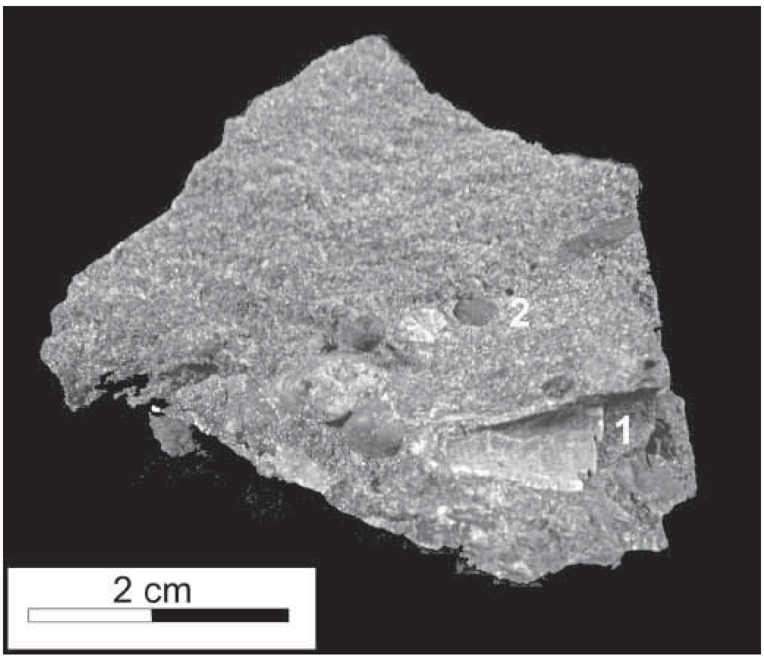

Fig. 2. Occurrence of the Kanna tooth (NDC-P0001) as gravel granule in sandstone. 1. cast-off theropod tooth, 2. gravel granule.

for the overlying and underlying formations. A comparison of the dinosaurian remains from the Sanchu Cretaceous was carried out to determine the palaeozoogeographical relationships of the Sanchu fauna.

This tooth was compared mostly with specimens described in the literature, but also with casts of the Mifune tooth (MDM 341; Chure et al. 1999) and of a tooth of *Carcharodontosaurus saharicus* from the collections at the University of Chicago. To facilitate comparison measurements of the tooth were plotted following the method of Farlow et al. (1991) and compared with the data presented there and as well as with data for Asian teeth taken from published measurements or measurements made from published figures. Following the precedents of Farlow et al. (1991) and Smith (2005), the distance from cervix (neck or base) to apex (tip) of the crown will be termed the height, the mesiodistal distance the length, and the labiolingual distance the width. This differs from colloquial usage in which the apicobasal distance is often called the length. Phylogenetic systematic methods were not employed, because it is felt that the character states of teeth are too few for reliable results at this time.

Anatomical abbreviations: CBL, crown basal length (equivalent to fore-aft basal length of Farlow, et al., 1991); CBW, crown basal width; CH, crown height.

Preservation

The crown of the tooth lacks apparent distortion or substantial breakage, although the enamel is missing over the basal 10 mm of the mesial margin. The enamel is cracked and small pieces have been dislodged on both lingual and labial surfaces of the crown leaving nicks in the enamel. Other than this, the condition of the enamel is well preserved, and the serrations distinct, but worn at the tips. The root is missing entirely, with a block of matrix adhering to the broken surface and along the base of one face. The break appears to be at the cervix. There is some slight scoring and loss of enamel at the apex, and abrasion of the denticles along the mesial and distal margins. This latter loss gives the appearance of a slight convexity of the apical portion of the distal margin (Fig. 3B). The distal carina extends to 1 mm from the matrix at the basal break. The mesial carina extends from the apex to about 10 mm from the basal break, to the region where the surficial enamel has been lost. The denticles of both carinae are abraded, with only their bases remaining.

Systematic Paleontology

DIAPSIDA Osborn, 1903
DINOSAURIA Owen, 1842
THEROPODA Marsh, 1881
CARNOSAURIA von Huene, 1920
Fukuiraptor Azuma and Currie, 2000

