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Paleosol profiles in the Shiohama Formation of the Lower Cretaceous Kanmon Group, Southwest Japan and implications for sediment supply frequency

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ABSTRACT

This paper describes the pedogenic features of paleosols in the upper Lower Cretaceous Shiohama Formation, the lowest unit of the Shimonoseki Subgroup, in Yoshimi, Yamaguchi Prefecture, southwest Japan. The paleosol profiles in the Shiohama Formation are compound and complex, characterized by the presence of abundant calcrete horizons. An analysis of these profiles reveals that the floodplain upon which the Shiohama Formation was deposited was part of an unstable aggradation system characterized by the intermittent influx of sediments and occasional erosion. Furthermore, the mean annual range of precipitation was less than about 30 mm, suggesting only minor seasonal change between wet and dry conditions during deposition of the Shiohama Formation. The microstructures of the observed calcretes include dense microfabric, floating detrital grains, micronodules, circum-granular cracks, and complex cracks. These features formed by chemical precipitation under dry conditions, with little bioactivity. The calcrete horizons are classified into seven types (I–VII) based on their modes of occurrence. Two processes of carbonate accumulation can be identified based on the size and abundance of nodules: VI–V–III–(II)–I and VI–(V)–IV–II–I. These processes represent the development of calcrete horizons from the early to late stages of calcretization. Type I represents the most highly developed stage of calcretization. Calcretes within the Lower Member sequence of the Shiohama Formation show repetitions of type I and types II and III. Thus, it is interpreted that the frequency of sediment supply to the floodplain changed repeatedly over time.

1. Introduction

A paleosol is a soil that formed on a landscape of the past (Ruhe, 1965; Retallack, 2001). Soils that develop in alluvial sequences may be preserved within floodplain sediments as paleosols (Miall, 1996). The development of soils in alluvial sequences is a common phenomenon because the rate of sedimentation on floodplains is generally slow enough to allow sediments to be pedogenically modified (Wright, 1986). Paleosols preserved in floodplain deposits commonly show complex profiles because of spatial and temporal variations in floodplain deposition (Kraus and Aslan, 1993; Kraus, 1996; McCarthy et al., 1998); indeed, previous studies have sought to clarify the spatial and temporal development of floodplain paleosols (Kraus, 1997; McCarthy et al., 1998). Knowledge of the relationship between pedogenic and sedimentologic features can help in estimating the rate of sediment supply.

Details of the mode of occurrence of paleosols in Japan were first reported by Lee and Hisada (1997) in a study of the Shiohama Formation of the Lower Cretaceous Kanmon Group, southwest Japan. The paleosols in the Shiohama Formation are developed in floodplain deposits within an alluvial fan setting (Lee and Hisada, 1997, 1999; Horiuchi et al., 2008). Lee and Hisada (1999) described calcretes from these paleosols, focusing mainly on a chemical analysis of calcrete, and estimated paleoatmospheric P_{CO_2} to be 1700–3200 ppmV based on the stable isotopic composition of the calcretes. However, the formative process of these paleosols has yet to be considered.

The aim of the present study is to characterize the development of the floodplain paleosol profiles preserved in the Shiohama Formation. Furthermore, we seek to reconstruct the formation process of the calcretes, based on their mode of occurrence, and to identify the relation between rate of sediment supply and pedogenesis.

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2. Geological setting

Cretaceous red beds are widely distributed throughout East Asia (Miki, 1992). In Japan, their occurrence is restricted to the Inner Zone of Southwest Japan, where their presence is attributed to this region having been either emergent or in a shallow-sea environment under a hot arid/humid climate during the Cretaceous (Miki and Nakamuta, 1997).

The Cretaceous Kanmon Group, characterized by intercalations of red beds, is widely distributed throughout westernmost Honshu and northern Kyushu Islands (Fig. 1). The Kanmon Group disconformably overlies the Jurassic marine Toyora and Toyonishi Groups, and also unconformably overlies the Sangun high P/T metamorphic rocks and granitic rocks (Okada and Sakai, 1993).

Fig. 2 shows the age and stratigraphy of the Kanmon Group. The group is subdivided into the Wakino and Shimonoseki Subgroups based on lithology (Matsumoto, 1951). The Wakino Subgroup is characterized by clastic sediments intercalated with minor felsic tuff and tuffaceous sediments, whereas the Shimonoseki Subgroup is characterized by large volumes of andesitic to dacitic volcaniclastic sediment.

The Shimonoseki Subgroup, about 3,000 m thick, disconformably overlies the Wakino Subgroup, and unconformably overlies older basement rocks. The Shimonoseki Subgroup is composed of conglomerate, sandstone, shale, tuff, tuff breccias, and lavas of andesite, dacite, and rhyolite. This subgroup has been assigned to the Aptian–Albian based on fission track ages of zircon in acidic tuff (Murakami, 1985) and K-Ar dating of hornblende in volcanic rocks (Imaoka et al., 1993). The Shimonoseki Subgroup is subdivided into the following four formations (in ascending stratigraphic order): the Shiohama, Kitahikoshima, Sujigahama, and Fukue Formations (Fig. 2; Ueda, 1957; Hase, 1960).

