What is essential for metamorphic lithology with and without excess ^{40}Ar on Argon dating?

Tetsumaru Itaya[1] and Chitaro Gouzu[2, 3]

[1] *Research Institute of Natural Sciences, Okayama University of Science, 1-1 Ridai-cho, Okayama 700-0005, Japan*
[2] *Open Research Center, Okayama University of Science, 1-1 Ridai-cho, Okayama 700-0005, Japan*
[3] *Hiruzen Institute for Geology and Chronology, 161-1 Sai, Okayama 703-8248, Japan*

Introduction

K-Ar system dating method is powerful tool to study cooling ages of metamorphic rocks. However, discordant K-Ar and Ar/Ar age relations in ultrahigh-pressure metamorphic (UHPM) and High-pressure metamorphic (HPM) rocks are widely reported from the Dora Maira massif (Scaillet et al., 1996; Arnaud and Kelley, 1995), the Su-Lu and Dabie areas, China (Li et al., 1994; Giorgis et al., 2000), the Kaghan valley area, Pakistan (Tonarini et al., 1993), the Gourma area, Mali (Jahn et al., 2001), the Sesia-Lanzo zone, Italy (Ruffet et al., 1995, 1997; Inger et al., 1996), the Tavsanli Zone, Turkey (Sherlock and Arnaud, 1999), and the Betic Zone, Spain (De Jong, 2001). In each K-Ar and Ar/Ar analysis, it is hard to identify the existence of excess ^{40}Ar in the rocks, and even if it is identified, it is also difficult to subtract quantitatively it from the total ^{40}Ar to get the radiogenic ^{40}Ar because we cannot distinguish atmospheric ^{40}Ar, radiogenic ^{40}Ar and excess ^{40}Ar in analysis. Metamorphosed continental crust materials like Dora Maira massif in western Alps, which have experienced complicate metamorphic histories, have provided the discordant ages due to the excess ^{40}Ar that was inherited from the protolith (Fig. 1). Imperfect resetting for the Ar isotopic system gives older apparent ages in the conventional K-Ar system dating. This type of rock is so hard to date the cooling age.

We have a working hypothesis that the rock with a simple metamorphic history such as the metamorphosed oceanic materials has no significant amount of excess ^{40}Ar. This hypothesis is based on the experience of K-Ar dating on phengites from the Sanbagawa metamorphic rocks, Japan (Isozaki and Itaya, 1990; Itaya and Takasugi, 1988; Itaya and Fujino, 1999; Miyashita and Itaya, 2002) and from the Otago schists, New Zealand (Nishimura et al., 2000). The pelagic sediments are composed of fine-grained

