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Preliminary geological and geochemical characteristics of sapphire bearing rock of Chilla area, central Tigrai, northern Ethiopia

Características geológicas e geoquímicas preliminares da rocha hospedeira do mineral safira da área de Chilla, centro de Tigrai, norte da Etiópia

Mulata Haftu[1], Berihu Gidey[1]

[1] Mekelle University, College of Natural and Computational Sciences, School of Earth Science, Mekelle, Tigray region, Ethiopia. (haftumulata345@gmail.com; berihug12@gmail.com)

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ABSTRACT

Even though, Ethiopia is endowed with suitable geological setting to host varieties of gemstones, it has not yet been well investigated and explored. In Northern Ethiopia, Tigrai regional state, sapphire mineral has been extracted by traditional and artisanal miners. Chilla, which is 35 km north of Axum, is one of the sapphire's artisanal mining activities has been practiced. In Ethiopia, particularly in Chilla area there is no any geological and geochemical study on Sapphire mineral and its host rocks. In Chilla area, most of sapphires are found in alluvial or eluvial deposits, making it grim to study the relationship between the sapphires and their host rocks. Here, we present preliminary geological characteristics of sapphire mineral within alkaline basalts from the tertiary Chilla volcanic terrain. Geological investigation and geochemical analysis (XRF) indicates; the sapphire mineral is hosted in tertiary alkaline basalts and occur in the contact between alkaline basalt and intrusive granite rocks.

Keywords: Sapphire; Alkaline basalt; Host rock; Alluvial.

RESUMO

Embora a Etiópia seja dotada de um cenário geológico adequado para abrigar variedades de pedras preciosas, ainda não foi bem investigada e explorada. No norte da Etiópia, estado regional de Tigrai, o mineral safira foi extraído por garimpeiros tradicionais e artesanais. Chilla, que fica a 35 km ao norte de Axum, é uma das atividades de mineração artesanal de safira praticada. Na Etiópia, particularmente na área de Chilla, não há nenhum estudo geológico e geoquímico sobre o mineral safirae suas rochas hospedeiras. Na área de Chilla, a maioria das safiras é encontrada em depósitos aluviais ou eluviais, tornando difícil estudar a relação entre as safiras e suas rochas hospedeiras. Aqui, apresentamos características geológicas preliminares do mineral safira dentro de basaltos alcalinos do terreno vulcânico terciário de Chilla. A investigação geológica e a análise geoquímica (XRF) indicam que o mineral safira está hospedado com basaltos alcalinos terciários e ocorreu no contato entre basalto alcalino e rochas graníticas intrusivas.

Palavras-chave: Safira; Basalto alcalino; Rocha hospedeira; Aluvião.

INTRODUCTION

Corundum (sapphire and ruby) are an alumina-rich mineral (Al_2O_3) that may have variable color (gray, blue-gray, brown, yellow, green or colorless) due to substitution of metal ions for Al^{3+}. The most common gems of corundum are red for ruby linked to $Cr^{3+}$and blue for sapphire which has substitution of Ti^{4+}, Fe^{3+} and Fe^{2+} and in some cases V^{4+}, Co^{2+} or Ni^{2+} (Giuliani and Groat, 2019; Phillips and Griffen, 1981). Sapphire is found in magmatic deposits (plutonic and volcanic), metamorphic rocks (gneiss, marble, granulite, met shale and mafic to ultramafic rocks) and placer deposits (Brownlow and Komorowski, 1988; Simandl and Hancock, 1997; Sutherland et al., 1998; Sutherland and Schwarz, 2001; Simonet et al., 2002, 2008; Giuliani et al., 2007, 2014). Megacrystic sapphires are commonly associated with alkaline basalts, most notably in Asia and Australia. Many deposits gem corundum (sapphire) are associated with alkali basalt. Best known are the occurrences in Southeast Asia and Australia. Sapphire which are common on the world market today are hosted in alkali basalt (Levinson and Cook, 1994). In East Africa (Kenya) some gemstones (including sapphire) deposits are associated with Tertiary volcanic rocks (Simonet et al., 2002). The host rock (alkaline basalt) and the associated sapphire mineral may have been derived/produced by partial melting from considerable depths (Cox et al., 1979; Le Bas et al., 1986; Levinson and Cook, 1994; Giuliani et al., 2014) (Figures 1 and 2).

