Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Geochemical Exploration 85 (2005) 63–79

JOURNAL OF GEOCHEMICAL EXPLORATION

www.elsevier.com/locate/jgeoexp

Petrogenetic reconnaissance investigation of mafic sills associated with flood basalts, Mekelle basin, northern Ethiopia: implications for Ni–Cu exploration

D. Küster[a,*], S.B. Dwivedi[a], K. Kabeto[a], K. Mehari[b], G. Matheis[c]

[a]*Department of Applied Geology, Mekelle University, Mekelle, Ethiopia*
[b]*Ezana Mining Development plc, Mekelle, Ethiopia*
[c]*Institut für Angewandte Geowissenschaften, Technische Universität Berlin, Germany*

Received 4 December 2003; accepted 10 November 2004
Available online 6 January 2005

Abstract

Mafic sills of the Mekelle basin were explored on a reconnaissance level for their magmatic sulphide potential. The sills are related to Oligocene flood basalt magmatism in Ethiopia. They intrude Jurassic shales and limestones and crystallized from high-Ti tholeiitic basalt magmas. Three compositional groups were differentiated. Among them GD1 gabbrodolerites (11.6–4% MgO) show evidence of a fractionation controlled magmatic lineage, while GD2 (~5.2% MgO) and GD3 gabbrodolerites (5.4–3% MgO) show element depletion and enrichment patterns which deviate from the magmatic fractionation trend. Compared to GD1 rocks with MgO values ~5%, GD2 gabbrodolerites have higher SiO_2 and Na_2O but lower FeO_{tot}, TiO_2, P_2O_5, Nb, Zr, Y, Cu, and Ni values, while GD3 gabbrodolerites show higher SiO_2, Na_2O, P_2O_5, Ba and Sr and lower FeO_{tot}, TiO_2, Nb, Zr, Y, Cu, and Ni values. The distinct geochemical signatures of the latter two gabbrodolerite groups are likely caused by conjunct processes of crustal assimilation and fractional removal of silicate/oxide mineral phases. Depletion of chalcophile elements in the contaminated gabbrodolerites indicates also the segregation of Ni and Cu sulphides. However, settling of sulphide minerals occurred prior to sill emplacement probably in a deeper seated magma chamber. The indication of chalcophile element depleted mafic sills, genetically related to a major flood basalt province clearly warrants further exploration in the area.

Keywords: Ethiopia; Flood basalts; Gabbrodolerite sills; Crustal contamination; Chalcophile element depletion; Magmatic sulphide exploration

1. Introduction

The paper presents results of lithogeochemical exploration for magmatic sulphide mineralisation (Ni–Cu-PGE) carried out on gabbrodoleritic sills in Tigrai Regional State, northern Ethiopia. The sills are

* Corresponding author. Tel.: +251 4 402270; fax: +251 4 409304.
E-mail address: kuesterreeck@freemail.et (D. Küster).

0375-6742/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.gexplo.2004.11.002

related to Oligocene flood basalt magmatism of the Ethiopian Province and intrude Jurassic sediments of the Mekelle basin. The exploration approach is based on similarities in geological setting between the Mekelle sills and sills hosting world-class Ni–Cu-PGE deposits of the Noril'sk region in Russia. The similarities include (1) relation of the intrusive bodies with a major flood basalt province, (2) sill emplacement in calcareous partly gypsiferous sediments and (3) association of the sills with deep reaching crustal structures.

The existence of abundant doleritic sills and dikes in the Mekelle area was first evidenced by Merla and Minucci (1938) and further substantiated by Arkin et al. (1971) and Justin-Visentin (1974). However, geological research in the area was severely hampered during the 1970s and 1980s due to mainly political reasons. The intrusive bodies of the Mekelle basin are thus not mapped in detail, they have not been studied with standard petrogenetic techniques (i.e. trace element and isotope geochemistry), and they have never been explored for their mineral potential. We have therefore undertaken a reconnaissance investigation by collecting samples (38 in total) from mafic sills/dikes outcropping along motorable roads, and analysing them for major and trace elements by standard XRF techniques. Our investigation aims to outline the petrogenetic characteristics of the mafic intrusives, focussing on the possible identification of magma contamination and chalcophile element depletion. Both latter processes are envisaged to be prerequisites and exploration guides for magmatic sulphide mineralisation (Maier et al., 1998; Naldrett, 1999).

2. Background geology

2.1. Ethiopian flood basalt province

Lavas of the Ethiopian flood basalt province were extruded during the Oligocene, mainly between 31 and 26 Ma (Pik et al., 1999; Ukstins et al., 2002). They are part of the larger Ethiopia/Yemen Igneous Province which is related to the Afar plume and the Red Sea-Gulf of Aden-Ethiopian Rift triple junction (Fig. 1). Flood basalt magmatism resulted in a basaltic lava pile of more than 2000 m with an estimated volume of 10^6 km^3 (Rochette et al., 1998). In the upper parts of the pile the basalts are partly interlayered with rhyolitic volcanics (Ayalew et al., 2002; Kabeto et al., 2004). Traditionally the Ethiopian flood basalt province is divided into four stratigraphic units (cf. Merla et al., 1979; Mohr and Zanettin, 1988), these are from bottom to top the Ashange, Aiba, Alage and Termaber Formations (Fig. 3). More recently Pik et al. (1998, 1999) have classified the lavas into three distinct geochemical groups: low-Ti basalts (LT), high-Ti 1 basalts (HT1), and high-Ti 2 basalts (HT2). The different basalt types were generated contemporaneously and rather reflect spatial control, with the low-Ti basalts located in the western part of the plateau and both high-Ti basalt types located in its eastern part (Fig. 1). High-Ti flood basalts in the Maichew area, south of Mekelle (see Fig. 1), were divided by Kabeto et al. (2004) into four chemostratigraphic units (Fig. 3). Alkaline and strongly incompatible element enriched basalts occur at the base while subalkaline basalts with both HT1 and HT2 characteristics make up the major part of the Maichew profile.

Flood basalt magmatism was succeeded during the Mio-Pliocene by rifting, widespread bimodal alkaline volcanism and crustal uplift. The rift-related uplift of the Ethiopian Plateau continues until today and has led to substantial erosion of parts of the flood basalt pile. In the northern part of the province (Tigrai and Eritrea, Fig. 1) only erosional remnants of flood basalts are left and the subvolcanic level is widely exposed. In the Mekelle region abundant mafic sills occur within Mesozoic to Paleozoic sedimentary strata (Figs. 1 and 2). A reconnaissance K–Ar age of 32 Ma (Justin-Visentin, 1974) obtained on gabbrodoleritic rocks from an intrusion near Mekelle indicates a coeval relationship between these sills and the flood basalts.

2.2. Mekelle sedimentary basin

The pre-flood basalt sedimentary deposits in Ethiopia are usually made up of Mesozoic sandstone. The Mekelle sedimentary basin (Fig. 2) is a rather unique feature, since it also consists of Upper Jurassic limestone-shale sequences (see Fig. 3). Together the Mesozoic deposits achieved a total