The present study area, the Yoshimi area, is located upon Ajironohana headland, Shimonoseki City (Fig. 3). The sequence of the Shiohama Formation, about 350 m thick, is well exposed along the rocky coast, although the upper contact of the formation is not seen.

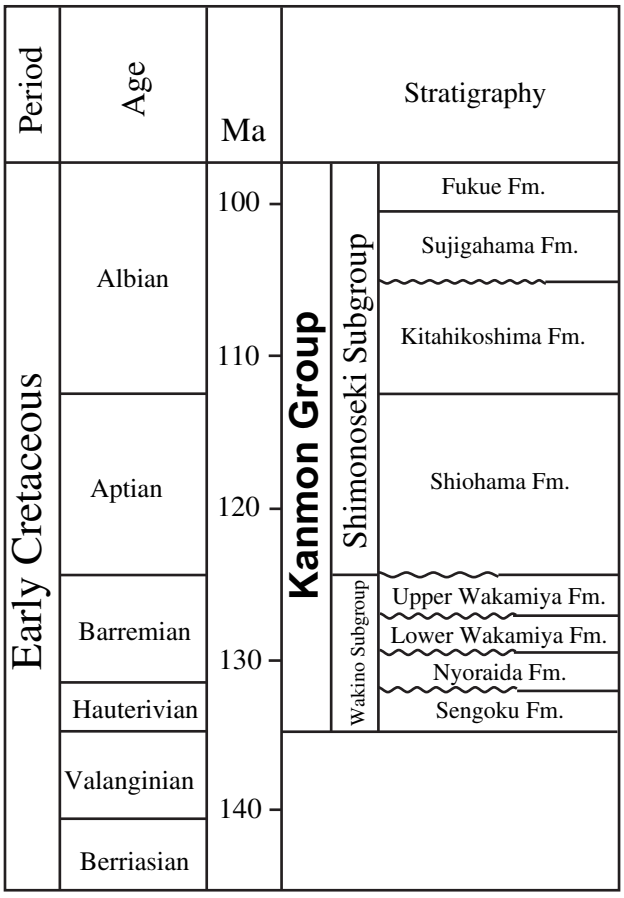

Fig. 2. Stratigraphy and age of the Kanmon Group. Compiled from Hase (1958). Absolute age is cited from Sakai and Okada (1997).

3. Stratigraphy and depositional environments

Fig. 3 shows a route map of the Yoshimi area. The studied section extends for about 500 m along the coast-line, where conglomerate, sandstone, and mudstone of the Shiohama Formation are exposed. In the northern part of this section, the Shiohama Formation conformably overlies the Upper Wakamiya Formation of the Wakino Subgroup. The strata in this section strike NE–SW and dip to the SE at 40–50°. Fig. 3 also shows a columnar section of the Shiohama Formation in the studied section, subdivided into Lower, Middle and Upper Members (Horiuchi et al., 2008).

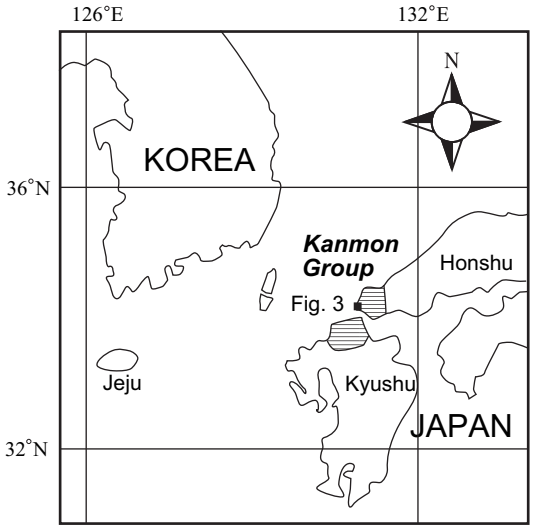

Fig. 1. Distribution of the Kanmon Group, southwest Japan.

The Lower Member is characterized by abundant red beds. The member is about 80 m thick, and is composed of conglomerate, sandstone, and mudstone. The conglomerates generally show the characteristics of sediment gravity-flow deposits, and the sandstones and mudstones are indicative of floodplain deposits, with some paleosol features. Sediment gravity-flow deposits are thought to represent components of debris-flow-dominated alluvial fans, whereas floodplain deposits with abundant paleosols are interpreted to represent the distal part of a sheet-flooding-dominated alluvial fan or the overbank fines of an alluvial plain (Horiuchi et al., 2008).

The paleosols within the Lower Member contain numerous calcareous nodules known as "calcrete" (Wright and Tucker, 1991). The paleosols also locally contain slickensides and are mottled. Calcrete within paleosols is a feature of arid environments (Wright and Tucker, 1991). The uppermost part of each reddish sandstone bed in the Lower Member preserves parallel laminations disturbed by burrows and surfaces with raindrop imprints. Although bedding planes within these floodplain deposits are sometimes obscured by pedogenesis, a number of calcrete horizons can be recognized.

The Middle Member (about 60 m thick) is characterized by thick conglomerate with intercalated thin sandstone and mudstone beds (less than 50 cm thick). Sediment gravity flows are the main