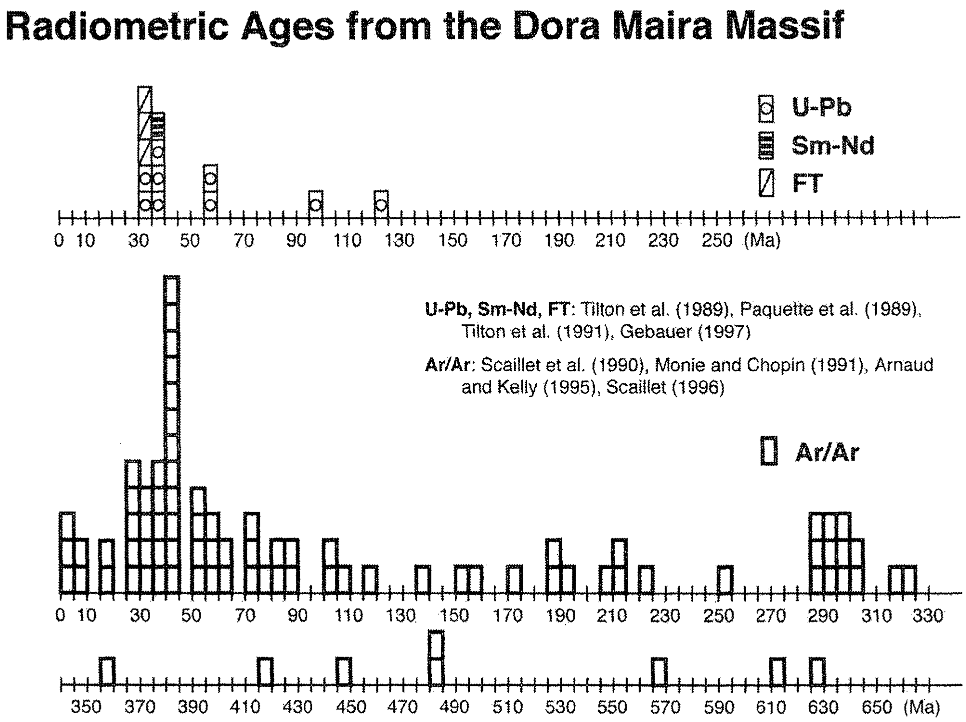

Fig. 1. Radiometric ages from Dora Maira massif in western Alps.

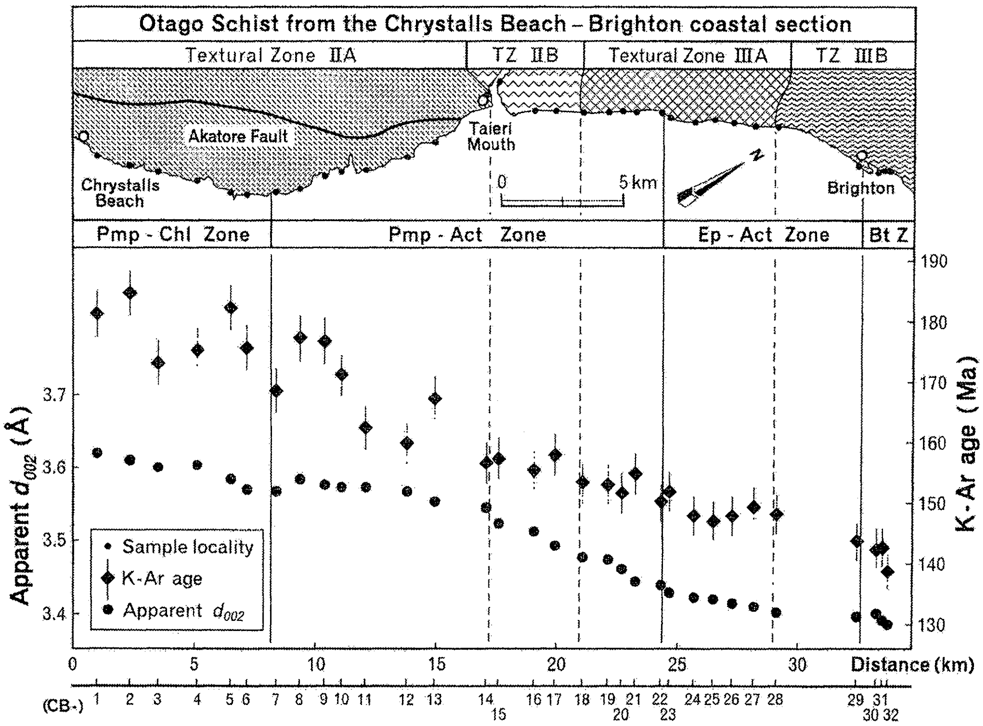

Fig. 2. K-Ar ages for phengite separated from pelitic and semipelitic metamorphic rocks in Otago schist, South Island, New Zealand. XRD data of carbonaceous materials are also plotted (after Nishimura et al., 2000).