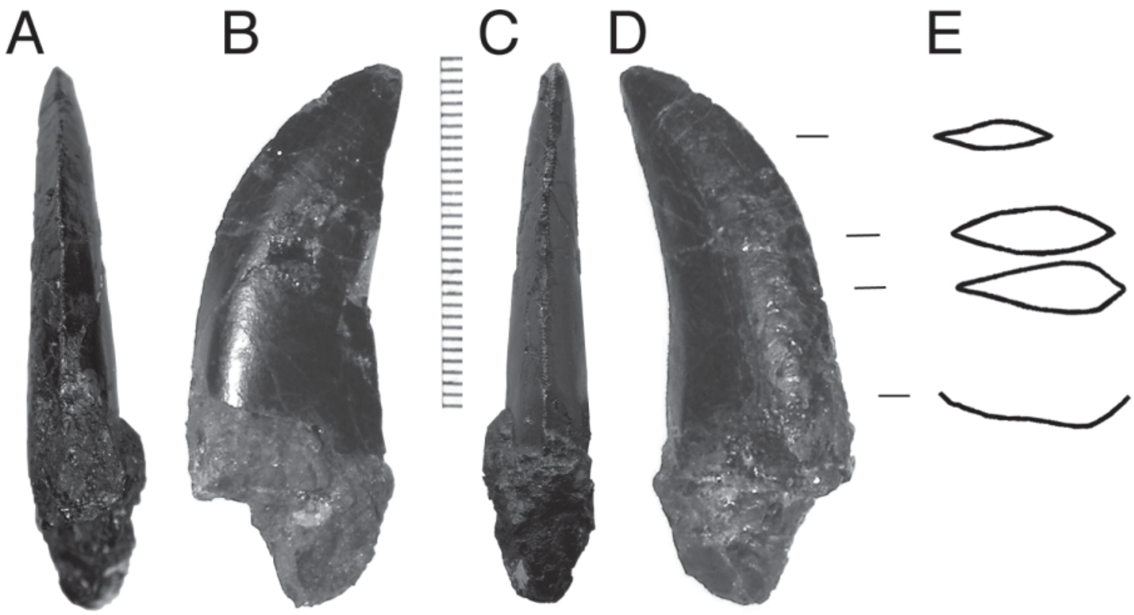

Fig. 3. The Kanna tooth (NDC-P0001) in mesial (A), lateral (B, D), distal (C) views and in cross-section (E). The cross-sections are at the levels indicated by the bars in D. Only one face of the most basal section is given, as the other is partly obscured by matrix. The sections are viewed from the base of the crown, with mesial to the right. Scale in mm.

Fig. 4. The region near the apical mesial margin of the Kanna tooth (NDC-P0001), showing ripple-like crenulations in the enamel (indicated by bars). Photographed from cast.

Fukuiraptor aff. *F. kitadaniensis* Azuma and Currie, 2000

Figs. 3, 4

Compare.

2000 *Fukuiraptor kitadaniensis* Azuma and Currie, p. 1737–1753, figs. 3–19.

2006 *Fukuiraptor kitadaniensis* Azuma and Currie, Currie and Azuma, 173–193.

Depository. The described specimen is stored in the exhibition room in the Kanna Town Dinosaur Center under the registration number NDC–P0001.

Dimensions. See Table 1 and Table 2.

Description. The crown (NDC–P0001) is laterally compressed and recurved, with the apex distally overhanging the cervix (or neck) by 5 mm (Fig. 3). In mesial view, one face is nearly straight (in fact slightly concave) to within 4 mm of the apex (Fig. 3A). The other is very gently convex.

The crown is nearly symmetrical in cross section (Fig. 3E), and midway along the crown the maximum width of the tooth is about one third of the distance from the mesial to the distal edge. At the cervix, the maximum width is mesially placed, only about 13% of the distance from mesial to distal margin. Between the maximum width and the distal margin, each face is slightly convex in horizontal section, but from the maximum width to the mesial edge, each face is flat. There is a slight lateral concavity in one face at the cervix. Near the apex, the widest region of the crown is approximately halfway between the mesial and distal margins. In section neither face is obviously more strongly convex than the other, as is the case in maxillary and dentary crowns of *Tyrannosaurus rex* (Osborn, 1912).

In labial or lingual view, the mesial margin is smoothly convex along approximately the distal half of the crown and nearly straight basally. The mesial margin is serrate along its apical two thirds, but too poorly preserved basal to that to determine if serration was present. In mesial view, the carina extends from the apex to its basal termination (due

Table 1. Measurements of the Kanna tooth of *Fukuiraptor* aff. *F. kitadaniensis* (NDC-P0001).

AL (apical length)	40.40 mm
CH (crown height)	34.80 mm
CBL (crown basal length = FABL)	16.75 mm
CBW (crown basal width)	6.20 mm
MAVG (length of mesial margin)	41.85 mm
DAVG (length of distal margin)	31.60 mm
CA (crown angle)	60°

Table 2. Comparison of measurements of the Kanna crown (NDC-P0001) *Fukuiraptor* aff. *F. kitadaniensis*, with those of *Fukuiraptor kitadaniensis*.

