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The onset of flood volcanism in the north-western part of the Siberian Traps: Explosive volcanism versus effusive lava flows

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ABSTRACT

The Siberian Traps large igneous province was formed during the end-Permian, about 252 Ma ago. Basaltic melt was injected into the organic and salt rich Tunguska sedimentary basin, forming interconnected sill complexes and associated hydrothermal vent complexes. Thick deposits of basaltic tuff and tephra covered the paleosurface before the onset of flood volcanism, commonly taken as direct evidence for the explosive nature of the initial phase of volcanism. The field work in this study revealed that tuffs are virtually absent along a 150 km long transect along the Dyupkun lake and Kureika river, even though tuff is shown on available geological maps. Towards the south and west, the transition between the end-Permian sediments and the flood basalts is either characterized by thin (2–5 m) to no tephra deposits (Khantaika area), hyaloclastites and associated lake-deposited tephra (Kureika area), or massive tephra deposits from local eruptive centers (Severnaya area). The new results can be put into the context of other studies about volcanic tuff horizons in Siberia, and questions the notion of province-scale explosive volcanism in Siberia during the onset of flood volcanism. Moreover, the main thicknesses of explosive tuff deposits, up to 700 m, are located in the central and southern parts of the province where the LIP erupted through thick Cambrian salt and carbonate sequences. Since numerous phreatomagmatic pipes are present in these areas, we suggest a causal relationship between deep magma–sediment interactions, explosive eruptions and the resulting environmental stress that initiated the end-Permian mass extinction.

1. Introduction

Continental flood basalts that form the majority of the Earth's large igneous provinces (LIPs), represent some of the largest outpourings of volcanism on the planet (Bryan et al., 2010). They are characterized by an onset, main acme phase of emplacement and waning phase which occur over relatively short geological time scales (Jerram and Widdowson, 2005). With short emplacement timescales of <1 Ma for the main peak phase of volcanic activity and with the vast volumes of magma involved (several million km^3), the emplacement of a flood basalt province will have a marked effect on the planet and in many cases such eruptive episodes have been linked to mass extinction events such as the end-Permian and the end-Triassic (e.g. Stothers, 1993; Wignall, 2001; Callegaro et al., 2014). A key area of focused work is now looking specifically at the onset of flood volcanism, where in many cases previously poorly exposed contact sections have been ignored for better exposed fresh material higher in the volcanic pile (Jerram and Widdowson, 2005; Ukstins-Peate and Elkins-Tanton, 2015). The importance of understanding the onset of these vast provinces, is that they have the potential to interact with the palaeo-environment occurring directly prior to the volcanics, which can be anything from dry continental, to lake and river sequences, and even large open water bodies and seaways (e.g. Jerram et al., 2000, 2009; Jerram and Stollhofen 2002; Ross et al., 2003; Petry et al., 2007; Jerram et al., 2015-in this issue). Eruption into water and through sedimentary basins will have marked implications in terms of explosive activity and the generation of additional gases from contact metamorphic sedimentary rocks, as well as providing a more efficient way to release such gases higher into the atmosphere (Svensen et al., 2004, 2007, 2009a; Planke et al., 2005).

The Siberian Traps is one of the largest of these LIPs and has been linked to the end-Permian extinction and climate change using a number of constraints (e.g. Renne and Basu, 1991; Wignall, 2001; Beerling et al., 2007; Svensen et al., 2009a,b; Sobolev et al., 2011; Benton and Newell, 2014; Courtillot and Fluteau, 2014). Fig. 1 provides the latest