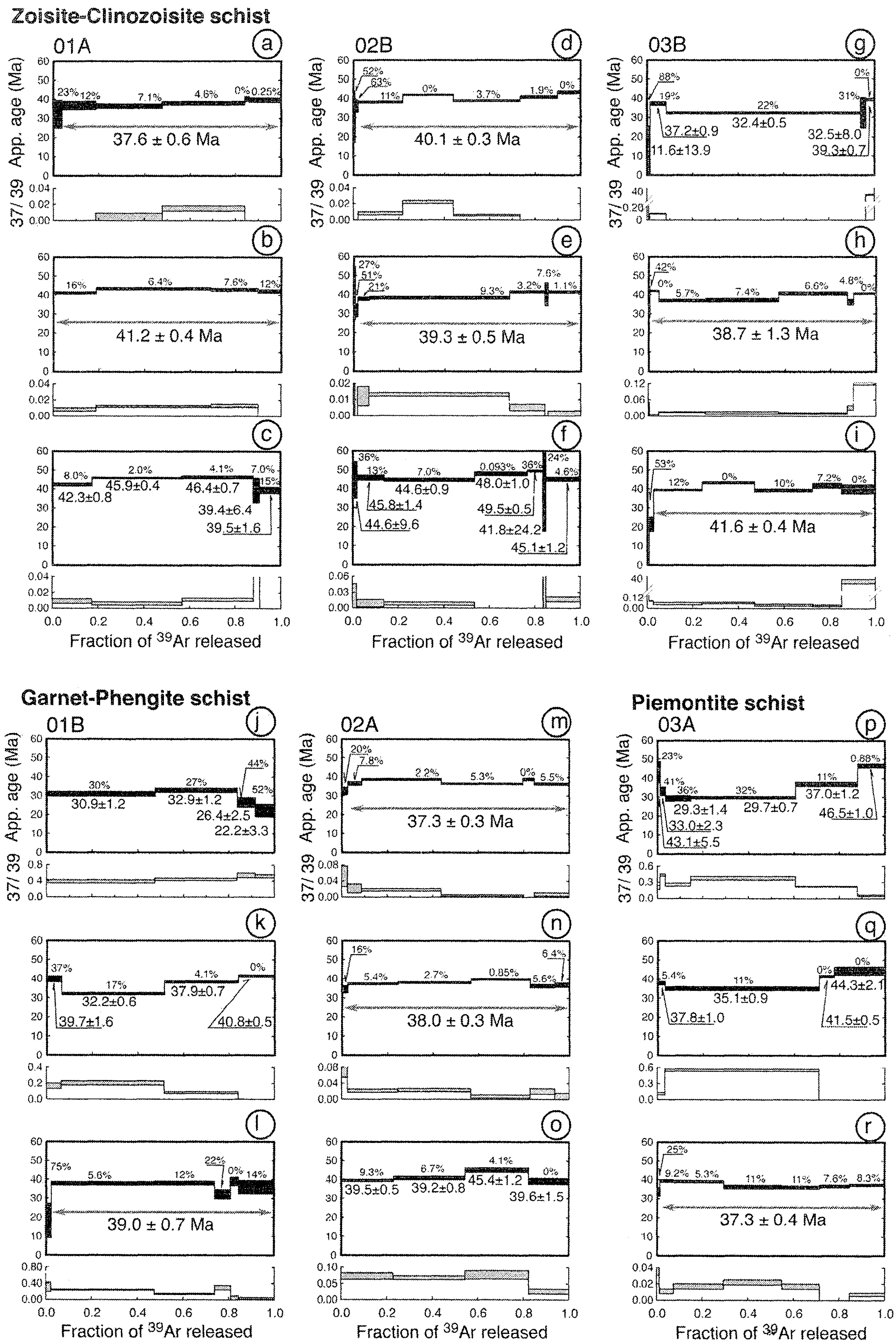

Fig. 3. Ar/Ar age spectra and $^{37}Ar_{Ca}/^{39}Ar_{K}$ ratio of phengites in ultrahigh-pressure metamorphic rocks from the Lago di Cignana area, Western Alps (after Gouzu et al., 2006a).

materials. When they underwent HP - UHP metamorphism in a subduction zone, the fine-grained materials can be recrystallized, resulting in complete resetting in K-Ar system. Well-documented examples of this concept are reported from the systematic K-Ar phengite analyses in the Sanbagawa schists, SW Japan and the Otago schists, New Zealand. In these areas, no sign of excess ^{40}Ar, i.e. discordant ages and/or significantly older ages, are found because the metamorphic gradient, documented by K-Ar analyses of the phengites, are "continuous" (Fig. 2).

