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P-t Path of Sediment Subduction-Underplating-Exhumation Process Related to the Formation of the Sambagawa Schists

By

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with 1 Table and 7 Text-figures

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Abstract: The Valanginian accretionary complex and the Barremian accretionary complex of the Chichibu megaunit I of the Southern Chichibu belt in east Shikoku, which consist of prehnite-pumpellyite facies rocks and overlie the Albian accretionary complex of the Chichibu megaunit I and the Cenomanian-Turonian accretionary complex of the Shimanto megaunit, have been clarified by Hara *et al.* (1992) to be of the same age with reference to the subduction beginning age (youngest fossil age) as the Saruta nappe (I+II) schists and the Fuyunose nappe schists of the Sambagawa megaunit as high P/T type metamorphic rocks respectively. K-Ar ages of muscovites from the former two accretionary complexes, which are considered to have been roughly comparable with the exhumation beginning age, were determined in this paper to be 114±6Ma and 108±5Ma respectively. The exhumation beginning age appears to have been different by ca. 20Ma between the Chichibu megaunit I of subcretion depth of a few kilobars (less than 4kb) and the Sambagawa megaunit of subcretion depth of ca. 10kb with the same subduction beginning age. It would said that this is a rough estimate of P-t path of sediment subduction-underplating-exhumation process related to the formation of the Sambagawa megaunit.

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I. Introduction and Geological Setting

The accretionary complexes (OA supermegaunit) of the Outer Zone of Southwest Japan are considered to have been developed in the southern front of the Kurosegawa-Koryoke continent (K-continent), which was collided with the Hida continent and its associated accretionary complexes (IA supermegaunit) of the Inner Zone of Southwest Japan during the earliest Cretaceous time (Hara *et al.*, 1992). These consist of four megaunits as nappes, Chichibu megaunit II, Sambagawa megaunit, Chichibu megaunit I and Shimanto megaunit in descending order of structural level (Fig. 1). The Chichibu megaunit II in east Kyushu-Shikoku-west Kii consists of four nappes, Kurosegawa nappe with Permian accretionary complex, Sawadani-Higashiura nappe as early Jurassic accretionary complex, Nakatsuyama nappe as middle Jurassic accretionary complex and Mikabu nappe as late Jurassic accretionary complex in descending order of structural level (Fig. 1) (Hara *et al.*, 1992). The Sambagawa megaunit as high P/T type metamorphic rocks, which is covered with nappes of the Chichibu megaunit II, consists of three nappes, Saruta nappe (II+I), Fuyunose nappe and Sogauchi nappe (ST subnappe, KAT subnappe and NOM subnappe) in descending order of structural level (Fig. 1) (Hara *et al.*,1992; Seki *et al.*, 1993). The Chichibu megaunit I, which is covered by the Chichibu megaunit II and Sambagawa megaunit, consists of many nappes, Sakamoto-Niyodo nappe as middle Jurassic accretionary complex exposed in the Sambagawa belt ~ Northern Chichibu belt (Hara *et al.*, 1992; Hada & Kurimoto,1990), Subzone I of Southern Chichibu belt as late Jurassic accretionary complex (Ishida,1985), Northern part of Subzone II of Southern Chichibu belt as Valanginian accretionary complex (Ishida,1985), Middle part of Subzone II of Southern Chichibu belt as Barreminan accretionary complex (Ishida,1985) and Southern part of Subzone II of Southern Chichibu belt as Albian accretionary complex (Ishida,1985) (Hara *et al.*, 1992) (Fig. 2). The uppermost member of the Shimanto megaunit, which is just covered with the Southern part of Subzone II of Southern Chichibu belt, is a nappe as Cenomanian-Turonian accretionary complex (Tominaga,1990). It is also covered with the Sogauchi nappe in the Sambagawa belt of west Kii (Kanai *et al.*, 1990; Hara *et al.*, 1992) (Fig. 3). The Sogauchi nappe in Shikoku is underlain by the Oboke nappe (I+II) in the northern part of the Sambagawa belt, though it overlies the Chichibu megaunit I (Sakamoto-Niyodo nappe) in the southern part of the Sambagawa belt. With regard to such the structural relationship between the So-