	Kanna tooth	V9712203	Range in *F. kitadaniensis*
CH/CBL	2.08	2.03	1.02–2.78
CBL/CBW	2.70	2.52	1.61–2.84
CH/CBW	5.61	5.13	2.61–6.67

to wear) in a straight line, but appears slightly offset from the centerline of the crown toward the flatter face (Fig. 3A). The entire distal carina is serrate to about 1 mm from the matrix at the base. In labial or lingual view, it is composed of two straight line segments, meeting at about the middle of the margin (Fig. 3D). The basal segment is about 13 mm long, and the apical about 19 mm. The appearance of a slight convexity basally on the apical segment is due to abrasion of the carina apically as mentioned previously. In distal view, the basal two thirds extends in a straight line towards the apex, but deviates toward the flatter face apically (Fig. 3C). The denticles are too poorly preserved for description, except to point out that shallow grooves extend from between the bases of the distal denticles toward the midline of the crown. These grooves appear not to have been orthogonal to the distal margin but inclined towards the base of the crown, and can be seen only on the left face of the crown when viewed distally. The mesial denticles apparently lacked these grooves. The surface of the enamel is smooth to the naked eye (where well preserved), except along one face of the mesial carina near the apex, from about 9 to 17 mm from the apex (measured along the curve). Here four low ridges, perhaps more easily felt than seen, form a ripplelike pattern in the surface (Fig. 4). The distance between corresponding parts of the ridges ('wavelength') is a little less than 1.5 mm. These ridges are linear and project towards the centerline of the crown, orthogonal to the mesial edge of the tooth.

The distance from the cervix to the apex, perpendicular to the presumed long axis of the jaw, is 36 mm. Other measurements, following the proposed standardised measurements of Smith (2005), are given in Table 1. These measurements assume that when complete the enamel of the tooth terminated at what is now the broken base of the crown.

The position of this crown in the jaw is difficult to determine. Smith (2005) failed to determine tooth position in *Tyrannosaurus rex* from detailed measurements of the individual crowns. With the collection of further data, it may be possible to determine from which side and which element this tooth derives. At present, we merely suggest that the ratio of the height to the mesiodistal length (CH to CBL) and the bladelike form suggest that it derives from the posterior part of either the maxilla or dentary.

Comparison. In lateral aspect, the Kanna crown resembles those of lateral maxillary or mandibular teeth of moderate to large theropods such as *Allosaurus*, *Ceratosaurus*, *Albertosaurus* and *Gorgosaurus*. However, the Kanna tooth differs from more typical large theropod teeth in details of form. Two features may be of taxonomic significance: (1) that the surfaces adjacent to the mesial carina are flat (cf. Rauhut, 2004), and (2) the degree of compression of the crown as indicated by the ratio of basal width (CBW) to mesiodistal length (CBL).

The Kanna tooth, like that from Mifune, falls just at the lower margin of the envelope of more typical theropod teeth in the ratio of basal width to mesiodistal length as found by Farlow et al. (1991) (Fig. 5). Some other Asian theropod taxa based on (or including) teeth fall even further below the envelope of typical theropod teeth. *Wakinosaurus satoi* (Okazaki, 1992), *Dandakosaurus indicus* (Yadagiri, 1982) and *Prodeinodon kwangshiensis* (Hou et al., 1975) have unusually narrow crowns (Figs. 5, 6). The crowns of *D. indicus* and *P. kwangshiensis* plotted in Fig. 5 were not measured at the base, unlike all of the other data of that graph. However, in theropod teeth the mesiodistal dimension usually decreases more rapidly as the apex is approached than the labio-lingual dimension, thus these points would represent the crowns as broader than measurements at the base, and hence diminish their difference from more typical crowns. The narrow teeth of *P. kwangshiensis* are unlike those of the type species *Prodeinodon mongoliensis* (Osborn, 1924) in this respect (Figs. 5, 6: *P. mongoliensis* tooth also not measured at the base) and, hence, not all teeth attributed to *P. kwangshiensis* may pertain to that genus (as recognised by Okazaki, 1992). Assuming that none of these crowns has suffered significant crushing (and such is not apparent in the illustrations), the narrowness of the crowns may suggest that *D. indicus*, *W. satoi* and *P. kwangshiensis* may derive from ceratosaurs (cf. Rauhut, 2004; but see comments below). The tooth of *P. kwangshiensis* and that of *W. satoi* also share a nearly straight distal margin (Hou et al., 1975; Okazaki, 1992), although the distal margin of that of *D. indicus* (like that of the Kanna tooth) seems to consist of two straight segments (Fig. 6).

The Kanna tooth is slightly narrower and longer than most theropod teeth measured by Farlow et al. (1991). This is also true of the Mifune tooth (CBL/CBW = 2.1), but that from Kanna is even more compressed (CBL/CBW = 2.7). The flat surfaces adjacent to the mesial carina are also found in teeth of *Ceratosaurus* and some abelisaurids, but not in those of most other theropods (Rauhut, 2004). Strongly compressed lateral crowns are found in advanced carcharodontosaurs and some neoceratosaurs (Rauhut, 2004), as well as the Asian