Ar/Ar dating in three different kinds of metamorphic sequences

Recently, we and our colleague have carried out Ar/Ar dating of micas from ultrahigh-pressure metamorphic rocks from the Lago di Cignana area, Western Alps (Gouzu et al., 2006a), eclogitic rocks in the Tso Morari Complex, western Himalaya, India (Gouzu et al., 2006b) and Barrovian type rocks in the Danba area, eastern Tibet (Itaya et al., 2006). We summarize their results here.

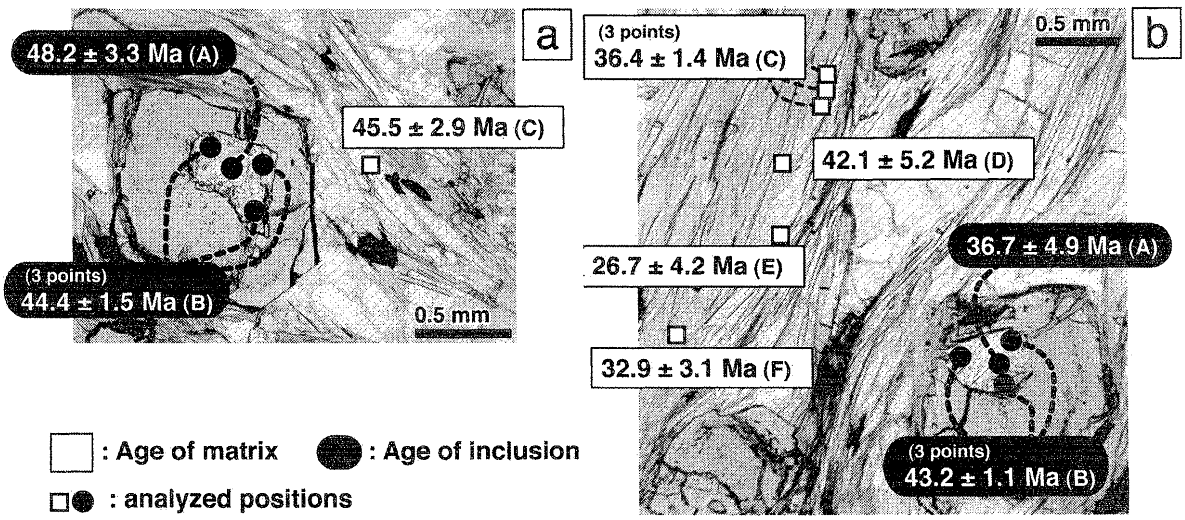

Fig. 4. Ar/Ar spot ages of phengites in the garnet-phengite schist from the Lago di Cignana area, Western Alps (after Gouzu et al., 2006a).

Lago di Cignana area

The Zermatt-Saas zone in western Alps is regarded as an ophiolite. We carried out the Ar/Ar analyses of phengites from the coesite-bearing pelitic schist, piemontite schist and Ca-rich schist. The protoliths of latter two were formed by hydrothermal activity and in pelagic setting, respectively. Phengites in the rocks from the Lago di Cignana area provide 37-42 Ma plateau ages (Fig. 3) that have very little variation in comparison with those from Dora Maira massif and are consistent with Sm-Nd and Rb-Sr mineral ages (38

– 40 Ma: Amato et al., 1999) of eclogites and phengite-quarzites. Phengite inclusions in garnet give ages of 43.2 ± 1.1 Ma and 44.4 ± 1.5 Ma, which are significantly older than the spot age (36.4 ± 1.4 Ma) from the matrix phengites, and the plateau ages (Fig. 4). Inclusion ages (43 and 44 Ma) are consistent with a zircon SHRIMP age (44 ± 1 Ma: Rubatto et al.,1998) (Fig. 5). These results suggest that the oceanic materials that underwent a simple subduction related UHPM, form excess ^{40}Ar-free phengite and that the peak metamorphism is ca. 44Ma or little older. These analyses confirm our working hypothesis mentioned above. We also suggest that matrix phengites experienced a retrograde reaction changing their chemistry contemporaneously with deformation related to the exhumation of rocks and releasing significant radiogenic ^{40}Ar from the crystals. This has lead to the apparent ages of the matrix phengites that are significantly younger than the inclusion age.

