Tectonophysics 608 (2013) 792–803

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

The origin and role of a calcite-filled microcrack generation in a metamorphic crystalline complex: The characterization of a fossilised seismic permeability system

Gergely Dabi [a,*], Bernadett Bajnóczi [b], Félix Schubert [a], Tivadar M. Tóth [a]

[a] Department of Mineralogy, Geochemistry and Petrology, University of Szeged, 2 Egyetem street, 6722 Szeged, Hungary
[b] Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, 45 Budaörsi street, 1112 Budapest, Hungary

ARTICLE INFO

Article history:
Received 25 January 2013
Received in revised form 22 July 2013
Accepted 31 July 2013
Available online 22 August 2013

Keywords:
Seismic damage
Microcrack porosity
Co-seismic fluid redistribution
Palaeoseismology

ABSTRACT

The Mecsekalja Zone metamorphic rocks are cross cut by a generation of a pervasive calcite filled microcrack system. Cathodoluminescence images reveal that the microcracks develop due the fragmentation of the rock forming feldspar crystals, and the microcrack density is proportional to the feldspar content of the host rock. Stable isotope data from the microcrack calcite display a linear trend with oxygen isotope compositions between 14.6‰ and 30.3‰ and carbon isotope compositions between −9.7‰ and 1.7‰, and indicate that the parent fluid is related to the Early Cretaceous dyke magmas. The trend itself provides a twofold interpretation, both of which are consistent with earthquake activity. The microcrack generation is thus interpreted as the seismic damage zone of the Ófalu Fault (the north-western boundary of the Mecsekalja Zone) during its active period in the Early Cretaceous. The microporosity system is considered to be the fossilised analogue of the pervasive crack systems detected around recently active faults (Hiramatsu et al., 2005; Li et al., 2006), which calls the attention on the relevance of short lived co-seismic pervasive crack damage in the redistribution of crustal fluids subsequent to earthquakes. The rock-type dependent microcrack density calls the attention on the existence of a compartmentalized seismic damage zone around seismic faults in metamorphic complexes of heterogeneous lithology, like the Mecsekalja Zone. This suggests that the damage zone in a metamorphic complex is basically different from those described in more homogeneous lithologies, and the decrease of microcrack density is not monotonous towards the protolith. Homogenisation temperatures of the fluids entrapped in the microcrack calcite reveal the existence of rock-type dependent fluid–rock subsystems, in conjunction with the formation of different crack densities in different rock-types. The more narrow range of fluid densities suggests hydrostatic fluid pressure in the feldspathic rocks, while the wide range of densities in the less feldspathic chlorite gneiss indicates deformation related fluid pressure increase in an undrained fluid–rock subsystem or the decrease of the parent fluid's temperature due to lower water–rock ratio. The parent fluid's salinities indicate the connection between the microcrack fluids and interpillow sulphate chimneys in the western continuation of the Mecsekalja Zone to the west and suggest that they were part of the same hydraulic system.

1. Introduction

Seismically active faults and their surroundings are areas of intensive and dynamically changing stress fields. Lithologies in seismically active regions are exposed to intense deformation that gives rise to the brecciation and cataclasis of the rocks in the fault core zone and fracture formation in the damage zone around the core (Gudmundsson, 2011; Gudmundsson et al., 2010). The damage can be detected with the use of seismic detection methods around recently active faults. For example Hiramatsu et al. (2005) and Li et al. (2006) explain the co-seismic decrease of seismic wave velocities with pervasive cracking of the rocks in the environs of the seismic fault. The redistribution of subsurface fluids is imminent in the formation of newly formed crack volume in the crust, which is constrained by the disturbance of groundwater levels and chemistry during earthquake activity (Scholz et al., 1973). Large scale in situ measurements of crustal permeability around fault zones give several orders of magnitude higher permeabilities than measurements on intact core samples (Townend and Zoback, 2000), which calls the attention on the role of active faults and possibly open fractures of the damage zone in fluid conduction. The redistribution of crustal fluids can in turn take effect on the behaviour of the seismic fault itself. For example fluid injection into the interior of the continental crust can activate earthquake activity (Zoback and Harjes, 1997; Špičák and Horálek, 2001). The involvement of crustal fluids is constrained by pre-earthquake changes of subsurface fluids (Scholz et al., 1973; Tsunogai and Wakita, 1995). The decrease of fluid pressure

* Corresponding author. Tel.: +36 62 544 058; fax: +36 62 426 479.
E-mail address: dabi@geo.u-szeged.hu (G. Dabi).