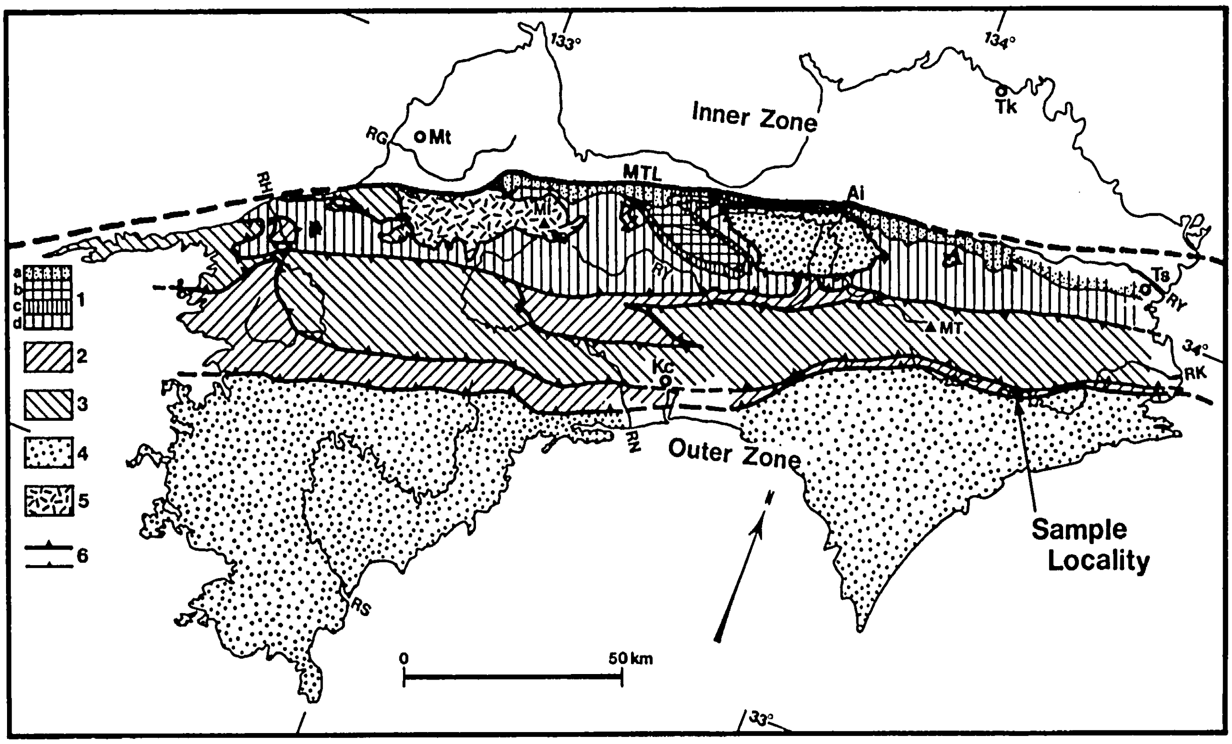

Fig. 1 Structural division of the Outer Zone of Shikoku and locality of samples for K-Ar age determination of the Chichibu megaunit I. 1: Sambagawa megaunit (a: Inouchi-Ojoin melange, b: Saruta nappe, c: Fuyunose nappe, d: Sogauchi nappe), 2: Chichibu megaunit I, 3: Chichibu megaunit II, 4: Shimanto megaunit, 5: Ishizuchiyama Tertiary System, 6: nappe boundary, MTL: Median Tectonic Line, Tk: Takamatsu, Ts: Tokushima, RY: River Yoshino, RK: River Naka, Ai: Awaikeda, MT: Mt. Tsurugi, MI: Mt. Ishizuchi, Mt: Matsuyama, RG: River Shigenobu, RH: River Hiji, KC: Kochi, RN: River Niyodo, RS: River Shimanto.

gauchi nappe and its underlying nappes and their radiometric ages (Figs. 1 & 4), the western extension of the Cenomanian-Turonian accretionary complex of west Kii has been assumed to be exposed as the Oboke nappe (I+II) (Hara *et al.*, 1990, 1992).

