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Research paper

Facies, provenance and paleoclimate interpretation using spectral gamma logs: Application to the Lower Cretaceous of the Scotian Basin

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ABSTRACT

Spectral gamma logging has been useful in some settings for correlation of wells, for identification of sediment facies, and for interpretation of hinterland paleoclimate. We have taken advantage of the hundreds of geochemical analyses of sandstones and shales from conventional core that are available from the Scotian Basin to test the relationship of the elements K, U and Th measured by spectral gamma to sedimentary facies. These elements are also known to be useful in characterising provenance of sediment to different parts of the basin. The geochemical and spectral gamma data both show that there are subtle differences in K, U and Th in different lithofacies, such as higher Th/U in low sedimentation rate facies, but they are not sufficiently distinctive to identify the lithofacies of any unknown interval. The main control on abundance of these elements is the effect of grain size, that is the proportion of sand to mud in sediment. Volcanic sources have a high K/Th ratio, and early Albian sediments with relatively high volcanic component have unusually high K/Th. In distal shale-prone successions, the grain size effect is sufficiently small that climate controlled variations in Th/K ratio are recognised in the Early Cretaceous, with the ratio being higher at times of humid weathering on land. The variations in Th/K ratio through time are broadly similar to those known from Western European sections, notably with topmost Hauterivian and topmost Aptian humid events. Overall, this study provides an assessment of the use and pitfalls of spectral gamma logs in a deltaic succession.

1. Introduction

Spectral gamma-ray logging is a rapid method of measuring K, U and Th abundance in petroleum basins. It may be useful in some sedimentary rocks as a quantitative method of defining lithofacies where conventional core is sparse (North and Boering, 1999; Ehrenberg and Svana, 2001). Humid terrestrial weathering preferentially leaches K and U relative to Th, and spectral gamma may thus provide information on climate or rate of tectonic uplift in the hinterland of a sedimentary basin (Ruffell and Worden, 2000; Ghasemi-Nejad et al., 2010). Spectral gamma may also allow chemostratigraphic correlation (Doveton and Merriam, 2004).

The Tithonian (latest Jurassic) to early Cenomanian succession in the Scotian Basin consists of deltaic rocks several kilometres thick. The Early Cretaceous succession has been divided into the Missisauga (Berriasian–Barremian) and Logan Canyon (Aptian–Cenomanian) formations (Fig. 2). Studies of conventional core have resulted in the recognition of a wide range of fluvial, coastal and prodeltaic lithofacies (Cummings and Arnott, 2005; Gould et al., 2012). Spectral gamma data is available for some of this core and thus raises the question as to whether facies recognised in core might be interpreted from wireline logs, where no core is available, on the basis of variation in K, U and Th abundance. The elements K, U and Th, along with Rb and Sr, were shown to be the most useful in determining provenance of Scotian Basin sandstones and mudstones on the basis of principal component analysis of geochemical analyses of bulk sediment samples (Pe-Piper et al., 2008). Large numbers of whole-rock geochemical analyses are available for samples of sandstone and mudstone from conventional core from the Scotian Basin (Zhang et al., 2014).

The goal of this study was to evaluate the use of spectral gamma logs in providing information on changes in lithofacies and provenance of sediment in the Lower Cretaceous of the Scotian Basin (Figs. 1, 2). First, rock geochemistry is used to evaluate the extent to

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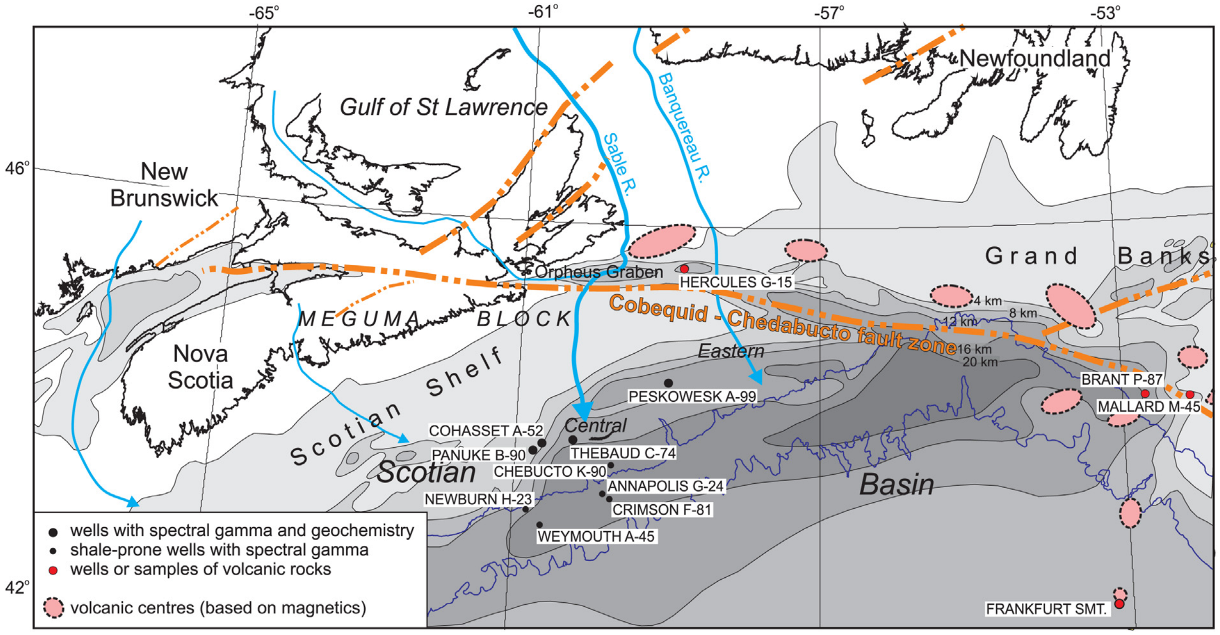