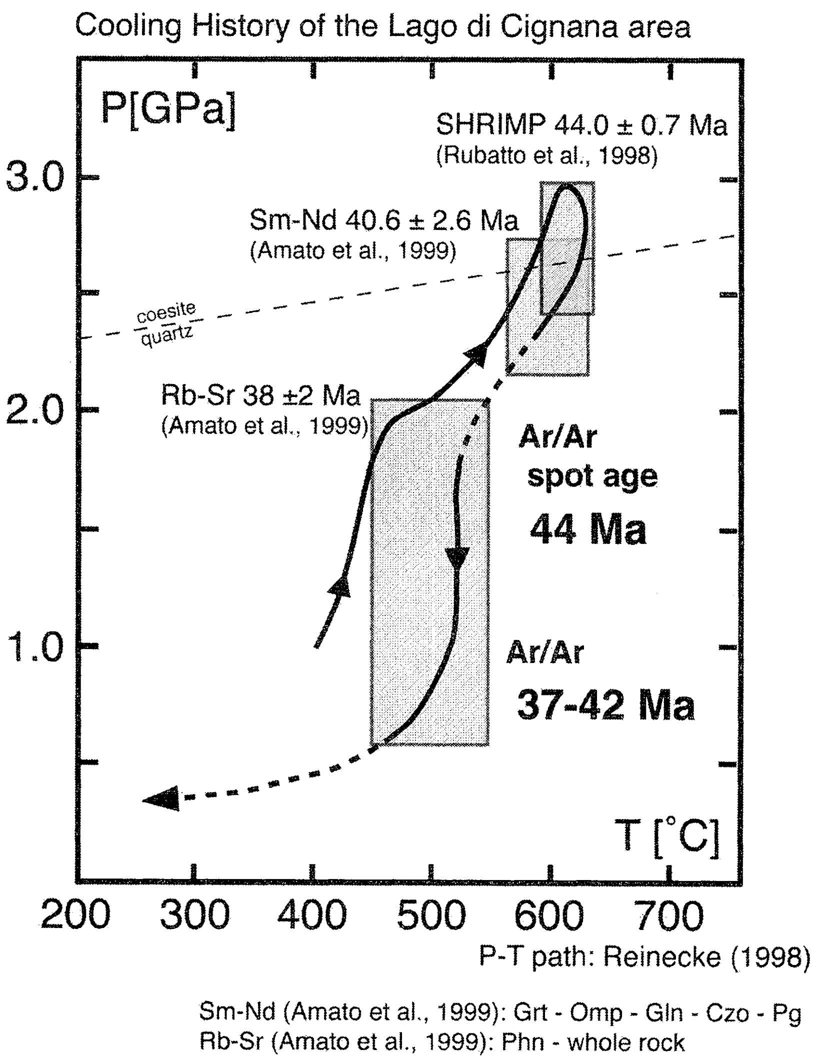

Fig. 5. P-T-t path of ultrahigh-pressure metamorphic rocks from the Lago di Cignana area, Western Alps.

Tso Morari Complex

The Tso Morari Complex in western Himalaya, which is thought to be originally the margin of the Indian continent, is composed of pelitic gneisses and schists including mafic rock lenses (eclogites and basic schists). Eclogites have coesite pseudomorph in garnet and quartz rods in omphacite. They occur only in the cores of meter-scale mafic rock lenses intercalated with the pelitic schists. Small mafic lenses and the rim parts of large lenses have been strongly deformed to form the foliation parallel to that of the pelitic schists and show the mineral assemblages of upper greenschist to amphibolite facies metamorphism. The garnet-omphacite thermometry and the univariant reaction relations for jadeite formation give 13 – 21 kb at 600°C and 16 – 18 kb at 750°C for the eclogite formation (Fig. 6). Phengites in pelitic schists show variable Si/Al and Na/K