The beginning age for the subduction of an accretionary complex would be assumed from the youngest age fossils which are found in terrigenous sediments of the accretionary complex. If an accretionary complex is low-grade metamorphic rocks, the ending age of the subduction (probably beginning age of exhumation) of the accretionary complex may roughly be assumed from the oldest one of K-Ar ages of its muscovites. This is because, under the temperature of lower than Ar-closing temperature in muscovites, K-Ar age of them should show the phase when they recrystallized. Following such the assumption, Figs. 4, 5 and 6, which have been drawn by Hara *et al.* (1992) on the basis of many authors' fossil and radiometric age data, have been regarded as to roughly give the subduction beginning ages and the exhumation beginning ages for the above-mentioned nappes of the OA supermegaunit. From the age data for the nappes summarized in such the figures and the above-described structural relationship among the nappes, it has been assumed by Hara *et al.* (1991, 1992) that the Sambagawa megaunit corresponds to the deeply subducted parts of the lower Cretaceous accretionary complexes and that the nappes of the Chichibu megaunit I, which are exposed in the Southern Chichibu belt, are the members underplated in the shallow tectonic position of the subduction zone. Thus it can be read that the measurement of radiometric ages of the Sambagawa megaunit and the lower Cretaceous accretionary complexes in the Southern Chichibu belt must give an important information for understanding the picture of sediment-subduction, underplating and exhumation in the subduction zone. Though radiometric ages for the Sambagawa megaunit have been measured by many authors as summarized in Fig. 5, these of the lower Cretaceous accretionary complexes in the Southern Chichibu belt of Shikoku have not been yet determined. In this paper, therefore, K-Ar ages for two specimens, which have been collected respectively from the Valanginian accretionary complex nappe and the Barremian accretionary complex nappe of the Chichibu megaunit I exposed in the Southern Chichibu belt of Shikoku, are described and their tectonic implication is discussed. The previously published data and present data must give am important information on P-t path of sediment subduction-underplating-exhumation process related to the formation of the Sambagawa schists.

II. K-Ar Ages of Muscovites

The geology of the lower Cretaceous accretionary complexes of the Southern Chichibu belt exposed along the River Naka of east Shikoku has been mainly studied by Ishida (1982,1985). Fig. 2 is a route map for the Valanginian accretionary complex and the Barremian accretionary complex along the River Naka from Matsukubo to Hiradani, which

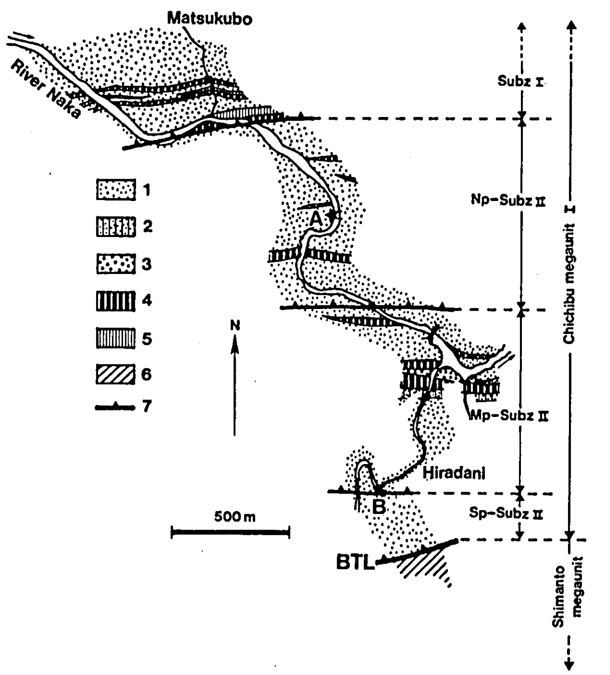

Fig. 2 A route map of Chichibu megaunit I along the River Naka which shows the localities of the samples for the K-Ar age determinetion (partly modified from Ishida, 1979,1985). 1: psammitic rock with pelitic rock, 2: psammitic and pelitic rocks, 3: conglomerate, 4: chert, 5: limestone, 6: Shimanto megaunit, 7: nappe boundary, BTL: Butsuzo Tectonic Line, Subz I : Subzone I, Np-Subz II: Northern part of Subzone II, Mp-Subz II: Middle part of Subzone II, Sp-Subz II: Southern part of Subzone II, solid stars: localities of Sample A and Sample B.