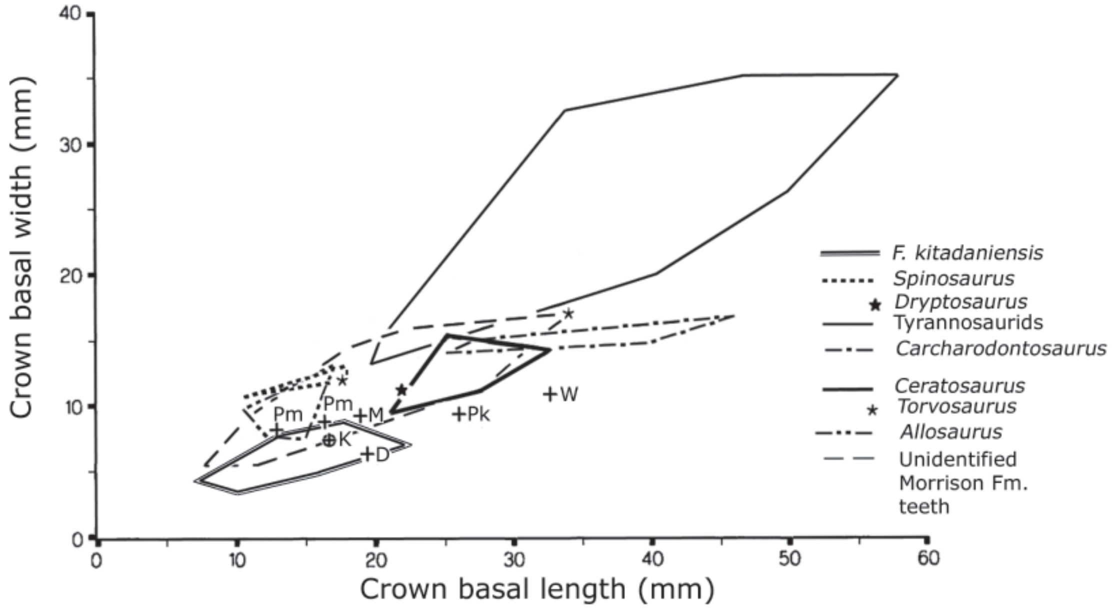

Fig. 5. Relationship between basal width (CBW) and basal length (CBL) for various theropod teeth. Dot: K, the Kanna tooth, Crosses: M, Mifune tooth, D, *Dandakosaurus indicus*, Pk, *Prodeinodon kwangshiensis*, Pm, teeth of *Prodeinodon mongoliensis*, W, *Wakinosaurus satoi*. See text for further comment. Data for tyrannosaurids, Morrison teeth, *Spinosaurus*, *Torvosaurus* and *Dryptosaurus* from Farlow, et al., (1991); data for *Carcharodontosaurus*, *Allosaurus* and *Ceratosaurus* from Smith (pers. comm., 2004), the Mifune tooth from Chure, *et al*. (1999), *Wakinosaurus* from Okazaki (1992), *Dandakosaurus* from Yadagiri (1982), *Prodeinodon kwangshiensis* from (Hou, et al., 1975) and *Prodeinodon mongoliensis* from Osborn (1922). CBW for the Kanna tooth is approximate, but almost certainly not in error by more than a few mm.

taxa just discussed.

In addition to having a very restricted area with crenulations, the Kanna tooth obviously differs from those of *C. saharicus* in general form, specifically in that the Kanna tooth is more recurved, that is the crown angle is less than in *C. saharicus*, and the projection of the tip beyond the distal end of the cervix is greater. In at least the cast of a tooth of *C. saharicus* available to us, the cross section of the crown is lenticular, each side being smoothly convex with the thickest region approximately at the midline of the crown: the cross section of the Kanna crown is different (Fig. 3E). In mesial and distal views, this cast tooth of *C. saharicus* is distinctly flexed, so that in distal view the central and apical regions make an angle of about 15° with the base, whereas the Kanna crown is much straighter (Fig. 3A, C).

In general form the Kanna crown most closely resembles those of *Fukuiraptor kitadaniensis* (Currie and Azuma, 2006) (Figs. 5, 6). The specimen was found at the Kitadani Quarry, at Katsuyama, Fukui Prefecture, in rocks of the Okurodani Formation (Matsukawa et al., 2003; 2006). Although Currie and Azuma (2006) cited “Kitadani” Formation by Maeda (1961), this formation was shown to be a synonym of the Okurodani Formation by Matsukawa et al. (2003, 2006). Specific points of resemblance are the nearly straight apical and basal segments of the distal border, a broadly curved mesial border, in which the curvature is restricted to the apical two-thirds and the possession of marginal crenulations. However the crown of *F. kitadaniensis* differs in that the apical segment of the distal border is relatively longer than the basal, whereas in the Kanna tooth they are of almost equal length. The proportions of the crowns are also similar, Table 2. The values for *F. kitadaniensis* are taken from table 1 of Currie and Azuma (2006), and the ratios calculated from these. It can be seen that the proportions of the Kanna crown lie well within the range of those of the crowns of *F. kitadaniensis*(Fig. 5). Several of the crowns of *F. kitadaniensis* have arcuate crenulations, for example (fig. 4, lower image) of Azuma and Currie (2000). These crenulations differ in form from those of the Kanna crown in being arcuate, rather than straight, and more basally situated on the crown. The crowns of *Fukuiraptor* differ in being mildly sigmoid in mesial and distal view, unlike the Kanna crown. However, as mentioned previously, in mesial view one face of the Kanna crown is very slightly concave apically, so approaching the sigmoid condition. Although the Kanna crown differs from those of *F. kitadaniensis* in some