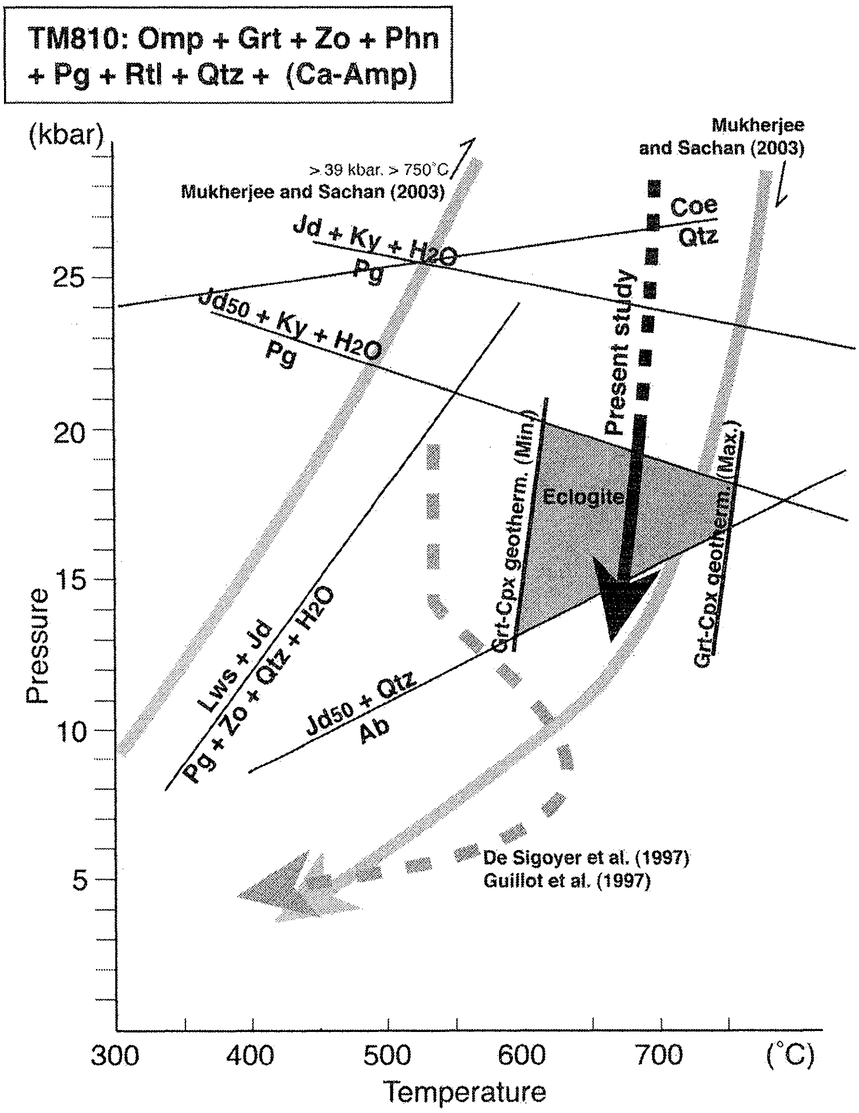

Fig. 6. P-T conditions of eclogite in the Tso Morari Complex, western Himalaya, India (after Gouzu et al., 2006b)

ratios among grains as well as within single grains, and give K-Ar ages of 50-87 Ma. A pelitic schist yielded K-Ar ages of 83.5 Ma (K=4.9 wt %) for paragonite-phengite mixture and 85.3 Ma (K = 7.8 wt %) for phengite and an isochron age of 91±13 Ma from the two dataset (Fig. 7a). The eclogite gives a plateau age of 132 Ma in Ar/Ar step-heating analyses using single phengite grain and an inverse isochron age of 130±39 Ma with an initial $^{40}Ar/^{36}Ar$ ratio of 434±90 in Ar/Ar spot analyses of phengites and paragonites (Fig. 7b). The Cretaceous isochron ages are interpreted to represent the timing of early stage of exhumation of the eclogitic rocks. The phengites in pelitic schists have experienced retrograde reaction, which modified their chemistry during intense deformation associated with the exhumation of these rocks with the release of significant radiogenic ^{40}Ar from the crystals. The argon release took place in the schists that experienced the retrogression to upper greenschist facies metamorphisms from the eclogite facies conditions.