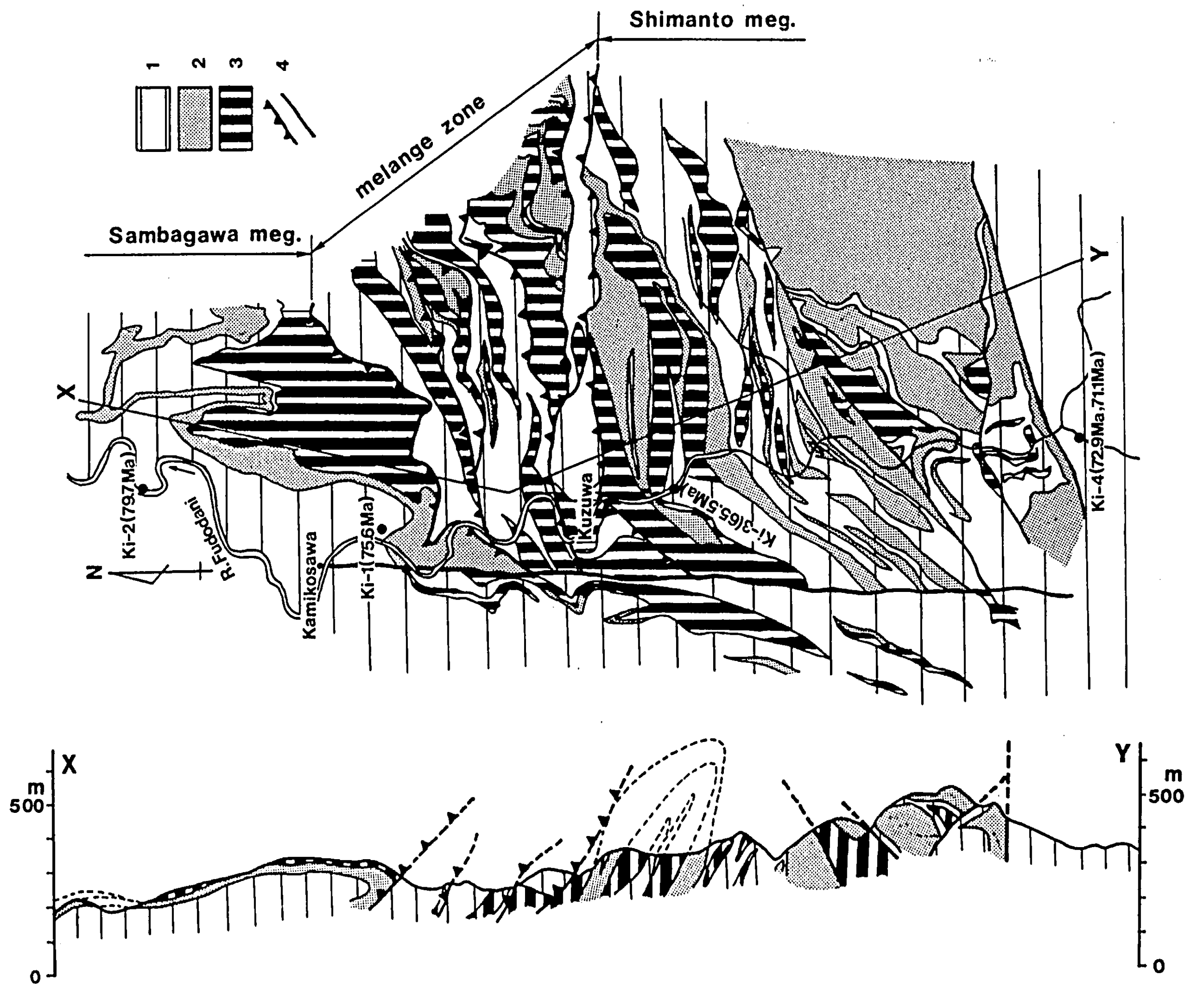

Fig. 3 a) Geological map and profile of the Kuzuwa district, west Kii [data of Tanino, Hara, Kanai and Hayasaka (1992)] (from Hara *et al.*, 1992). 1: pelitic rocks, 2: basic rocks, 3: siliceous rocks, 4: fault and nappe boundary. In melange zone is found the mixing of the Sambagawa megaunit rocks and the Shimanto megaunit rocks.
b) K-Ar data of muscovites in pelitic rocks of the Sambagawa megaunit and the Shimanto megaunit developed in the Kuzuwa district (Fig. 3-a) [data from Kanai *et al.*, 1991] (from Hara *et al.*, 1992).
Age data of the Sogauchi unit and Oboke unit in Shikoku are shown also in this diagram. Mt. Koyasan.

is mainly based on Ishida's (1982,1985) data, and it shows the localities of the specimens (Specimen A and Specimen B) collected for the determination of K-Ar ages of muscovites. The specimens are pelitic rock with a distinct set of slaty cleavage. The Specimen A and Specimen B belong respectively to the Valanginian accretionary complex and the Barremian accretionary complex. From Ishida's (1985) geological division, the latter is placed near the northern end of the Southern part of Subzone II of the Southern Chichibu belt. However, the structural position of the accretionary complex near Hiradani appears to be placed in the Middle part of Subzone II (Barremian accretionary complex) of the Southern Chichibu Belt from structural trend of lithologic layering. In this paper, therefore, the Specimen B is regarded as to belong to the Barremian accretionary complex.

