Journal of African Earth Sciences 100 (2014) 191–202

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Crystalline basement aquifers of Ethiopia: Their genesis, classification and aquifer properties

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ARTICLE INFO

Article history:
Received 1 August 2013
Received in revised form 27 May 2014
Accepted 2 June 2014
Available online 27 June 2014

Keywords:
Ethiopia
Crystalline basement aquifer
Aquifer classification
Aquifer genesis
Regolith
Deep weathering-stripping

ABSTRACT

The crystalline basement rocks of Ethiopia were traditionally described as one system of regional aquiclude. This attribution was made disregarding variations in groundwater occurrence and potential which often times is promising in some geologic settings. Systematic studies addressing their genesis and spatial variations are lacking. Based on a thorough review of existing data and field observations, this work has shown that the genesis of basement aquifers is the result of complex interplay between the present/past climate and geomorphic processes which are tectonically controlled. It thus follows that the groundwater occurrence and the type of aquifer exhibit important contrasts on the surfaces of crystalline basement terrains of Ethiopia. Three coherent zones have been identified in this work based on their genesis, thickness of regolith, mechanisms of flow and storage properties: (a) in Western Ethiopia the aquifer is characterized by a vertical profile of fractured low to high grade bedrocks mantled by thick weathering profiles leading to high groundwater storage but low hydraulic conductance, (b) in Northern Ethiopia the weathered mantle is stripped to negligible thickness; groundwater occurs in high conducting but low storage fractured low grade bedrocks, (c) in the Borena lowlands (the southern basement region, the occurrence of groundwater is associated with wadi beds. The orientations of wadi beds follow regional fractures. These fractures control groundwater flow regime and enhance preferential weathering of bedrocks. The presence of alluvial sediments (mostly derived from gneiss and inselbergs of gneisses and granites) over the weathered mantle, facilitates infiltration into the weathered mantle and fractured bedrocks underneath. This enhances groundwater storage and movement both in the regolith and fractured bedrock. Elsewhere outside the wadi beds, duri crusts limit vertical recharge and groundwater availability to the bedrock; aquifers are of intermediate type with regard to hydraulic properties. Potential remnants of weathered mantle are still visible but contribute little to groundwater flow.

It is therefore suggested here that more comprehension about groundwater in crystalline basement rocks of Ethiopia could be gained given the comparison is made based on the genesis of the aquifers as related to tectonics and climate induced stripping and deep weathering history.

1. Introduction

Crystalline basement rocks occur in tropical region of sub-Saharan Africa, India, South America and Australia (Wright, 1992). Aquifers of basement rocks occur within the weathered residual overburden (the regolith) and the fractured bedrock (Wright, 1992; Acworth, 1987; Chilton and Foster, 1995; UNESCO, 1984). Regoliths are developed over the bedrock by weathering process. The thickness of weathered mantle and the corresponding aquifer properties depend on a complex combination of controls that include bedrock characteristics, climate (past and present),age of land surface; relief and other site specific factors (UNESCO, 1984; Acworth, 1987; Wright, 1992; Jones, 1985). The vertical heterogeneity of aquifer properties depend on the type of regolith lithology (Acworth, 1987; Chilton and Foster, 1995). Fig. 1 depicts typical weathering profile and the vertical heterogeneity of aquifer properties (Hydraulic conductivity and effective porosity) of regolith and bedrock.

Several researches from Africa, (Foster, 1984; Acworth, 1987; Taylor and Howard, 1998, 2000; Edet and Okereke, 2005) and from India (Dewandel et al., 2006) emphasize that the hydrogeological characteristics (mainly hydraulic conductivity and storage) of the weathered mantle and the underlying bedrock derive primarily

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http://dx.doi.org/10.1016/j.jafrearsci.2014.06.002
1464-343X/

