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The growth and destruction of continental crust during arc–continent collision in the Southern Urals

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ABSTRACT

The Southern Urals of Russia contain a well preserved example of a Paleozoic arc–continent collision in which the Laurussia margin was subducted beneath the Magnitogorsk island arc in the Devonian, providing an ideal field area for studying the possible growth and destruction of the continental crust during this process. High-pressure rocks derived from the leading edge of the continental margin indicate that it was subducted to a depth of between 70 km (eclogite assemblages) and 120 km (micro diamonds). The vast majority of the high-pressure rocks have a sedimentary protolith, with mafic eclogite having been derived from dikes intruding into the sediments. High-pressure rocks derived from the mafic ganulite that currently makes up the middle and lower crust of the Southern Urals do not occur in outcrop, suggesting that much of the subducted margin remained in the upper mantle. However, extensive geological, geochemical, and geophysical data do not unequivocally clarify its subsequent fate. Crustal delamination and foundering into the mantle can be ruled out, and recycling through the volcanic arc system appears to have been minor. While the metamorphic products of subducted continental crust can remain in the mantle for long periods of time, in the Southern Urals it has not been imaged by the available geophysical data sets. A possible explanation for this is that the progressive metamorphism of mafic granulite to eclogite assemblages would have altered its physical properties to those of typical mantle lithologies, making them difficult to detect by geophysical methods. It is estimated that the volume of continental crust that was subducted and lost to the mantle was approximately one third of the volume that was added to the Laurussia margin by the accretion of the Magnitogorsk arc.

1. Introduction

Understanding the processes of growth and destruction of continental crust remains one of the key and intriguing areas of research among Earth scientists. While there is general agreement that the accretion of intra-oceanic volcanic arcs to a continental margin is one of the major processes in which new material has been added to the continental crust throughout geological time (Rudnick, 1995; Rudnick and Fountain, 1995), the means by which, or even if, continental crust is recycled back into the mantle is less well understood. Erosion of the continents and subduction of the resultant sediments along active margins has been shown to be an important mechanism by which large volumes of continental crust can be recycled back into the mantle (e.g., Von Huene and Scholl, 1991; Clift and Vannucchi, 2004; Clift et al., 2009). Evidence from the geochemistry of volcanic rocks erupted above subduction zones suggests that at least part of this material is recycled back into the volcanic arc rocks (Draut and Clift, 2001; Draut et al., 2002; Elburg et al., 2005; Herrington et al., 2005; Wang et al., 2008). There is, however, an apparent first order volume balance between what is subducted and what is erupted in volcanic arcs (Clift et al., 2009), suggesting that no, or little, of the subducted material is lost to the mantle. In areas of thickened crust, delamination (or crustal foundering) and sinking of the lower crust into the mantle has also been proposed as a way to remove and/or recycle the lower continental crust (Arndt and Goldstein, 1989; Kay and Mahlburg-Kay, 1991) and should, therefore, act as a recycling mechanism (e.g., Gao et al., 2008). However, the increasing number of seismic reflection images of relict subduction zones within the upper mantle in fossil collisional orogens (Calvert et al., 1995; Warner et al., 1996; Cook et al., 1999; White et al., 2003; Van der Velden and Cook, 2005) suggest that crustal delamination may not have occurred in these orogens (e.g., Van der Velden and Cook, 2005) and that this process may not be as widespread as first thought.

Another potential, yet largely unstudied, mechanism of continental crust recycling is its subduction and eventual assimilation into the mantle (e.g., Hildebrand and Bowring, 1999). The occurrence of high-pressure rocks derived from continental crust provides first order evidence for its deep subduction (Ye et al., 2000; Liou et al., 2000; Chopin, 2003). Seismic tomography across active orogens also indicates that the continental crust can be deeply subducted (e.g., Wang et al., 2006; Bokelmann and Maufroy, 2007; Negredo et al., 2007). Modelling of physical properties of subducting continental

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crust and its overlying sediments also suggests it can be deeply subducted into the mantle (Van den Beukel, 1992; Ranalli et al., 2000; Boutelier et al., 2003; Massone et al., 2007). Finally, calculations by Ryan (2001) show that thermally mature continental crust with a thickness of up to 10 km can be subducted without influencing the dynamics of the subduction zone. Since it appears that continental crust can be deeply subducted, then its subsequent fate must involve either being brought back to the surface to form (ultra) high-pressure massifs, being recycled back into magmatic rocks via melting processes, or reside in the mantle as the metamorphic products of the original lithologies. Whatever its fate, it is clear that the subduction of continental crust must be taken into account in the global calculation of the growth of the continents over geological time. In this paper we investigate the possible importance of the subduction of a continental margin on the growth and destruction of the continental crust during arc–continent collision in the Uralides. A range of geological and geophysical data are used to discuss the subduction of the Laurussia continental margin during the Magnitogorsk arc–Laurussia plate collision in the Southern Urals and the possible fate of the subducted material subsequent to the collision.