The Specimens A and B are pelitic rocks. The K-Ar age determination was carried out for muscovites from these specimens by the Teledyne Isotopes. The results are shown in Table 1. The K-Ar age for muscovites from the Specimen A, which was collected from the Valanginian accretionary complex of the locality A in Fig. 2, is 114±6Ma, and that from the Specimen B, which was collected from the Barremian accretionary complex of the locality B in Fig. 2, is 108±5Ma.

Table 1. Radiometric age data of Specimen A and Socciem B.

Locality No.	Sample No.	Meneral analyzed	^{40}Ar * rad (Scc/gm·10^5)	% ^{40}Ar * rad	% K	Age (Ma)
A	91203	muscovite	1.78	92.8	3.75	114±6
			1.66	94.5	3.75	
			1.77	95.3		
			1.68	96.5		
B	91209	muscovite	1.36	91.8	3.17	108±5
			1.38	91.0	3.14	
			1.34	91.5		

^{40}Ar *: radiogenic ^{40}Ar. Decay constants used to caluclate age are after Steiger and Jäger (1977). $K\lambda^{\beta}=4.962\times10^{10}$/yr, $\lambda^{\varepsilon}=0.581\times10^{-10}$/yr, $^{40}K/K=1.167\times10^{-4}$atm%, $^{40}Ar/^{36}Ar$ atmosphere=295.5.

III. Discussion

The descending order of structural level from the Chichibu megaunit II, through the Sambagawa megaunit, to the Cènomanian-Turonian accretionary complex of the Shimanto megaunit, which is found in the northern part of the Sambagawa belt, is also clearly shown as the younging order of the oldest one of radiometric ages (exhumation beginning age) (Fig. 4). It is also clearly shown as the younging order of the youngest one of fossil ages (subduction beginning age), though the pelitic schists of the Sambagawa megaunit do not contain any available fossil for age determination (Fig. 4). With reference to the structural position and radiometric ages, the Oboke nappe (I+II) schists

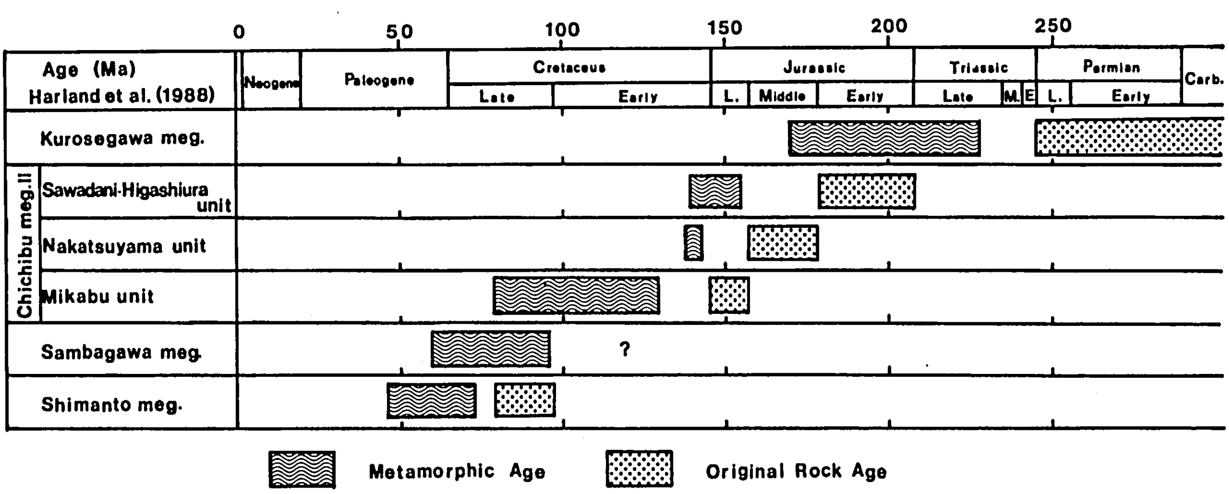

Fig. 4 Age relationship between the original rocks (fossil ages) and the metamorphism (radiometric ages) for the Kurosegawa megaunit, Chichibu megaunit II, Sambagawa megaunit and Shimanto megaunit in east Shikoku and west Kii (from Hara *et al.*, 1992). The data are from Maruyama *et al.* (1984), Iwasaki *et al.* (1984), Ishida (1985), Isozaki (1988), Itaya and Takasugi (1988), Monie *et al.* (1988), Fukui and Itaya (1989), Takasu and Dallmeyer (1989a,b), Takasu (1990), Isozaki and Itaya (1990a,b), Isozaki *et al.* (1990), Suzuki *et al.* (1990a,b), Kawato *et al.* (1990), Tominaga (1990), Kanai *et al.* (1990) and Hara *et al.* (1992).