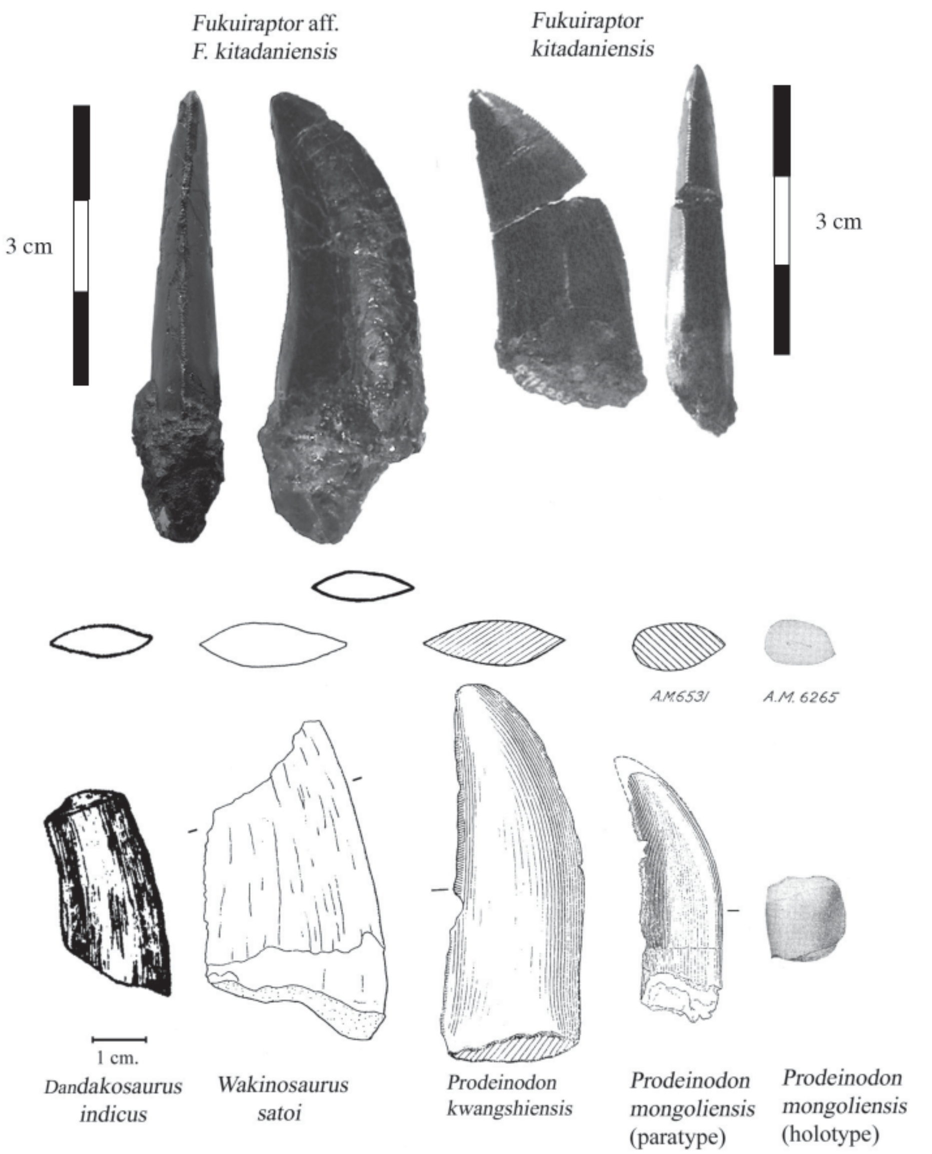

Fig. 6. The Kanna crown (NDC-P0001), *Fukuiraptor* aff. *F. kitadaniensis* compared with one of the maxillary crowns of *Fukuiraptor kitadaniensis* (FPDM-V9712203), and with Asian theropod teeth discussed in the text. Cross sections of the teeth in the lower row are shown above the teeth, and that of NDC-P0001 is shown below the crown. All of the teeth in the lower row are to scale, but not to scale with those in the upper row. (Adapted from Currie and Azuma, 2006; Hou et al., 1975; Okazaki, 1992; Osborn, 1924; and Yadagiri, 1982.)

features, it would not appear out of place among the teeth in fig. 2 of Currie and Azuma (2006).

The teeth of *F. kitadaniensis*, like those of ceratosaurs, are narrower than those of most teeth plotted by Farlow et al. (1991), thus showing that the teeth of *Dandakosaurus indicus*, *Wakinosaurus satoi* and *Prodeinodon kwangshiensis* discussed above could pertain to ceratosaurs or to plesiomorphic allosauroids like *Fukuiraptor*.

