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Outcrop gamma-ray logging of siliciclastic turbidites: Separating the detrital provenance signal from facies in the foreland-basin turbidites of the Moravo-Silesian basin, Czech Republic

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ABSTRACT

Standard and spectral gamma-ray (GRS) logs are widely used as indicators of facies in the subsurface. In siliciclastics, however, the gamma-ray signal is often influenced by changes in the provenance of the K, U and Th-bearing detrital minerals. In this paper, we have compared outcrop and laboratory GRS with modal and chemical sandstone and mudstone composition and facies in an approximately 2.5 km-thick siliciclastic turbidite system of the Moravo-Silesian Culm Basin (Lower Carboniferous), Czech Republic. The aim was to separate the facies signal from the detrital provenance one. The siliciclastics have moderately high outcrop gamma-ray values (174 API on average) and slightly lower laboratory values (127 API). Both the outcrop and laboratory data show low sensitivity to facies, which is demonstrated by the low contrast between the K, U and Th concentrations in the seven facies types ranging from proximal to distal turbidites. Markedly higher GRS variability is observed between equivalent facies at different stratigraphic levels. Major carriers of the GRS signal include K-feldspars, muscovite, sericite, biotite and albite for K, zircon, apatite, monazite and xenotime for U and monazite, thorite, REE secondary minerals, xenotime, apatite and zircon for Th. With the effect of facies filtered out, the GRS values reveal a stratigraphic variability, which coincide with the changes in the sandstone modal composition. A shift from the low-grade metamorphic and volcano-sedimentary provenance to predominantly magmatic sources with ultrapotassic plutonites in the early Late Viséan is associated with a marked increase in U and Th concentrations and generally higher sandstone radioactivity compared to mudstones. Another provenance shift to high-grade metamorphic sources with granulites in the latest Viséan is associated with a rapid decrease in Th, U and partly K concentrations and an increase in the GRS contrast between sandstone and mudstone facies. The GRS data sensitively reflect the extremely rapid exhumation of mid-crustal and deep-crustal rocks in the major source area, the Moldanubian Zone of the Bohemian Massif.

1. Introduction

Gamma-ray spectrometry (GRS) logging in subsurface and outcrop, using portable scintillation spectrometers, has achieved a wide application in stratigraphic analysis. The main output from the GRS logging, the concentrations of potassium (%), uranium (ppm) and thorium (ppm), represents important geochemical information, which can be used for facies identification, stratigraphic correlation and sequence-stratigraphic analysis (Slatt et al., 1992; Doveton, 1994; Postma and Ten Veen, 1999; Rider, 1999; Ehrenberg and Svana, 2001; Lüning et al., 2004; Bábek, et al., 2007; Koptíková et al., 2010). Subsurface GRS data are primarily used for the interpretation of facies parameters such as clay content, grain size, detrital composition of sandstones and sandstone porosity (Bristow and Williamson, 1998; Rider, 1999; Fiet and Gorin, 2000; Svendsen and Hartley, 2001; Fabricius et al., 2003). In terms of siliciclastic strata, it is widely acknowledged that higher gamma-ray counts are attributed to mudstones while low gamma-ray counts are typical for sandstones and conglomerates (Rider, 1990, 1999). The high counts in fine-grained facies are related to the stoichiometric contents of K in common clay minerals such as illite and I/S mixed layer clays, and the presence of U and Th revealing a tendency to adsorb on the surface of the clay minerals and organic matter. Shaly facies are therefore enriched in K, U and Th. The low counts are driven by the dilution effect of non-radioactive quartz, carbonate cement and pore space in sandstones and non-radioactive calcium carbonate in carbonate rocks. However, these simple effects are often complicated by the variable contents of the K-bearing framework grains (e.g. K-feldspars, albite and micas) and Th- and U- bearing heavy minerals (zircon, apatite, monazite, rutile, davidite, brannerite, etc.) in sandstones (cf.

