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Numerical simulation of strain localization and its relationship to formation of the Sue unconformity-related uranium deposits, eastern Athabasca Basin, Canada

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ABSTRACT

Unconformity-related uranium deposits in the Athabasca Basin (Canada) are spatially associated with reactivated basement faults that cut the unconformity surface between Archean to Paleoproterozoic basement and Paleoproterozoic to Mesoproterozoic sedimentary rocks of the Athabasca Group. The Sue deposits (Sue A, B, C, D, and E) are located in the eastern Athabasca Basin along a 2-km-long north-northeast-trending structural corridor and have both sandstone-hosted (Sue A and Sue B; to the north) and basement-hosted (Sue C, Sue D, and Sue E; to the south) orebodies. All the deposits are structurally controlled by north-northeast-trending basement faults that demonstrate different degrees of reverse displacements of the unconformity surface. However, it is not clear why the mineralization is distributed in such a pattern along the corridor. In this study, both 2-dimensional (2D) and 3-dimensional (3D) numerical modeling of deformation were conducted to examine the relationship between the distribution of strain and uranium mineralization. The modeling shows that dilation (positive volumetric strain), thought to correlate with the development of extensional fracture systems and dilational jogs that represent potential mineralization sites, is primarily controlled by the rheological contrasts in basement rocks and the degree of deformation. The presence of faulted graphitic pelitic gneiss associated with the sandstone-hosted Sue A and Sue B deposits favours dilation localized within the sandstone at low degrees of deformation mainly due to the overlying competent hangingwall granitic gneiss. In contrast, the basement-hosted Sue C, Sue D and Sue E deposits are associated with dilation zones localized along the contact between the faulted graphitic pelitic gneiss and competent footwall silicified gneiss at higher degrees of deformation. The modeling results highlight the importance of both graphitic basement structures and strong rheological contrasts between basement rocks in uranium exploration in the Athabasca Basin.

1. Introduction

Many structurally-controlled hydrothermal ore deposits are formed by large volumes of ore-forming fluids focused into depositional sites such as contractional jogs, dilational jogs, or damage zones, which are induced by inelastic deformation associated with active faulting and/or fault reactivation (Cox et al., 2001; Sibson, 2001). The dilation of fracture systems associated with fault ruptures enhances permeability and fluid flux, and sites of dilation have been interpreted to be a primary control on the location of mineralization zones (Muir-Wood, 1994; Cox, 2005, 2010; Zhang et al., 2008, 2011a; Zhao et al., 2012). In addition, for a given tectonic setting, the distribution of dilation may be affected by geometries of pre-existing faults (Zhang et al., 2009), pore pressure gradients (Zhang et al., 2011b), degree of deformation (Li et al., 2017), and local variation of lithology (Li et al., 2018).

Numerical modeling of deformation has greatly contributed to the understanding of deformation processes and its relationship to the genesis of ore deposits (Cox, 2005; Oliver et al., 2006). In some cases, numerical modeling has been used to assist mineral exploration (Schaubs et al., 2006; Zhang et al., 2011a; Liu et al., 2012). For example, Liu et al. (2012), based on the modeling of the syn-stretching cooling processes of the Yueshan intrusion in China, showed that zones of high dilation developed near the contact of the intrusion are favourable for metal deposition and the modeling results have facilitated