Remarks. As above mentioned, the Kanna crown is similar in form to those of *Fukuiraptor kitadaniensis*, and exhibits three specific points of resemblance, but shows also some differences. Tooth form may change with age: juvenile teeth may differ from adult ones in the same taxon. Thus, in view of our present knowledge, we consider that the minor differences could be caused by growth. Anyway further material including teeth from the Sebayashi Formation is desirable. The material presently at our disposal is only a tooth, which is why we refrain from identifying the Kanna specimen as *Fukuiraptor kitadaniensis*.

Significance in the inter regional correlation

As *Fukuiraptor kitadaniensis* and its allied *Fukuiraptor* aff. *F. kitadaniensis* occurred in the Okurodani Formation in the Tetori area and in the Sebayashi Formations in the Sanchu area, respectively, we can evaluate these taxa as a geological correlation tool and for their paleobiological significance (Fig. 7).

To date, as to the stratigraphy of the Sanchu Cretaceous, it is subdivided into the Shiroi, Ishido, Sebayashi and Sanyama Formations in ascending order (Matsukawa, 1983) (Fig. 8). The marine fossiliferous Ishido Formation yields twenty Barremian ammonoids, and especially several species of *Barremites*, *Heteroceras* etc. were described from the uppermost part of the formation (e.g. Matsukawa et al., 2007). The Upper Member of the Sebayashi Formation yields *Barremites, Crioceratites* (*Paracrioceras*) and others (Matsukawa and Tomishima, 2009). Thus the occurrence of the Kanna tooth named as *Fukuiraptor* aff. *F. kitadaniensis*, from the basal Sebayashi Formation is safely assigned to the Barremian.

On the other hand, the geological age of the Tetori Group seems to be unstable. For example, *Fukuiraptor kitadaniensis* from the Kitadani quarry of the Kitadani Formation has reported from the Albian (Azuma and Currie, 2000), but later from the Barremian (Currie and Azuma, 2006). *Fukuisaurus tetoriensis* from the same Kitadani quarry of the same Kitadani Formation has reported from the Late Hauterivian to Barremian (Kobayashi and Azuma, 2003).

Based on geological correlation of several areas of the Tetori Group, a coherent stratigraphy of the Tetori Group throughout the entire area in the Mt. Hakusan section, type region, was demonstrated by Matsukawa et al. (2003, 2006, 2007, 2008, 2009) (Fig. 8). As the result, the Kitadani Formation has been judged as a junior synonym of the Okurodani Formation. Furthermore, upper Hauterivian to lower Barremian ammonoids *Pseudothurmannia* and *Acrioceras* (*Paraspinoceras*) species, and Barremian *Phyllopachyceras* have been reported from the Inagoe Formation in the Hida-Furukawa Region, which is nearly equivalent to the Okurodani Formation in the Mt. Hakusan Region (Matsukawa et al., 2007; Matsukawa and Fukui, 2009).

Sano et al. (2008) commented on the work of Matsukawa et al. (2006) regarding what they perceive as problems pertaining to the stratigraphy and geological correlations within the Tetori Group in the Mt. Hakusan and Kuzuryugawa Regions. They proposed alternative stratigraphic interpretations and correlations. Sano et al. (2008) did not agree with Matsukawa et al.'s. (2006) stratigraphy of the Takinamigawa Area in the Mt. Hakusan Region because Matsukawa et al. (2003, 2006) considered the Kitadani Formation of Maeda (1961) as a synonym of the Okurodani Formation. Then, Matsukawa et al. (2008) replied to Sano et al. (2008); (1) litho-stratigraphic sequence in the Takinamigawa Area can be correlated with the type stratigraphical section of the Tetori Group in the Mt. Hakusan