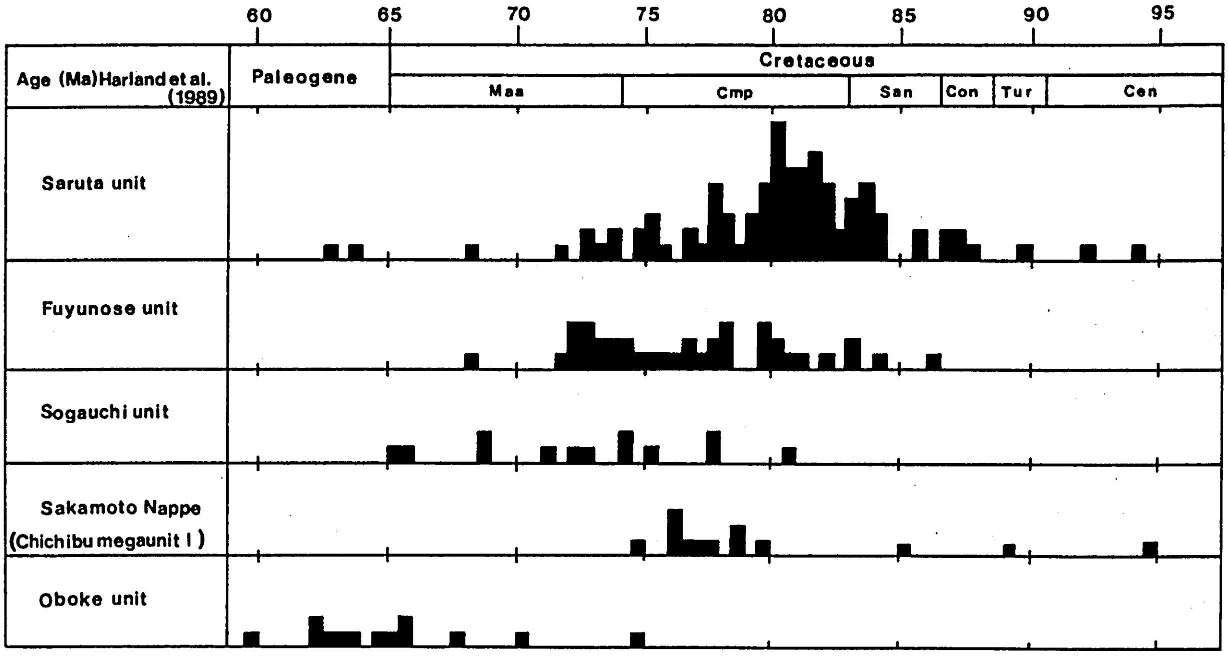

Fig. 5 Frequency distribution of radiometric ages of the Sambagawa megaunit and its underlying schists in central Shikoku (from Hara *et al.*, 1992). The data are from Monie *et al.* (1988), Itaya and Takasugi (1988), Takasu and Dallmeyer (1989a,b), Takasu (1990) and Hara *et al.* (1992).

