Authigenic illite formation - A tool for constraining timing of brittle deformation. Case studies from Europe, Japan and Australia.

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Near-surface deformation related to neotectonics is accommodated by brittle faults. Displacement on the fault planes often results in the development of fault gouges composed of rock fragments and authigenic illite. Previous studies have highlighted the potential for determining the absolute timing of brittle fault history using isotopic dating techniques, (see summary, Zwingmann *et al*. 2004). Methods for dating shallow faults in the earth's crust are still in evolution and their reliability remains controversial. One of the main problems is distinguishing and separating authigenic from detrital clays prior to isotopic dating. Authigenic, or newly formed illite, contains potassium and is therefore suitable for age determination using the potassium–argon, (K/Ar) geochronometer. Authigenic illite is of interest in many geological applications as it can, for example, provide a K/Ar date constraining a heating or fluid flow event within a sedimentary basin or, in structural geology, constrain the timing of brittle faulting. Dating of K-bearing illite minerals using the K/Ar isotopic system offers the prospect of establishing the absolute timing of the brittle faulting events. The understanding of fault processes and the timing and extent of clay-rich fault gouge formation is important for: (1) hydrocarbon exploration, as faults may act as either a conduit or a seal for fluids and/or hydrocarbons; (2) civil engineering, in the evaluation of earthquake hazards and (3) ascertaining the suitability of sites for nuclear waste storage. K/Ar and 40Ar/39Ar data using microencapsulation of authigenic illite, (to address 39Ar recoil), from gouge developed in different geological settings ranging from Europe, Japan and Australia will be presented.

The first study involves gouge zones from the European Alps where the protolith consists of high grade metamorphic or magmatic rocks, (Zwingmann and Mancktelow, 2004; Zwingmann *et al*. 2010). In these rocks a clear distinction is possible between newly-grown illite, which is the only K-bearing mineral in the fine-grained fractions separated from the gouge, and the precursor assemblage. Several samples originate from the well-preserved fault gouge in the AlpTransit deep tunnel site in Switzerland, thus eliminating natural weathering. We dated fault movement on young faults related to the regional-scale Periadriatic Fault in the European Alps, using neocrystalline illite. Fine-grained clay separates from fault gouges consist of illite 1M and $2M_1$ polytypes, smectite and chlorite, with minor amounts of feldspar in some sample fractions. The K/Ar ages for < 2 μm illite fractions range between 7.1 and 9.5 Ma, (mean 8.5 ± 1.4 (2σ) Ma), and for < 0.1 μm, between 3.9 and 7.2 Ma, (mean

6.0 ± 2.1 Ma), with ages consistently decreasing with grain size. These ages are close to published apatite fission track ages of ~6 Ma from the immediate vicinity, consistent with illite stability in fault gouges generally occurring slightly above the partial annealing zone of apatite. The influence on authigenic illite gouge ages of potential contamination by fine-grained cataclastic protolith was evaluated by dating coarse K-feldspar fractions from host rock clasts in two samples. The K-feldspar ages are significantly older, around 13.5 Ma. However, measured illite K/Ar ages are quite constant and do not correlate with the amount of K-feldspar impurity, which suggests that fine-grained cataclastic feldspar grains have isotopically re-equilibrated, presumably due to fluid-rock interaction within the fault zone. This study provides absolute time constraints on the youngest, retrograde, neotectonic movements that occurred in the Alpine orogeny.

The second study is located within the Nojima fault zone on Awaji Island, Japan. K/Ar ages from clay fault gouges of outcrop and core samples, (UG500 well) are again consistent internally with established field constraints, and with apatite and zircon fission track ages, demonstrating the suitability of this method for dating brittle deformation. Six unspiked and thirty conventional samples of clay minerals separated from gouge zones were analysed. Characterized by protoliths of high-grade metamorphic and magmatic rocks, the samples from the Nojima fault zone offer the opportunity to distinctly identify newly grown illite in the fault planes. All dated sample fractions were characterized by XRD, SEM and TEM. K/Ar ages of 29 separates have an age range from 63.4 ± 1.3 Ma, to 42.2 ± 1.0. Some <0.1 and <0.4 μm fractions of samples in close proximity to a pseudotachylyte zone are thermally influenced and indicate loss of radiogenic Ar. The K/Ar data from illite support a model that the Nojima fault zone was initiated ~ 55 Ma ago based on zircon fission track data. The data confirm elevated temperatures and a heterogeneous thermal history within the study area. The <2 μm ages of the outcropping samples document the age of gouge formation, whereas the <0.1 and <0.4 μm illite fractions suggest the influence of a secondary thermal heating event probably caused by circulation of hot fluids within the fault zone about 31-38 Ma ago and even a potential influence of Quaternary faulting (Zwingmann *et al.*, 2010).

The third study focuses on two fault zones in the northern Sydney Basin, Australia. The faults are hosted by Early Permian siltstones, tuffs, coal seams and foliated gouges; comminution and dilational breccias are developed within the fault zones. Clay minerals of detrital or authigenic origin are present within the sedimentary protolith and in the gouges. K/Ar ages obtained from samples in the gouge and tuffs in the damage zones range from 119 to 172 Ma, respectively. Illite ages of 196-245 Ma are thought to reflect the time at which diagenetic smectite-illite formed in the host rocks. 119-150 Ma ages from the <0.4μm fractions in the tuffs and gouges date the last slip event in the faults and can be related to the rifting of the eastern margin of the Australian continent. The data indicate the time at which diagenesis occurred in the host rocks and slip movement in the faults and constrain the deformation events associated with the rifting of the eastern margin of Gondwana during the Early Cretaceous.

The three case studies highlight the potential of authigenic illite K/Ar dating in constraining the timing of brittle deformation. Special sample preparation and clay characterization using extended SEM, TEM and XRD analyses are required prior to age dating to identify suitable samples.

References

Zwingmann H, Mancktelow N (2004) Timing of Alpine fault gouges. *Earth and Planetary Science Letters*, **223**, 415-425.

Zwingmann H, Offler R, Wilson T, Cox S (2004) K-Ar dating of fault gouge in the northern Sydney basin, Australia – implications for the breakup of Gondwana. *Journal of Structural Geology*, **26** (12), 2285-2295.

Zwingmann H, Mancktelow N, Antognini M, Lucchini R (2010) Dating of shallow faults – new constraints from the AlpTransit tunnel site (Switzerland). *Geology*, v.**38**, no 6, p. 487-490; doi10.1130/G30785.1

Zwingmann H, Yamada K, Tagami T (2010) Timing of brittle deformation within the Nojima fault zone, Japan. *Chemical Geology*, doi10.1016/j.chemgeo.2010.05.006.