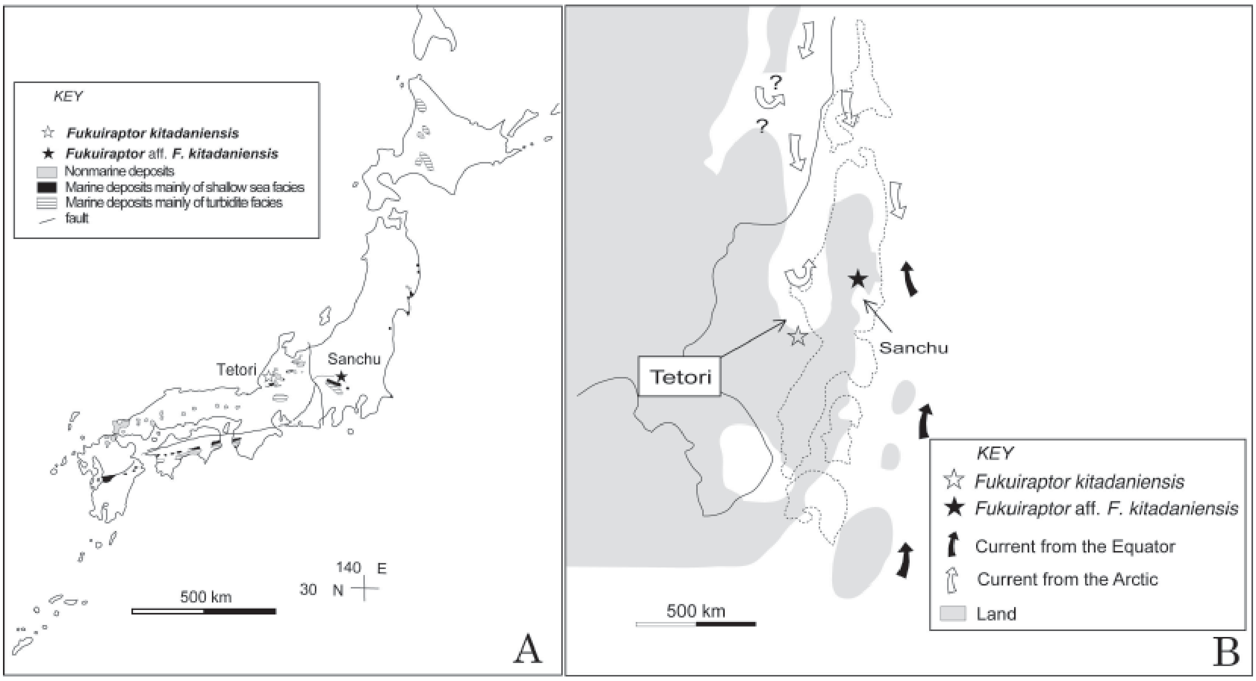

Fig. 7. Occurrence of *Fukuiraptor kitadaniensis* and its allied *Fukuiraptor* aff. *F. kitadaniensis* in the Tetori and Sanchu areas (A), and Early Cretaceous geographical distribution of these species (B).