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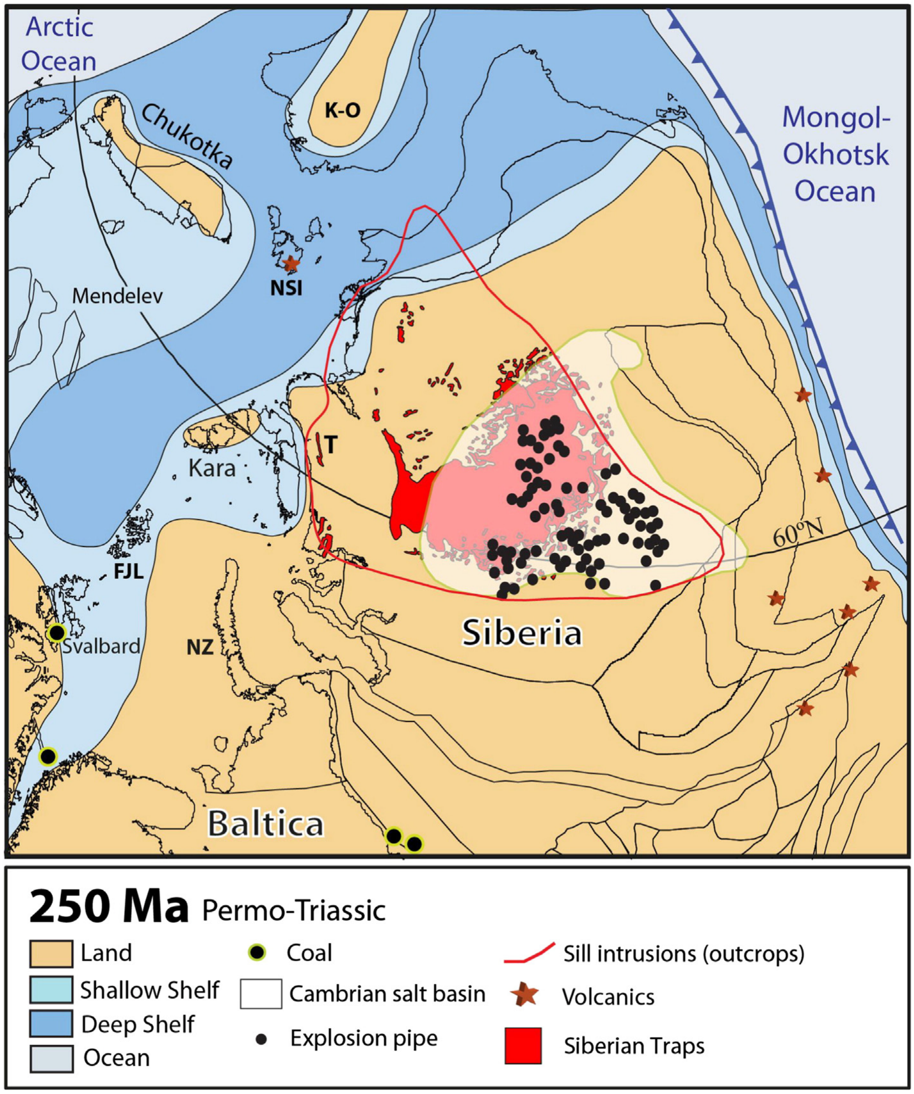

Fig. 1. Siberia and neighboring sectors of Pangea near the Permian–Triassic boundary time at 250 Ma, showing the contemporary pattern of lands and seas. The Mongol–Okhotsk Ocean separated Siberia from Central Mongolia (Amurian) and was about 3000 km wide at this time. Volcanics in New Siberian Islands (NSI) and Taimyr (T) are probably related to the Siberian Traps. In Taimyr, dykes and sills are folded and thus reflecting continuing convergence of the Kara Plate and Siberia into the Early Mesozoic. FJL, Franz Josef Land; K–O, Kolyma–Omolon; and NZ, Novaya Zemlya. The Siberian Traps erupted at around 60°N while the Cambrian salt basin (Svensen et al., 2009b) was originally deposited at sub-tropical latitudes in the southern Hemisphere. Updated from Cocks and Torsvik (2007, 2011). There are also un-exposed volcanic rocks present at depth in west Siberia which would extend the Siberia footprint more (Reichow et al., 2009).

reconstruction of the plate settings and the generalized palaeoenvironments at the onset of Siberian Traps. The outline of the exposed Siberian volcanics as well as red stars which indicate similar age volcanics, show that the provinces has a massive aerial footprint. The majority of the province was emplaced onto land with limited possible interaction with coastlines or deeper marine water (Fig. 1). The nature of the palaeoenvironments present at the onset of flood volcanism along this vast land surface is of clear interest, and will be discussed with examples later in this contribution.

Due to the vastness of the Siberian Traps and their location in the arctic taiga, detailed exploration of key sections of the province is difficult, and in many cases large parts of the province have not been looked at since early days of basic geologic mapping and reconnaissance studies. The best studied sections are located in the northern parts of the province (Norilsk and Maymecha areas, see Fig. 2), where economic interests have resulted in detailed exploration and numerous boreholes. The best outcrops are also located along glacial valleys in the north. In the basal parts of the stratigraphy of the Siberian Traps, vast areas have been mapped as 'volcanic tuffs' often with little or no detailed explanation as to what type, and also a number of phreatomagmatic pipes have been indicated, particularly in the southern sections of the province (Von der Flaass, 1997; Svensen et al., 2009a,b). If there was volcanic degassing, metamorphic degassing, and explosive volcanism associated with the onset of the Siberian Traps, this provides a dramatic start to the large igneous province and may help explain its role in the largest mass extinction (Fig. 2). The 'volcanic tuffs' are often not further described other than simply labeled 'tuff'. These could have a sedimented volcaniclastic origin or a more explosive origin, as basaltic volcanism is normally not explosive in nature it is important to constrain this further. However, there are very limited studies of the relationship between the types of 'tuffs' and the lava facies in Siberia (Buchl and Gier, 2003), even in the Norilsk cores, which makes their context difficult to realize and limits our understanding of how the Siberian Traps initiated.

In this contribution we present a detailed study of the initial stage of volcanism in the Siberian Traps and look at the development of the volcanic architecture at the onset of flood volcanism. The study covers a large area of the northwestern part of the Siberian Traps, and follows a little known section down through a glacial valley and a long river