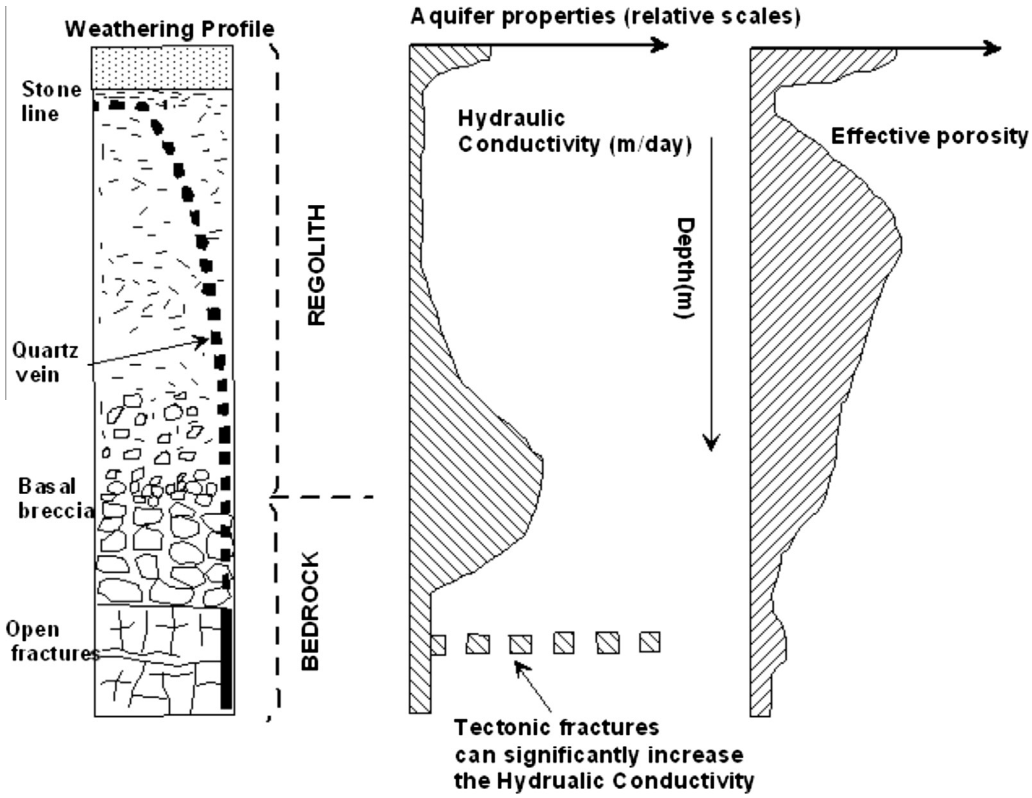

Fig. 1. The vertical profiles of hydraulic conductivity, transmissivity, effective porosity and storage for the regolith – fractured bedrock profile. (After: Acworth, 1987; Chilton and Foster, 1995.)

from the geomorphic processes of deep weathering and stripping. These authors underline the significance of tracing the geomorphic evolution of weathered land surfaces over basement rocks. They emphasize that identifying the dominant geomorphic process operating on surfaces, is of vital importance to comprehend the hydrogeological characteristics of basement rocks.

Particularly for Ethiopia, we came across no model that explains the hydrogeological set up and genesis of basement aquifers. Cherenet (1993), EIGS (1988), EIGS (1996) and many unpublished regional Hydrogeological studies (Alamirew et al., 2005; Belete et al., 2003; Belete et al., 2004; GSE, 2002; GSE, 2003) consider the Precambrian basement terrains of the country as regional aquiclude or very poor aquifers regardless of their spatial differences in terms of groundwater occurrence and potential. A literature based model depicting the polycyclic evolution of weathering surfaces over the basement bedrocks of the country has recently been developed by Kebede (2013). However, research on linkage between geomorphic processes and the hydrogeology of the crystalline basement terrains of the country is lacking. Like elsewhere, it is assumed that such understanding will foster our knowledge on basement hydrogeology of Ethiopia. Systematic studies that address the spatial and vertical heterogeneities of basement aquifers are absent. Albeit the spatial variation and vertical heterogeneities, the basement aquifers were interpreted as one regional aquiclude or poor aquifer.

The main objectives of this work therefore are a) to verify the validity of the previously developed, literature based deep weathering-stripping model of Kebede (2013) through field observation and b) to investigate the linkage between the validated weathering-stripping model with groundwater potential of the basement terrain.

2. Description of basement terrain and associated weathering-stripping processes

2.1. Geologic setup

In Ethiopia, the crystalline Precambrian basement terrains are exposed in the peripheral parts of the country: North, South, West, Southwest and East (Kazmin, 1972; Tefera et al., 1996; EIGS (Ethiopian Institute of Geological Surveys), 1988) (Fig. 2). They cover about 23% of the land area of the country (Cherenet, 1993) and over10 million people reside on these terrains and tap groundwater from basement aquifers for consumptive water uses.

The terrain comprises a wide variety of volcano-sedimentary and plutonic rocks, metamorphosed to varying degree of schist to amphibolites facies being intruded by several generations of granitoids and Gabbros (Kazmin, 1971).

The northern crystalline basement is part of Arabian Nubian Shield (ANS) (Fig. 2 label 1) that consists of low-grade metamorphic rocks of Volcano-sedimentary succession, mafic–ultramafic complexes that are intruded by granites and granodiorites (Beyth, 1972; Garland, 1980; Tadesse, 1997).

The southern, the eastern and part of the western basement rocks constitute part of the Mozambique Belt (Fig. 2 labels 2–4). These rocks are composed of high grade poly deformed rocks (gneisses, migmatites, granulites) and schistose which are intruded by plutonic rocks of gabbroic-to-granitic compositions (Alemu and Abebe, 2007; Kebede and Koeberl, 2003; Ayalew et al., 1990). The distribution of outcrops of basement rocks in Ethiopia marks the transition zone between the Arabian Nubian Shield and Mozambique Belt (Kazmin et al., 1978; Bonavia and Chrowicz, 1993).The proportion of high grade belts (Mozambique Belt) is significantly