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.07.039

can in turn increase the strength of the crust; this process is called strain hardening (Paterson and Wong, 2005).

The rather intrinsic and in most details still enigmatic interactions between earthquake activity and the redistribution of crustal fluids can be resolved by the investigation of fossilised seismic systems, i.e. fault zones and their internal structures. Fault zones are built up of a core zone, where the deformation is most intense, and a damage zone around the core that is characterized by a zone of enhanced fracture density (Faulkner et al., 2006; Gudmundsson, 2011; Gudmundsson et al., 2010). The analysis of the structures associated to the operation of the faults during their active phase can give rise to models of subsurface fluid flow in the crust during different phases of the fault action (Gudmundsson, 2001). The investigation of fault zones can aid the understanding of the hydraulic behaviour of the fault during its active phase (Caine et al., 2010).

In the present paper a new type of seismic damage zone is presented from the Mecsekalja Zone metamorphic complex, where a pervasive calcite filled microcrack system cross cuts the crystalline rocks. The stable isotope compositions of the microcrack calcites define a linear trend, pointing from the compositions of the Eastern Mecsek Mountains dyke ocelli towards the youngest vein calcite generation of the study area. The interpretation of the trend raises the role of seismic activity in the formation of the microcrack system, which is constrained by sedimentary features in the region (Jáger et al., 2012). Thus the microcrack systems are interpreted to be the damage zone of the Ófalu Fault (the north western boundary of the Mecsekalja Zone) during its active period in the Early Cretaceous. The extension of the microcrack subsystems indicates rock-type dependent efficiency of the microcrack forming process. Rock-type dependent microcrack densities suggest a compartmentalized damage zone, different from those described in more homogeneous lithologies (e.g. Faulkner et al., 2006). The microthermometry of the microcrack calcite confirms the formation of rock-type dependent fluid–rock subsystems. The microcrack systems are possibly the fossilised analogues of the pervasive cracks detected in the surroundings of recently active faults (Hiramatsu et al., 2005; Li et al., 2006). The geometry of the fragmented feldspar grains bear resemblance to septarian concretions (Pratt, 2001), and thus suggest the role of seismic shake in their formation.

2. Geological background

2.1. Regional geology

The study area is representative of the metamorphic complexes of the Tisza Mega-unit (TMU, Haas and Péró, 2004), or Tisza terrane (Csontos and Vörös, 2004), a large composite lithospheric block with complex internal structure made up of nappe systems (Fig. 1A, Haas and Péró, 2004; Kovács et al., 2000). The TMU is the basement of the southeastern part of the Pannonian Basin overlaid by thick Cenozoic sequences and has scattered surface exposures in the Papuk-Krndija, Moslavaćka Gora (NE Croatia), the Mecsek, Villány (SE Hungary) and Apuseni Mountains (Romania). Units of the TMU are built up of Variscan crystalline complexes beneath Upper Carboniferous to Triassic overstep sequences. Variscan granitoids and crystalline complexes of the TMU might be correlated with the Moldanubian (–Helvetic) Zone, which means that during the Variscan Orogeny, the TMU was an integral

