Eur. J. Mineral.
2012, **24**, 1017–1029
Published online July 2012

Hydrothermally altered mudrock of the Ciñera-Matallana coal basin, Cantabrian Zone, northern Spain

KAI H. FRINGS[1] and LAURENCE N. WARR[2,*]

[1] Institut für Geowissenschaften, Ruprecht-Karls-Universität, Im Neuenheimer Feld 234, 69120 Heidelberg, Germany
[2] Institut für Geographie and Geologie, Ernst-Moritz-Arndt Universität, JF.L. Jahn Strasse 17a, 17489 Greifswald, Germany
*Corresponding author, e-mail: warr@uni-greifswald.de

Abstract: An X-ray diffraction and electron microscopy study of very-low-grade metamorphic clay mineral assemblages of Upper Carboniferous (Stephanian) mudrocks from the coal-bearing Ciñera-Matallana basin of NW Spain reveals a complex mineralization history related to localized igneous and hydrothermal activity associated with strike-slip-faulting. This thermally active, pull-apart basin experienced peak temperatures (up to *ca*. 296 °C) that reached anchizonal grades in areas of high heat and fluid flow, with hot hydrothermal growth of well crystallized $2M_1$ illite–muscovite, chlorite, and pyrophyllite occurring pre- and synchronous with Late Carboniferous/Early Permian folding and faulting of the sedimentary sequence. No burial pattern could be recognized in the clay mineral reactions with stratigraphic depth due to the complexities of hydrothermal alteration. Clay mineral growth was controlled by the location of igneous activity and the circulation of CH_4-bearing fluids released during the maturation of coal seams and dispersed organic matter. Extensive retrograde reaction to illite-smectite ($1M_d$ polytype) with abundant R1 rectorite (50–50) in altered rocks adjacent to igneous intrusions and along faults is attributed to the circulation of cooler (<140 °C) hydrothermal fluids. These and younger fluids were also probably responsible for the extensive crystallization of kaolinite in pore spaces within the mudrocks and related quartz-carbonate veins.

Key-words: hydrothermal fluids, coal basin, Palaeozoic mudrocks, clay minerals, retrograde reactions, igneous activity, Cantabrian Zone, electron microscopy.

1. Introduction

Clay minerals are the most common solid phases formed in surface and upper crustal environments of the Earth and occur in all known geotectonic settings (Velde, 1995; Frey & Robinson, 1999). Their study provides an insight into the nature of fluid-rock interaction at low temperatures, and in particular information related to the conditions of weathering, diagenesis, very-low-grade metamorphism and hydrothermal alteration (*e.g.* Środoń, 1999). Within sedimentary basins, clastic sedimentary rocks such as shales, siltstones and sandstones typically contain complex, heterogeneous mixtures of fine-grained clay mineral phases, which usually include both detrital and authigenic minerals. A classic series of prograde clay mineral reactions has been recognized for burial diagenetic sequences from throughout the geological record (see Merriman & Frey, 1999), as was established in the Gulf coast sedimentary rocks investigated by Hower *et al.* (1976). The most studied mineral reaction is that of the smectite to illite transformation, which occurs via a series of intermediate illite–smectite (I–S) mixed-layered phases (*e.g.* Altaner & Ylagan, 1997). Other prograde reactions are the smectite, corrensite to chlorite series (Hillier, 1993; Jiang & Peacor, 1994) and the transformation of kaolinite to dickite, which also occur with increasing temperature and burial depth (Ehrenberg *et al*., 1993).

Despite the wealth of knowledge available on prograde diagenetic and low-temperature metamorphic burial environments, less attention has been given to the nature of the more complex mineral assemblages that result from the transient flow of hydrothermal fluids associated with thermally active, pull-apart sedimentary basins. With increasing application of high resolution transmission electron microscope (TEM) techniques in studies of low-temperature clastic sediments, there is an increasing awareness of the complexities of prograde and retrograde clay mineral reactions that occur within hydrothermal fluid systems (Nieto *et al.,* 1994; Nieto *et al.,* 2005; Schleicher *et al*., 2006) and in areas of fault-related fluid flow (Abad *et al*., 2010).

In this contribution, we outline a sequence of heating and cooling related to hydrothermal fluids that circulated in a small coal-bearing Ciñera-Matallana Basin (CMB)

0935-1221/12/0024-2244 $ 5.85
DOI: 10.1127/0935-1221/2012/0024-2244