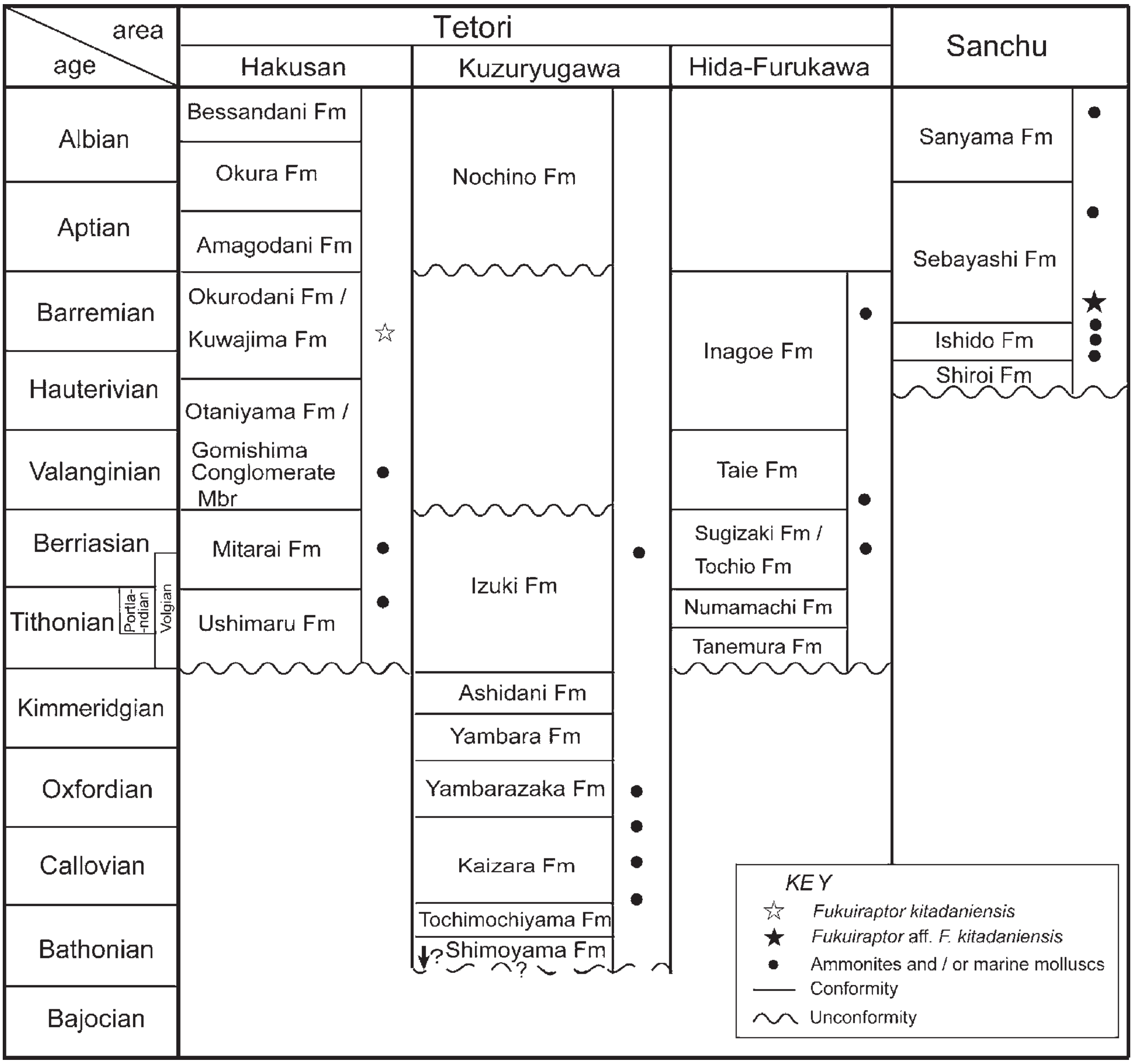

Fig. 8. Stratigraphic occurrences of *Fukuiraptor kitadaniensis* and its allied *Fukuiraptor* aff. *F. kitadaniensis* in the Okrurodani Formation of the Tetori Group and the Sebayashi Formation of the Sanchu Cretaceous.

Region based on precisely geological mapping principles, and (2) zoo-chronological ideas employed by Sano et al. (2008) did not support the Kitadani Formation of Maeda (1961) instead of the Okurodani Formation. After the reply of Matsukawa et al. (2008) the stratigraphy and geological correlations within the Tetori Group in the Mt. Hakusan and Kuzuryugawa Regions have not been discussed. Since Maeda (1961), many new outcrops developed in the Tetori area because many new roads were made in the deep mountainous area. Therefore, we can understand lithostratigraphic correlation through measuring many individual columnar sections to establish lithostratigraphic correlations throughout the whole region of the Tetori Group. Matsukawa et al. (2003, 2006, 2007, 2009) presented a coherent stratigraphy of the Tetori Group throughout the entire area in the type region, and the formation as a lithostratigraphic unit is the optimal geological correlation tool for the Tetori Group, and the best tool for geological mapping of the group. Although the subgroup unit has frequently been used as a geological correlation tool, these usages have been not always been consistent. Thus subgroup names should not be casually used for geological correlation. The unstable geological age of the Tetori Group is probably caused by lack of careful correlation.

Thus, the geological age of *Fukuiraptor kitadaniensis* and *Fukuisaurus tetoriensis* from the Kitadani quarry in the Fukui Prefecture is strongly suggested as the Barremian as in the case of *Fukuiraptor* aff. *F. kitadaniensis* in the basal

Sebayashi Formation of the Sanchu Cretaceous. This means *Fukuiraptor kitadaniensis* and its allied *Fukuiraptor* aff. *F. kitadaniensis* may be a primary terrestrial correlation tool, rather than demonstrating different taxon-ranges. Then, these forms must be derived from an ancestor of *Fukuiraptor*, that was or became distributed throughout the common fluvio-lacustrine environments, because the Okurodani and Sebayashi Formations were deposited under similar environmental conditions (Ito and Matsukawa, 1997; Matsukawa et al., 2003, 2006). As the Sebayashi Formation of the Sanchu Cretaceous was deposited under a subtropical and tropical and arid climate, and the Okurodani Formation of the Tetori Group were deposited under a temperate and moderately humid climate (Kimura, 1979, 1980, 1986), the biogeographical distribution of *Fukuiraptor kitadaniensis* and its allied *Fukuiraptor* aff. *F. kitadaniensis* may have been influenced by the climate difference. As conclusion, occurrences of *F. kitadaniensis* and *F.* aff. *F. kitadaniensis* suggest that the Sanchu area bordered on the Tetori area in Barremian.

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山中白亜系の瀬林層から産出した*Fukuiraptor* aff. *F. kitadaniensis*の歯の化石

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環境科学分野

要　旨

山中白亜系の瀬林層から産出した歯の化石は，獣脚類のもので，*Fukuiraptor kitadaniensis*の歯と形態的特徴が類似する。しかし，瀬林層産の標本は，歯冠の頂上弓状の両側の長さが，ほぼ等しく，手取層群の大黒谷層産の標本とは異なる。これは個体発生上の相異を示している可能性があり，瀬林層産の標本を*Fukuiraptor* aff. *F. kitadaniensis*として記載した。手取層群の大黒谷層から産出した*Fukuiraptor kitadaniensis*と類縁の*Fukuiraptor* aff. *F. kitadaniensis*が山中白亜系の瀬林層から産出したことにより，山中地域と手取地域の恐竜動物群の古生物地理上の関連性が示され，両地域の陸続き関係が解釈できた。地質学的な証拠により，山中白亜系の瀬林層と手取層群の大黒谷層の恐竜産出層準は，Barremianを示すので，*Fukuiraptor kitadaniensis*と*Fukuiraptor* aff. *F. kitadaniensis*は陸成層の対比の第一次的ツールとして有効であると考えられる。

キーワード: 日本，白亜紀，獣脚類，神流歯，鋸歯，瀬林層，山中白亜系，フクイラプトル・キタダニエンシス類縁種