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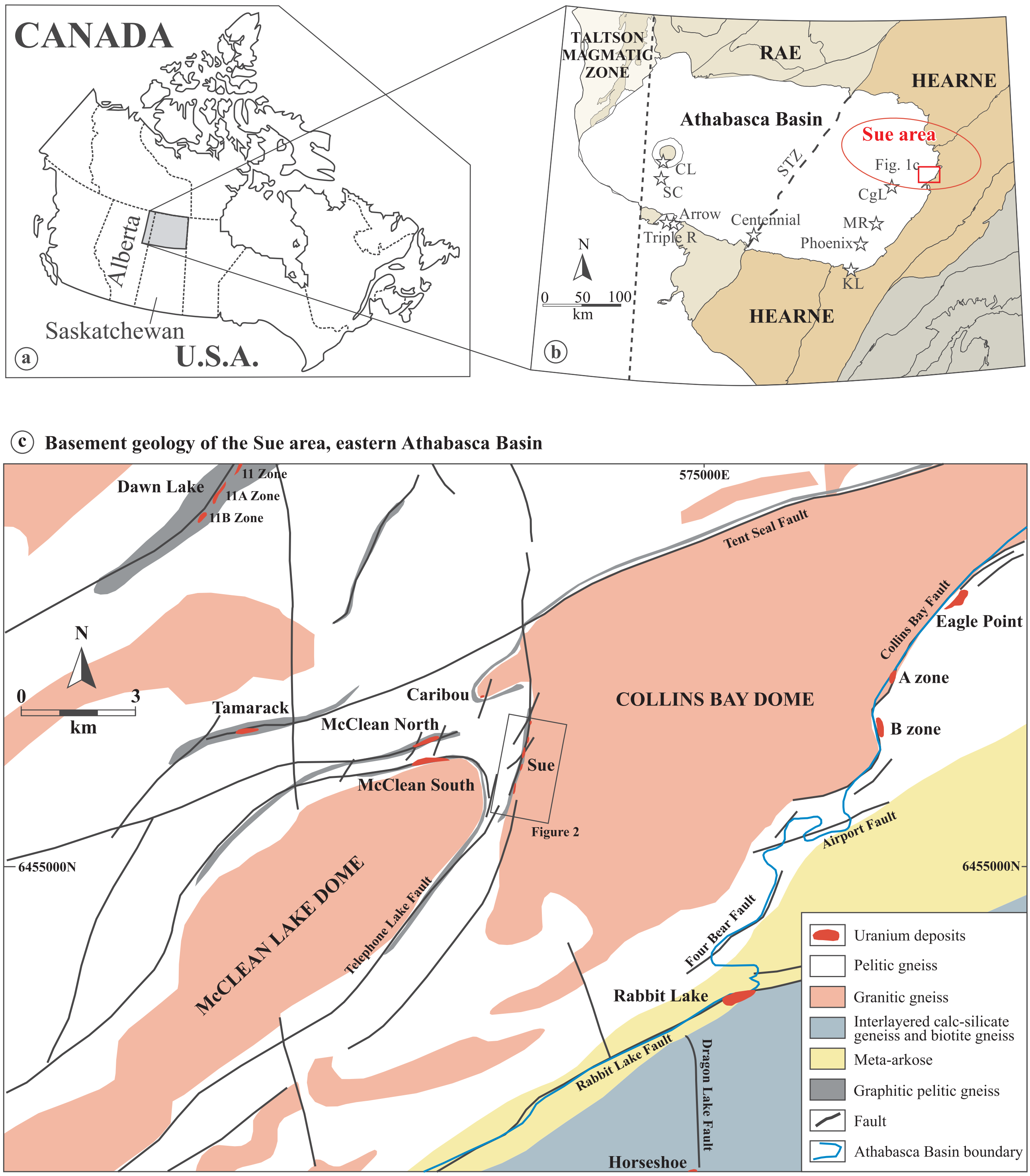

Fig. 1. (a and b) Location and regional geologic framework of the Athabasca Basin (after Card et al., 2007; Jefferson et al., 2007; Ramaekers et al., 2007). Stars represent major uranium deposits. CL = Cluff Lake; CgL = Cigar Lake; KL = Key Lake; MR = McArthur River; SC = Shea Creek. (c) Simplified basement geology of the eastern Athabasca Basin (after Quirt et al., 2012). See (b) for location.

the discovery of hidden orebodies. Leader et al. (2013) suggested that a numerical model of compressional reactivation of reef margins by oblique slip best simulated the observed distribution of strain and location of quartz reefs hosting gold mineralization in the Bendigo goldfield of Australia. Wilson et al. (2016) demonstrated that the local geometries of faults and stress fields controlled the localization of dilation and shear strain and thus the gold mineralization in the Ballarat gold deposit of Australia.

The Athabasca Basin in northern Saskatchewan, Canada (Fig. 1) hosts high-grade unconformity-related uranium deposits associated with reactivated basement-rooted fault zones near the unconformity between the crystalline basement and overlying Athabasca Group (Thomas et al., 2000; Jefferson et al., 2007; Kyser and Cuney, 2009). The formation of the deposits is linked to diagenetic-hydrothermal processes that involve oxidizing, U-bearing, basinal fluids reacting with reducing media coming out of reactivated basement faults to precipitate