Cleavage dating by K-Ar isotopic analysis in the Paleogene Shimanto Belt of eastern Kyushu, S.W. Japan

JOHN S. MACKENZIE*, SACHIRO TAGUCHI** and TETSUMARU ITAYA***

*Geothermal Research Center, Faculty of Engineering, Kyushu University, Hakozaki, Fukuoka 812, Japan
**Faculty of Science, Fukuoka University, Nanakuma, Fukuoka 814-01, Japan
***Hiruzen Research Institute, Okayama University of Science, Okayama 700, Japan

An axial-planar cleavage associated with folded sedimentary rocks of the Paleogene Shimanto Belt of eastern Kyushu was sampled and a <2 μ clay fraction separated and dated by K-Ar isotopic analysis. Experimental results yield a K-Ar age of 48.4 ± 1 Ma. The cleavage minerals sampled, being axial-planar to the folds, are assumed to be syn-tectonic, their crystallization age thus corresponding to the age of the folds themselves.

Introduction

Cleavage dating by K-Ar isotopic analysis has been previously attempted by conventional whole-rock methods (eg. Harper 1964, 1967; Dodson and Rex, 1971). Whilst yielding reasonably good estimates of the age of crystallization, such methods are complicated by the difficulties involved in excluding from analysis, samples contaminated by older detrital components such as micas and in particular K-feldspars. More recent studies have concentrated on trying to reduce or eliminate this detrital component by separating out the newly-formed authigenic (syn-tectonic) micas, taking advantage of their generally smaller grain sizes (usually less than 2 microns). Despite the difficulties inherent in the preparation of high-quality clay-sized fractions and the susceptibility of such fine-grained particles to diffusive loss of radiogenic 40Ar, a number of studies have demonstrated that this approach can yield concordant K-Ar ages which can be related to geologically significant events (eg. Hunziker 1979; Halliday and Mitchell 1984; Kligerfield et al., 1986).

The aims of this study were to determine the age of a series of folds developed in a sequence of weakly metamorphosed sedimentary rocks in the Paleogene Shimanto Belt of eastern Kyushu. These folds are thought to have formed during frontal accretion of trench sediments near the toe of an accretionary prism (Mackenzie et al., 1988). Shale containing a penetrative axial-planar cleavage associated with these folds was sampled, and a white mica (illite)-rich clay-size fraction separated and dated by K-Ar isotopic analysis. It is assumed that contamination by detrital material can be minimized and the authigenic cleavage-forming minerals concentrated by separating out the <2 μ size fraction. Thus, a maximum cleavage age can be obtained. These cleavage minerals, being axial planar to the folds, are assumed to be syn-tectonic, their crystallization age thus corresponding to the age of the
folds themselves.

Regional Geology

The Shimanto belt of eastern Kyushu comprises a series of NE-SW trending sub-parallel belts inclined at shallow to moderate angles towards the NW (see Fig. 1). These belts include the Morotsuka Group in the north, and the Kitagawa and Hyuga Groups in the south (Sakai, 1978; Sakai and Kanmera, 1981). The Morotsuka Group is of Middle to Late Cretaceous age, whereas the Kitagawa and Hyuga Groups are of early to middle Paleogene age respectively (Ogawauchi et al., 1984; Okumura et al., 1985).

This paper focuses on the Kitagawa Group, represented in the study area by the Urashiro Formation (Sakai, 1978). The formation out-
crops in the south-west of the study area, bounded by the Furue Thrust to the north and the Nobeoka Thrust in the south (see Fig. 1). Here a thick (ca. 2600 m) coarsening-upward turbidite sequence is preserved. Accurate biostratigraphic control in this region is precluded by the scarcity of well preserved microfossils. However, Ogawauchi et al. (1984) reported lower-middle Paleogene radiolarians from the base of the succession. A lower-Mid Paleogene age can also be inferred from the regional setting of the Kitagawa Group and its structural relationships with the neighboring Morotsuka and Hyuga Groups (Sakai and Kanmera, 1981; Sakai et al., 1984).

These sediments are deformed by a series of broad NNE-trending, ESE-directed asymmetrical folds. A wide range of fold styles and geometries are developed, ranging from upright, inclined to completely overturned. Wavelengths range from a few meters up to 1 or 2 km in scale with many of the smaller folds being parasitic, typically occupying the limbs of the larger structures. Early folding appears to have occurred when the sediments were still unconsolidated, sandstone dikes, mud injections and other delicate soft sediment deformation features being preserved. Later deformation structures include minor thrusting, slickensides and quartz veining, and imply continued folding of more compacted and consolidated sediments under the same stress regime. Low-grade regional metamorphism accompanied folding, illite crystallinity studies correlating with lower anchizonal metamorphic grades (~200-250°C, Mackenzie, unpublished data). Associated with the later stages of deformation is a prominent axial planar cleavage, manifest as a}

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**Fig. 2a.** Axial-planar cleavage developed in folded turbidites of the Urashiro Formation near the village of Yasui (see Fig. 1 for location). Note: beds are inverted (dotted arrow). Scale bar is 15 cm.
spaced fabric in the sandstones and as a scaly penetrative cleavage in the shales. The cleavage lies parallel or subparallel to the axial planes of the larger folds, inclined towards the NNW, although it may locally fan around minor parasitic fold hinges (see Fig. 2a and b). Experimental Procedure

Sample preparation

Approximately 5 kg of well-cleaved shale was collected for analysis from a locality approximately 5 km northeast of the city of Nobeoka, near the village of Yasui (see Fig. 1). In this region the cleavage is particularly well developed and the area free from the effects of later deformation. Furthermore, the geometrical relationships between cleavage and folding can be easily discerned (see Fig. 2a and b).