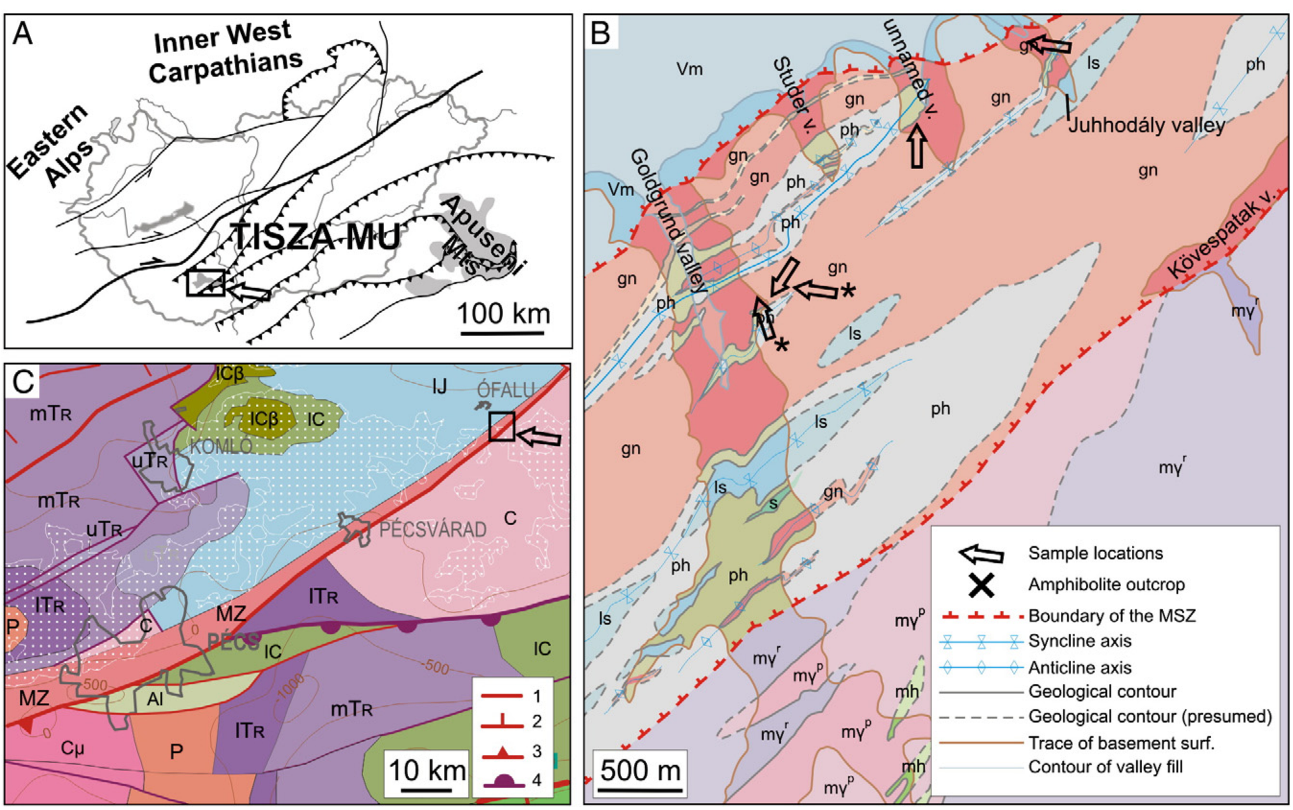

Fig. 1. (A) Position of the Tisza Mega-unit in the basement of the Pannonian Basin. Inset shows the position of B. (B) Regional geological map of the study area. The MZ is a narrow metamorphic zone between Mesozoic sequences in the Eastern Mecsek Mountains and the Variscan Mórágy Granite, Mórágy Hills. The contact of the MZ is tectonic both to the north and to the south. Dotted area marks surface outcrops of the pre-Cenozoic formations. 1. Cenozoic tectonic line, 2. Cenozoic fault, 3. Cenozoic overthrust, 4. Mesozoic nappe. Cμ, Variscan metamorphic complex; MZ, Mecsekalja Zone; C, Variscan granitoid rocks; P, Permian; lTR, Lower Triassic; mTR, Middle Triassic; uTR, Upper Triassic to Lower Jurassic; lJ, Lower to Middle Jurassic; lC, Upper Jurassic to Lower Cretaceous; lCβ, Lower Cretaceous basaltic rocks; Al, Albian; Inset shows the position of C. After Haas et al. (2010). (C) Outcrops of the MZ are exposed in the north–south valleys southeast of Ófalu village. Thick arrows indicate sample locations for stable isotope composition measurements of the microcrack calcite. Arrows marked with * indicate samples used for microthermometric measurements. gn, gneiss; ph, phyllite; s, serpentinite; ls, limestone; $m\gamma^r$, rarely porphyritic monzogranite; $m\gamma^p$, porphyritic monzogranite; mh, monzonite; Vm, Vasas Marl Formation. After Balla et al., 2009.