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Rider, 1990; Svendsen and Hartley, 2001). This puts the interpretation of facies and facies tracts simply from gamma-ray logs at considerable risk. In addition, there are additional factors which influence the concentrations of K, U and Th in siliciclastic rocks including variability in the clay mineral composition (illite, kaolinite, glauconite and smectite), the content of total organic carbon (TOC) and the diagenetic overprint (Durrance, 1986; Doveton, 1994; Lindqvist, 1997; Jain et al., 1998; Lüning et al., 2004). A number of these factors have been successfully used for the interpretation of the mineral composition of clays and heavy minerals in sedimentary rocks (Jain et al., 1998; Schnyder et al., 2006).

If we neglect the effects of post-depositional chemical changes, the K, U and Th signature in siliciclastic rocks can be generally regarded as an interplay of source rock composition (detrital provenance) and the effect of hydraulic sorting during transport and deposition (facies). Facies interpretation and core correlation from subsurface GRS data can therefore be impaired by vertical and lateral changes in the detrital provenance and, conversely, the interpretation of the detrital provenance can be adversely affected by facies. While facies are frequently interpreted from gamma-ray logging data, studies of the siliciclastic provenance utilizing the same technique are scarce (Atherton and Brotherton, 1979; van der Meer and Pagnier, 1996; Harris, 2000). With its rapid production of large compositional data sets directly in the field, the outcrop GRS logging combined with simultaneous facies logging provide a suitable tool to filter out the facies effect from the detrital provenance signal. In this paper, we summarize the facies analysis, the modal and chemical composition with outcrop and laboratory GRS data from the siliciclastic turbidite system of the Lower Carboniferous foreland basin, the Moravo-Silesian Culm Basin (Moravia, Czech Republic), with the aim of separating the facies signal from the detrital provenance signal.

2. Geological setting and stratigraphy

The Moravo-Silesian Culm Basin (Fig. 1) is preserved in an elongated structure trending SSW–NNE, bordered by Variscan crystalline nappes in the west (Schulmann et al., 1991) and by Tertiary to Quaternary deposits of the Carpathian Foredeep in the east. This area represents the easternmost promontory of the Rhenohercynian system of collision-related basins—remnant ocean basins and peripheral foreland basins (Hartley and Otava, 2001) filled with synorogenic deep-water siliciclastic sediments (Culm facies) with a total thickness of approximately 7.5 km (Mazur et al., 2006). The structure of the entire unit is described as a thin-skinned accretionary wedge composed of superficial flysch nappes, thrusted onto the Neoproterozoic crystalline rocks of the Brunovistulian terrane and its preorogenic Lower Palaeozoic sedimentary cover (Dudek, 1980; Kalvoda et al., 2008). The thrusting was caused by a final collision between the Lugodanubian and Brunovistulian terranes (Schulmann et al., 1991; Kalvoda et al., 2008).

The Moravo-Silesian Culm Basin can be subdivided into the Drahany Basin and the Nízký Jeseník Basin (NJB) — the focus of the present paper. The lithostratigraphy of the NJB is composed of the Andělská Hora, Horní Benešov, Moravice (MF) and Hradec–Kyjovice Formations (HKF) (Kumpera, 1983). The MF and HKF represent a sedimentary infill of a deep-marine peripheral foreland basin (Hartley and Otava, 2001; Bábek et al., 2004). The biostratigraphy of the MF and HKF is based on ammonoid fauna ranging from the upper Viséan *Pericyclus* Peγ Zone to the uppermost Viséan *Goniatites* Goγ Zone (Kumpera, 1983). Additional stratigraphic control is provided by three heavy-mineral zones (Hartley and Otava, 2001): (i) a lower zone with a predominance of epidote, tourmaline, garnet, sphene and zircon (lower to lowermost Upper Viséan); (ii) a middle zone, which approximately correlates with the MF (Upper Viséan) and (iii) an upper zone, which approximately correlates with the HKF