Ethiopia's geological setup is fortunate for the occurrence of metallic, industrial and construction minerals, dimension stones, precious and various types of gemstones (Tadesse, 2009). The geology of central and north western Tigrai has diversity of rock units including magmatic (alkaline basalts and phonolite to trachyte), Metamorphic (metavolcanics and metasediments) and recent sediment deposits (Alene et al., 2006; Hagos et al., 2010a). According to (Hagos et al., 2010b), Axum volcanic rocks are alkaline constituting a wide range in the TiO_2 content and highly diversified rocks (trachybasalts – basanites – tephrites). This geological setting is suitable for the occurrence of sapphire. That is why there is secondary transported sapphire minerals observed in Chilla area. But there is no any investigation conducted on geological and geochemical of sapphire hosted rocks so far. No scientific and geological research has been carried out on sapphire mineral occurrences of and host rock characteristics of the selected area. No single advanced exploration activity for sapphire mineral is conducted so far in this region except some artisanal mining activity. Therefore, this work ai-

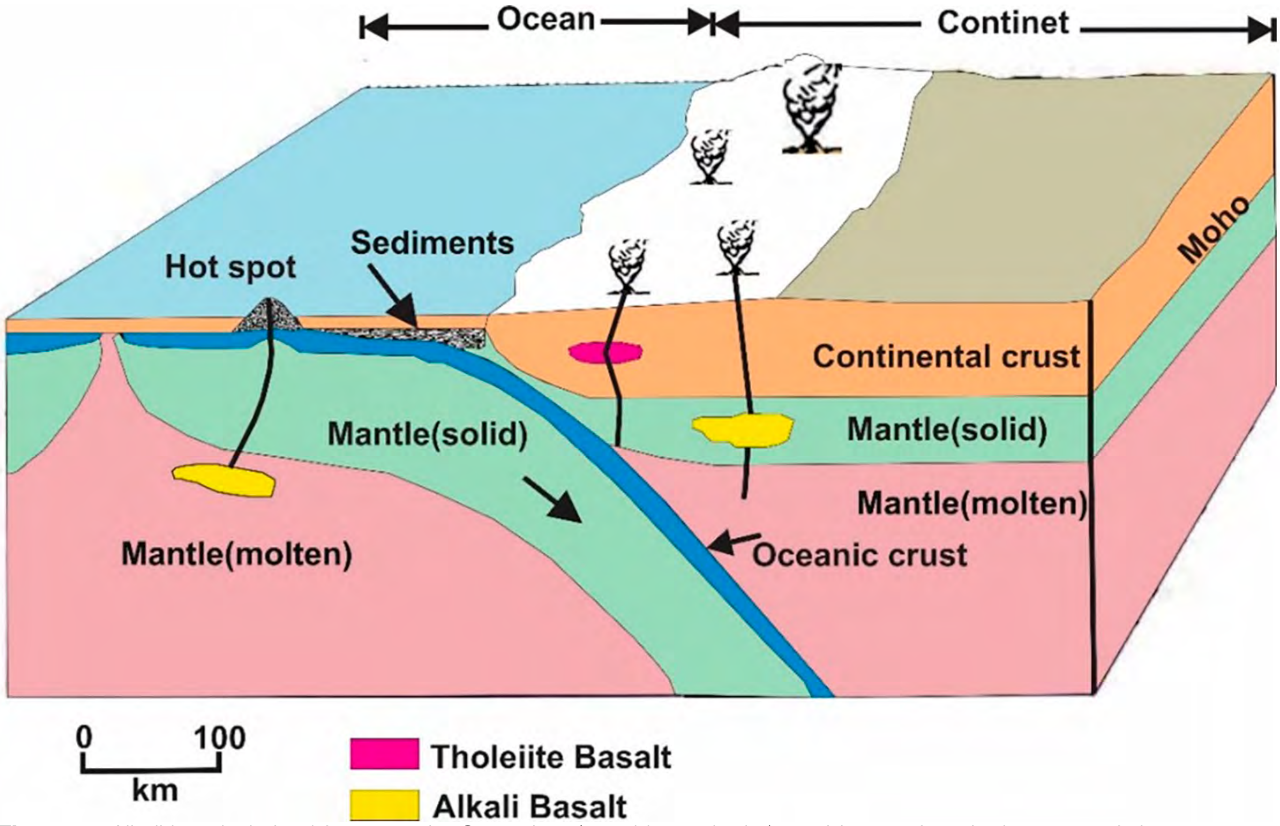
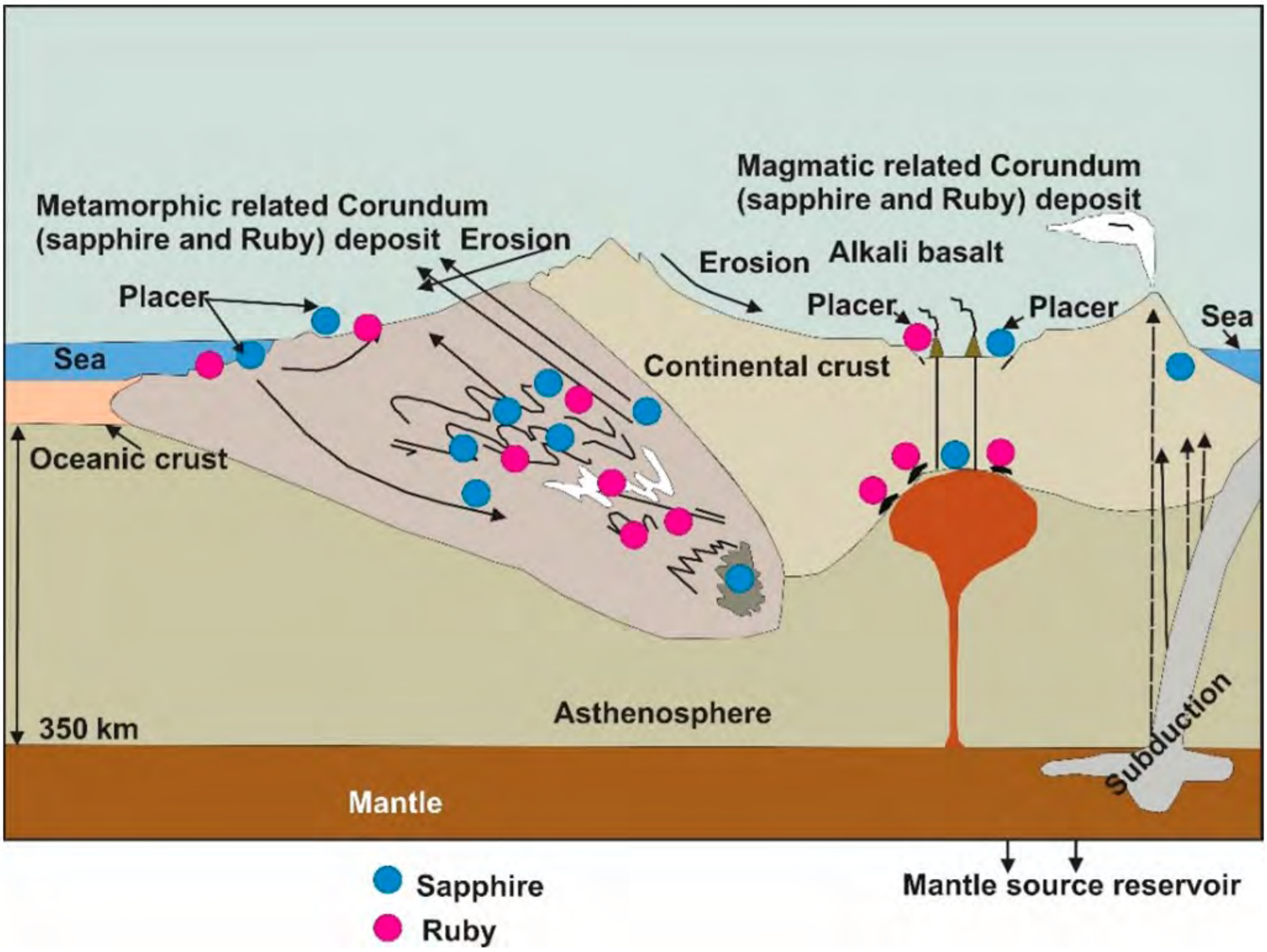