Figure 1. Map of Scotian Basin showing wells examined in this study. Also shows inferred input points to the basin for different rivers supplying sediment of different provenance and major active faults (both from Pe-Piper and Piper, 2012) and inferred location of volcanic sources based on magnetic anomalies (Bowman et al., 2012).

which covariation of K, U and Th can be used to identify (a) changes in facies and (b) changes in provenance that might then be identified from spectral gamma logs, and could not be more easily determined by other logging tools. Second, spectral gamma from conventional core is used to further evaluate whether lithofacies distinctions can be made using spectral gamma alone. Third, with the understanding gained as to the factors that might influence K, U and Th variability in sedimentary rocks in the basin, we apply the technique of using Th/K ratios from spectral gamma in shales to determine variation in the type of sediment supplied to the Lower Cretaceous of the Scotian Basin.

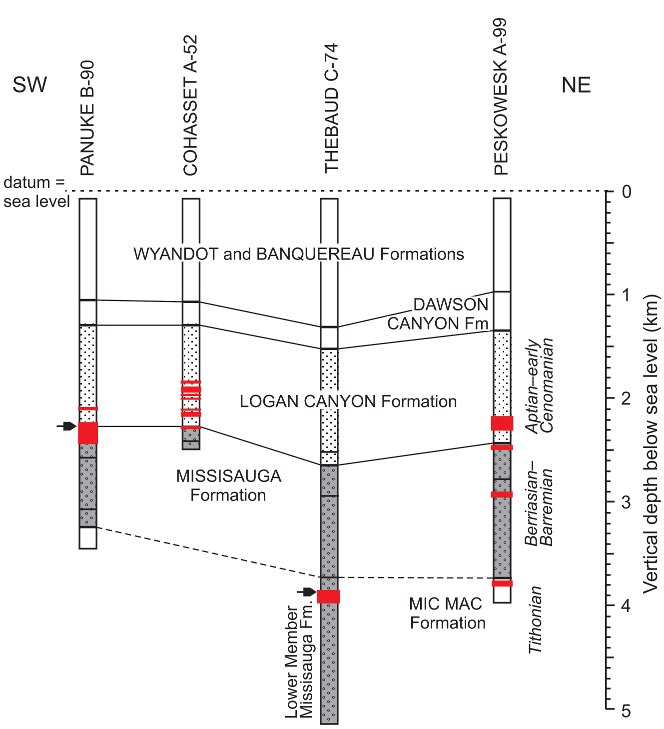

Figure 2. Summary of stratigraphic position of conventional cores examined in this study. Red bars indicate conventional core. Arrows indicate position of core illustrated in Figure 7. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Methods

Four types of data were used in this study: visual description of the conventional core, 1 cm^3 samples from conventional core that were analysed for bulk geochemical composition, core spectral gamma logs measured in the laboratory from selected conventional core, and wireline spectral gamma logs measured in the field from selected wells.

Visual descriptions of conventional core and geochemical samples were taken from conventional core in four wells: from the Tithonian interval in Thebaud C-74 and the Hauterivian to Albian intervals in the Panuke P-90 and Cohasset A-52 wells, all in the central part of the basin; and selected intervals from the Tithonian to the Albian in the Peskowesk A-99 well in the eastern part of the basin (Figs. 1, 2). Stratigraphic sections of conventional core for Thebaud C-74 and Peskowesk A-99 are presented by Okwese et al. (2011) and for Panuke P-90 and Cohasset A-52 by Gould et al. (2012). Lithofacies were described using a standard scheme (Table 1) that is described in detail by Gould et al. (2012). The facies scheme is hierarchical, with facies defined on the basis of the general environmental interpretation, as defined by lithology and sedimentary structures and are further subdivided into subfacies in order to discriminate between different rocks within the same depositional environment. The basic lithofacies scheme is: open shelf (lithofacies 1; mudstone); shoreface (lithofacies 2; sandstone and mudstone); transgressive shelf (lithofacies 3; sandstone, mudstone, or limestone); fluvial to tidal estuarine channel (lithofacies 4; sandstone); lower tidal flat, intertidal to subtidal (lithofacies 5; sandstone > mudstone); upper tidal flat, intertidal (lithofacies 6; mudstone > sandstone); tidal marsh or deltaic swamp (lithofacies 7; lignite or carbon-rich mudstone); lagoon (lithofacies 8, mudstone); river mouth turbidites (lithofacies 9;