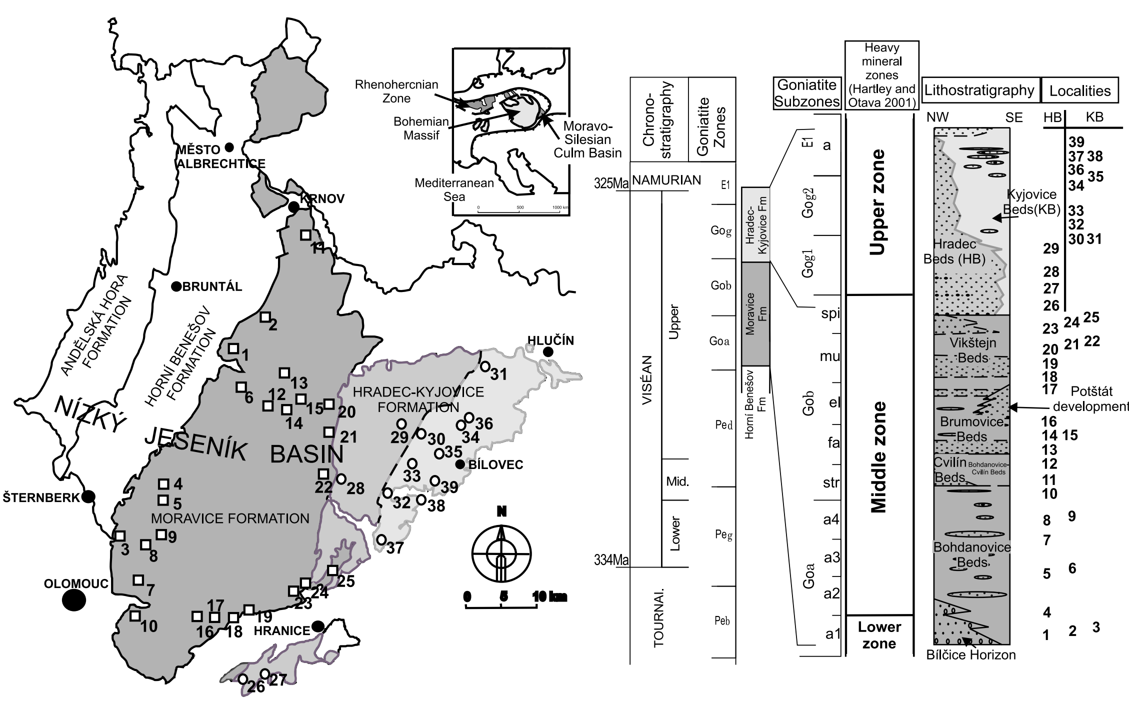

Fig. 1. Geological sketch-map of the Nízký Jeseník Basin (after Dvořák, 1994) with the position of the studied localities and a stratigraphic chart modified after Bábek et al. (2004). List of localities; Moravice Formation: 1. Slezská Harta, 2. Svobodné Heřmanice, 3. Bělkovice Quarry, 4. Domašov nad Bystřicí, 5. Malý Rabštejn, 6. Dvorce, 7. Hlubočky-Kovákov, 8. Hrubá Voda-Railway Bridge, 9. Hrubá Voda-Hotel Akademie, 10. Čechovice, 11. Úvalno, 12. Budišov nad Budišovkou, 13. Kružberk, 14. Svatoňovice, 15. Nové Těchanovice, 16. Výkleky, 17. Skoky, 18. Bohuslávky, 19. Lipník nad Bečvou-Loučka, 20. Vítkov-Podhradí, 21. Vítkov, 22. Klokočůvek, 23. Hrabůvka Quarry, 24. Olšovec Quarry, 25. Nejdek Quarry; Hradec–Kyjovice Formation: 26. Podhůra Quarry, 27. Paršovice, 28. Jakubčovice nad Odrou, 29. Skřípov 2, 30. Skřípov 1, 31. Josefovice, 32. Fulnek-Jerlochovice, 33. Fulnek-Lukavec, 34. Stara Ves u Bílovce Quarry, 35. Těškovice, 36. Kyjovice, 37. Fulnek-Stachovice, 38. Mankovice, 39. Fulnek-Jílovec.