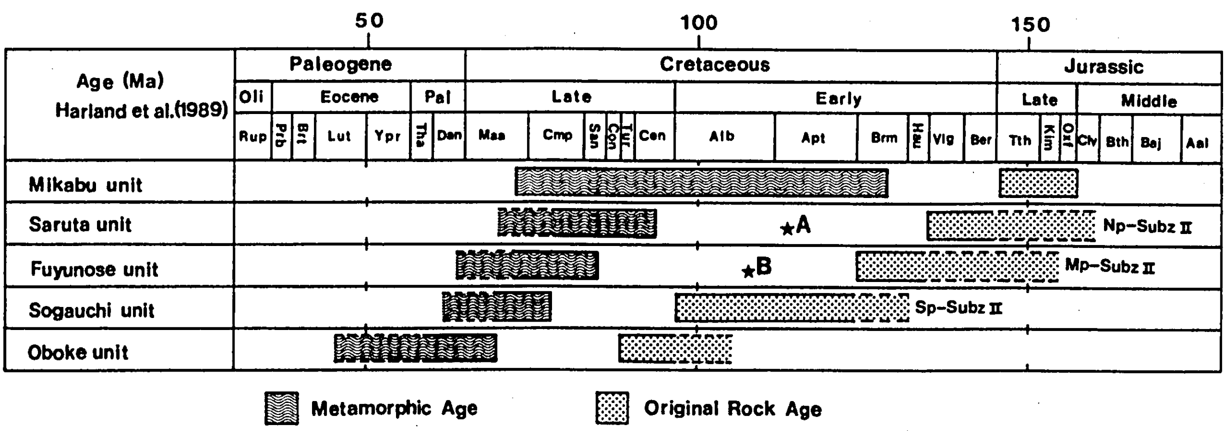

Fig. 6 Age relationship between the original rocks and the metamorphism for the Chichibu megaunit II (Mikabu unit), Sambagawa megaunit, Chichibu megaunit I and Shimanto megaunit (oboke unit). For fuller explanation see the Text. Np-Subz II: Northern part of Subzone II of Southern Chichibu Belt (Chichibu megaunit I)(Ishida,1985), Mp-Subz II: Middle part of Subzone II of Southern Chichibu Belt (Chichibu megaunit I)(Ishida,1985), solid stars: radiometric age data for Np-Subz II and Mp-Subz II.

are comparable with the Cenomanian-Turonian accretionary complex of the Shimanto megaunit (Hara *et al.*, 1990, 1992). On the basis of the regular relation shown in Fig. 4, therefore, it has been assumed by Hara *et al.*(1991, 1992) that the subduction beginning age of the Sambagawa megaunit is early Cretaceous.

The early Cretaceous accretionary complexes are found as the members of the Chichibu megaunit I in Shikoku (Ishida, 1985; Tominaga, 1990; Kochi Prefecture, 1991). The K-Ar ages for muscovites from pelitic rocks of the Langininan and Barremian accretionary complexes in east Shikoku were determined in this paper as shown in Fig. 6. This figure and Fig. 4 further indicates radiometric age data for the middle Jurassic accretionary complex, upper Jurassic accretionary complex, Valanginian accretionary complex and Barremian accretionary complex of the Chichibu megaunit (I+II) and the Cenomanian-Turonian accretionary complex of the Shimanto megaunit, clearly showing a downward younging age polarity. As is obvious in Fig. 5 and Fig. 6, there are two types of downward younging age polarity for the accretionary complexes of early Jurassic to middle Cretaceous: The one is for the accretionary complexes (Chichibu megaunit II~Sambagawa megaunit~Shimanto megaunit) developed in the northern part of the Sambagawa belt, and the other is for these (Chichibu megaunit II~Chichibu megaunit I~Shimanto megaunit) developed in the southern part and southern outside (Northern~Southern Chichibu Belt) of the Sambagawa belt. However, radiometric ages of the Sambagawa megaunit are between these of the Valanginian and Barremian accretionary complexes and these of the Cenomanian-Turonian accretionary complex (Fig. 6). This fact may suggest that the Sambagawa megaunit is post-Barremian and pre-Cenomanian accretionary complexes. Therefore, that may be comparable with the Albian accretionary complex of the Chichibu megaunit I or post-Albian accretionary complexes.The time-interval (Sub-Eh time) between the subduction beginning age and the exhumation beginning age is in general ca. 20Ma (smaller than 26Ma but larger than 15Ma) for the accretionary complexes of the OA supermegaunit (Figs. 4 & 5). Analogous scales of Sub-Eh time have also been found in the accretionary complexes of the IA supermegaunit (Nishimura & Shibata, 1984; Nishimura, 1990; Takami & Isozaki, 1993). Metamorphic facies of all these accretionary complexes is of prehnite-pumpellyite facies or of a little higher pressure type (cf. Banno & Sakai, 1989; Nishimura, 1990; Takami & Isozaki, 1993). Basic rocks of the Valanginian accretionary complex of the Chichibu megaunit I appear to be of prehnite-pumpellyite facies (Tominaga, personal communication), which suggests the subduction depth of a few kilobars (cf.Turner, 1968). Such the accretionary complexes, that show the Sub-Eh times of ca. 20Ma, are therefore considered to have been in general underplated at the subduction depth of and a little deeper than prehnite-pumpellyite facies.