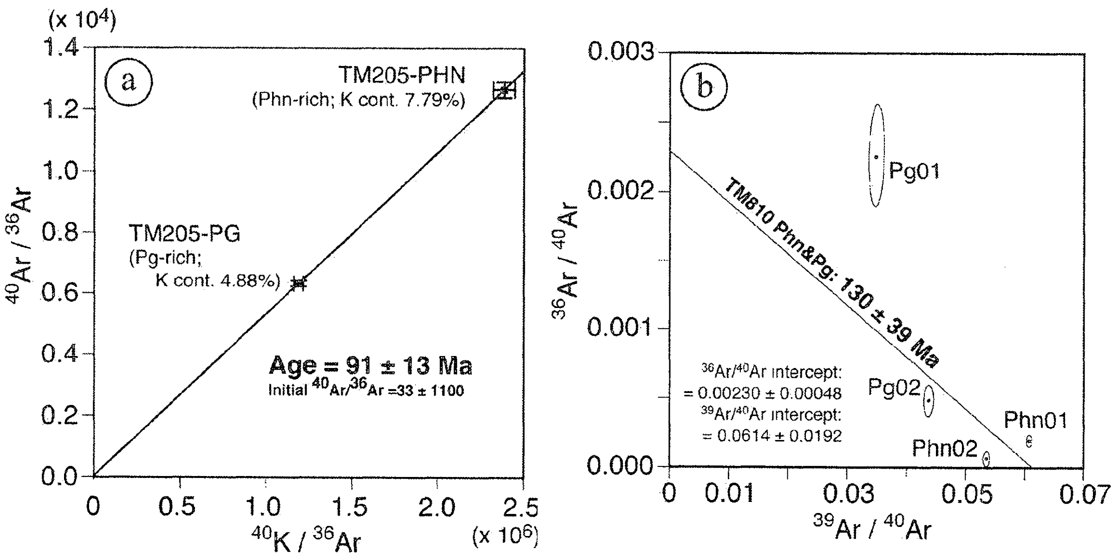

Fig. 7 K-Ar isochron age (a) calculated using two data sets, phengite rich fraction and phengite - paragonite mixture from pelitic schist and Ar/Ar inverse isochron age (b) calculated using four data sets of phengites and paragonites from eclogite in the Tso Morari Complex, western Himalaya, India (after Gouzu et al., 2006b).

Danba area

The Danba area in the central part of Longmenshan orogenic belt in Eastern Tibet consists mainly of Sinian to Triassic metasediments. The whole region has undergone Barrovian type metamorphism with progressive changes from chlorite-grade slates into sillimanite-K feldspar schists and estimated peak conditions of ca 8 kbar and 700℃

(Huang et al., 2003). Electron microprobe (CHIME) monazite dating in the metapelite and SHRIMP U-Pb dating of apatite in the metamorphosed granodiorite both from the sillimanite zone give compatible ages of ca. 65Ma that is the metamorphic age (Wallis et al., 2003). Laser step heating Ar/Ar analysis of single crystals of biotite and muscovite yielded consistent cooling ages of ca 40Ma in the sillimanite zone with metamorphic temperatures higher than 600℃ and discordant ages from 46 to 197Ma in the zones with peak metamorphic temperatures lower than 600℃. The higher kyanite zone gives, in particular, extreme old biotite ages more than three times the metamorphic age. We suggest biotite grains with apparent ages of 130 to 197Ma have trapped excess ^{40}Ar derived from degassing of muscovite in the sillimanite zone. We refer to this as a trapped 'excess argon wave'. Biotite grains with ages 46 to 94Ma in the lower grade zone trapped moderate excess argon inherited from the host lithologies during the metamorphism.

Conclusions

The oceanic materials with a single metamorphism less than 500℃ have the phengites without excess argon. The metamorphic sequences have the continuous metamorphic gradient in age and temperature. The metamorphic rocks, originated from continental materials with prehistory, have the micas with the excess ^{40}Ar that was inherited from the host lithologies during the metamorphism less than 600℃ and that trapped the excess ^{40}Ar wave which released by the decomposition of muscovite in the sillimanite zone during the exhumation of the metamorphic sequence. The metamorphic lithologies experienced higher than 600℃ have no significant excess ^{40}Ar in phengites, giving the reliable cooling age.

Acknowledgments

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