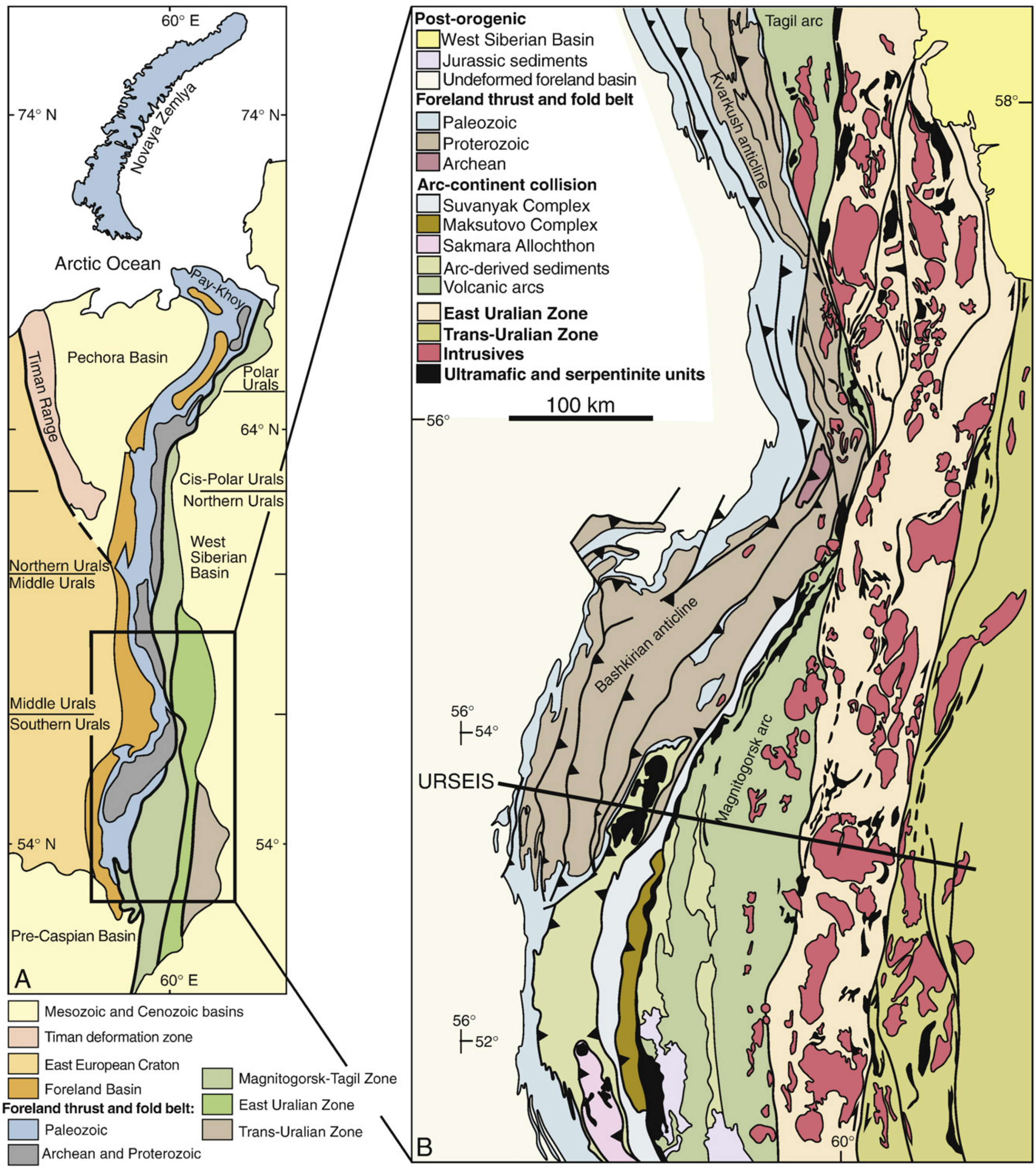

Fig. 1. A) Regional tectonic map of the Urals. B) Geological map of the Southern and Middle Urals showing the location and geological setting of the arc–continent collision units. The location of the URSEIS experiments is shown.