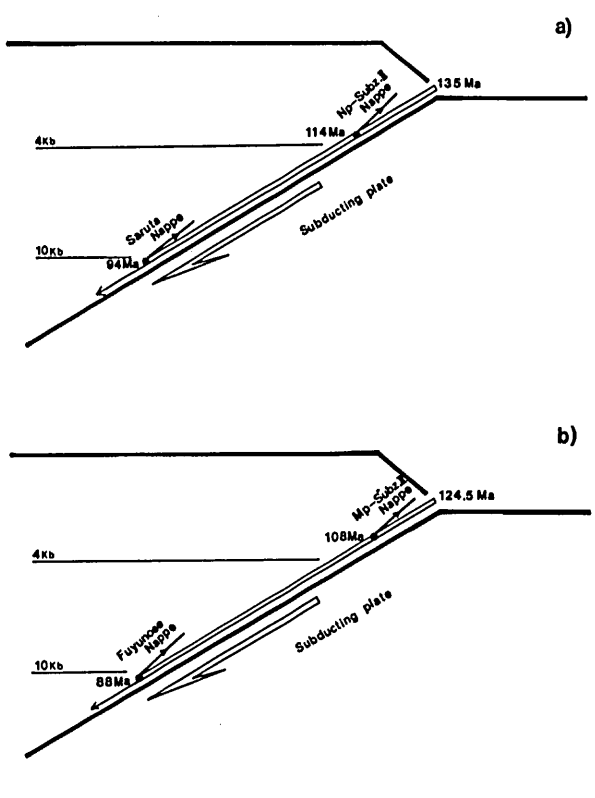

Fig. 7 Time sequence of sediment subduction, underplating and exhumation in subduction zone as inferred from the data of Sambagawa magaunit and Chichibu megaunit I. a) Vallanginian subduction complexes, b) Barremian subduction complexes.

The Sambagawa megaunit shows the subduction depth of ca. 10kb (e.g.Enami, 1983; Banno & Sakai, 1989). That was exhumed separating the previously subcreted Chichibu supermegaunit into the Chichibu megaunit II and the Chichibu megaunit I (Hara *et al.*, 1991, 1992). Such the phenomenon is shown as the coupling of the Sambagawa megaunit with the Sakamoto nappe of the Chichibu megaunit I. The position in the subduction zone, in which it occurred, would be roughly assumed to be the depth of ca. 4kb. This assumption is based on the pressure estimation for the metamorphism of the Sakamoto nappe, which has been performed by Watanabe and Kobayashi (1984) and Banno and Sakai (1989). The now-exposed part of the Chichibu megaunit I, whose metamorphic facies is of pumpellyite-actinolite facies to prehnite-pumpellyite facies (cf. Banno & Sakai, 1989), all appears to have been exhumed from the depth position in the subduction zone of less than 4kb. Therefore, the subcretion position of the Sambagawa megaunit is considered to be larger than twice as deep as that for the members of the Chichibu megaunit I and Chichibu megaunit II, suggesting that the Sub-Eh time of the Saruta nappe (I+II), Fuyunose nappe and Sogauchi nappe of the Sambagawa megaunit must have been much greater than 20Ma. If the Sub-Eh time for the Saruta nappe (I+II) was 20Ma, it should be comparable with the Albian accretionary complex. The accretionary complexes, which are of the same generation as the Sambagawa megaunit, must have also been underplated in the shallower position of the subduction zone. As pointed out by Hara *et al.* (1991,1992), thus, the Saruta nappe (I+II), Fuyunose nappe and Sogauchi nappe of the Sambagawa megaunit can be assumed to correspond respectively to the deeply subducted part of the Valanginian accretionary complex, that of the Barremian accretionary complex and that of the Albian accretionary complex of the Chichibu megaunit I.

In the subduction zone placed in the southern front of the Kurosegawa-Koryoke continent, subduction of sediments began during Valanginian age (ca. 135Ma). A part of them was underplated and began to exhume in the depth of a few kilobars and less than 4kb in 114Ma, i.e. after 21Ma from their subduction beginning age, forming the Valanginian accretionary complex of the Chichibu megaunit I in east Shikoku (Fig.7-a). Their remaining part was underplated and began to exhume in the depth of ca. 10kb in ca. 94Ma after 36Ma from their subduction beginning age, forming the Saruta nappe (I+II) (Fig.7-a). Subduction of sediments also began during Barremian age (ca.124.5Ma). A part of them was underplated and began to exhume in the depth of a few kilobars and less than 4kb in 108Ma, i.e. after 15Ma from their subduction beginning age, forming the Barremian accretionary complex of the Chichibu megaunit I in east Shikoku (Fig.7-b). Their remaining part was underplated and began to exhume in the depth of ca. 10kb in ca. 88Ma after 36Ma from their subduction beginning age, forming the Fuyunose nappe (Fig.7-b).

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