Shale fragments were initially broken up using a rock hammer, and chips then further reduced in size in a crushing mill to between 0.5 and 2 cm in diameter. After washing, samples were placed in 500 ml beakers containing distilled water, covered and stored. To assist disaggregation and clay-mineral separation, samples were periodically placed in an ultrasonic tray for 20-30 minutes. At 2-3 day intervals the accumulated clay fraction was removed and stored and the remaining sample topped up with distilled water again. After 3-4 weeks of treatment, the clay fractions removed at each stage were recombined and a less than 2 μ fraction separated by centrifugal sedimentation. A smear slide mount was made from a portion of the less than 2 μ fraction sample and analyzed by X-ray diffraction (XRD) to check for possible contamination by detrital Kfeldspar. Scanning electron microscope (SEM) measurements were also made to check the clay particle sizes. These were found to range from about 2 μ down to 0.5 μ although some particles as large as 10 μ were observed. The remaining fraction was re-centrifuged and then freeze-dried for K and Ar analysis.

Isotopic analysis

Potassium analysis was performed by flame photometry using a Cs buffer after decomposition of the original powdered samples with HF and H2SO4 in a platinum dish. Accuracy of potassium analysis was determined by analysis of chemical standards and is reported as ±2%.

Argon analysis was performed by mass spectrometry using the isotope dilution method and an 38Ar spike. Calibration of the 38Ar spike is reported to be accurate to within 1% (Nagao and Itaya, 1988). Age and error calculations follow the method described by Nagao et al. (1984). Further details of the experimental technique employed can be obtained from the authors upon written request.

Results and Discussion

The clay fraction analyzed yields a K-Ar age of 48.4 ± 1.1 Ma (see Table 1). The date obtained represents the crystallization age of the micas. Since these micas are assumed to be syntectonic, their crystallization ages are interpreted as defining the age of folding. The XRD trace shown in Fig. 3 indicates that the mineralogy of this clay fraction is predominant.
ly composed of quartz, chlorite and illite. Table 1 shows that the sample contains about 60% by weight of illite as estimated from the potassium content. Quartz and chlorite are not considered to have any influence on the resulting age of the sample analyzed as these minerals do not contain any potassium. However, a small amount of detrital feldspar (ca. 2%) is present in the sample and may contribute to the uncertainty in age, tending to produce a slightly older than expected K-Ar value. It is difficult to make a quantitative assessment of the contribution made by this detrital feldspar to the overall age of the sample. Taira et al. (1982) suggested that the Ryoke granites and acidic igneous rocks (70-100 Ma) of the inner zone of SW Japan were an important provenance of the Paleogene Shimanto sediments in much of southern Kyushu. Thus, it is possible that the detrital feldspar in the sample analyzed was derived from a similar source. However, it is not thought to have contributed significantly to the K-Ar age obtained.

The limited paleontological data available suggests that these sediments were deposited in Lower-Middle Paleogene times, and the K-Ar age implies folding of sediments relatively soon after deposition. As noted earlier, field evidence suggests that folding was progressive, initial deformation occurring in essentially unconsolidated sediments and continuing into the metamorphic environment. Helwig (1970) and

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**Table 1. K-Ar age for mica from the Urashiro Formation, Shimanto Belt, Kyushu, Japan**

| Sample No. | Location       | Mineral | $K$ (wt.%) | $\text{Rad}^{40}\text{Ar}$ (10$^3$ ccSTP/g) | Age (Ma) | Non Rad. $\text{Ar}(\%)$
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<td>U2</td>
<td>131°47'30&quot;E 32°36'30&quot;N</td>
<td>illite</td>
<td>5.11</td>
<td>972±10</td>
<td>48.4±1.1</td>
<td>9.7</td>
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Physical constants employed in the age calculation: $\lambda^* = 0.581 \times 10^{-10} \text{ yr}^{-1}$; $\lambda^\prime = 4.962 \times 10^{-10} \text{ yr}^{-1}$; $^{40}\text{K}/^{40}\text{Ar}_{\text{tot}} = 0.01167$ atomic percent (Staiger and Jäger, 1977).

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**Fig. 3.** X-ray diffraction chart showing the mineralogy of the less than 2μ clay fraction used in the analysis. chl, chlorite; m, mica; qtz, quartz; feld, feldspar.
Pickering (1987) argued that soft sediment folding is characterized by the absence of cleavage. However, a number of other researchers have suggested that slumping and tectonic deformation of unconsolidated sediments can produce preferred orientations of platy minerals (e.g., Woodcock, 1976; Lundberg and Moore, 1986). Thus, the exact stage at which cleavage developed during this progressive folding event remains problematical.

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九州東部古第三系四万十帯のK-Ar法によるへき開年代測定

マッケンジー, J.S.・田口 幸洋・板谷 徹丸

九州の古第三系四万十帯の低変成度の堆積岩中に発達する褶曲運動の時期を明らかにするためにK-Ar年代測定を試みた。試料は褶曲運動に伴って発達する軸面へき開を有する頁岩から分離したイライトで、褶曲運動と同時期の生成物と考えられ、48.4 Ma の年代を示す。古生物学的には下部～中部古第三系の堆積物と考えられることから、K-Ar年代は堆積直後の褶曲運動を示唆している。