Figure 1. Alkali basalt derived from mantle. Corundum (sapphire and ruby) would come form in the range of about 24 to 50 km below the continental surface. Modified from (Levinson and Cook, 1994).



Source: modified from Giuliani et al. (2014) by Giuliani and Groat (2019).

Figure 2. The corundum (Sapphire and Ruby) deposits suitable environments. The alkaline basalt (host for Sapphire and Ruby is comes from mantle source reservoir.

ming to preliminary geological and geochemical investigations of placer sapphires host rocks.

METHODOLOGY

Fieldwork was conducted with detailed observations. Representative surface rock samples were taken from tertiary basalt and granitic rock. Test Pits were dug to investigate the vertical thickness of alluvial deposit that accumulates the sapphire mineral (Figures 3A and 3B). Magnetic pen was used to detect accessory heavy minerals like magnetite which are commonly associated with sapphire (Figures 3C and 3D). Thirteen (ten from basalt and three from granite) rock samples were collected for geochemical analysis.

All rock samples analyzed were powdered using jaw crusher and pulverized at laboratory of Mesobo cement factory plc (Mekelle). The fine rock powders weighted about 100gm each were arranged for geochemical analysis (major oxides) using XRF (PANAlytical- 2424) at laboratory of Mesobo building material production plc, Mekelle. The result is given in Table 1.

GEOLOGICAL SETTING

Regional Geology

Geology of northern Ethiopia is dominated by low grade metamorphic rocks belonging to ANS (Kazmin, 1971; Tadesse et al., 1999; Asrat et al., 2001). Six tectonic bounded and north to northeast trending tectono stratigraphic sequences were recognized including; the Shiraro, Adi Hageray, Adi Nebrid, Chila, Adwa and Mai Kenetal Blocks. The geology of each block is briefed in detail by (Tadesse et al., 1999). According to (Tadesse, 1997; Tadesse et al., 1999) the geology of Axum sheet comprised of Low grade Proterozoic metavolcanics and metasediments rocks, intrusives bodies, and Paleo-Mesozoic sedimentary strata, tertiary volcanic and quaternary deposits (Figure 4). The study area is related to Chilla block of Axum sheet.

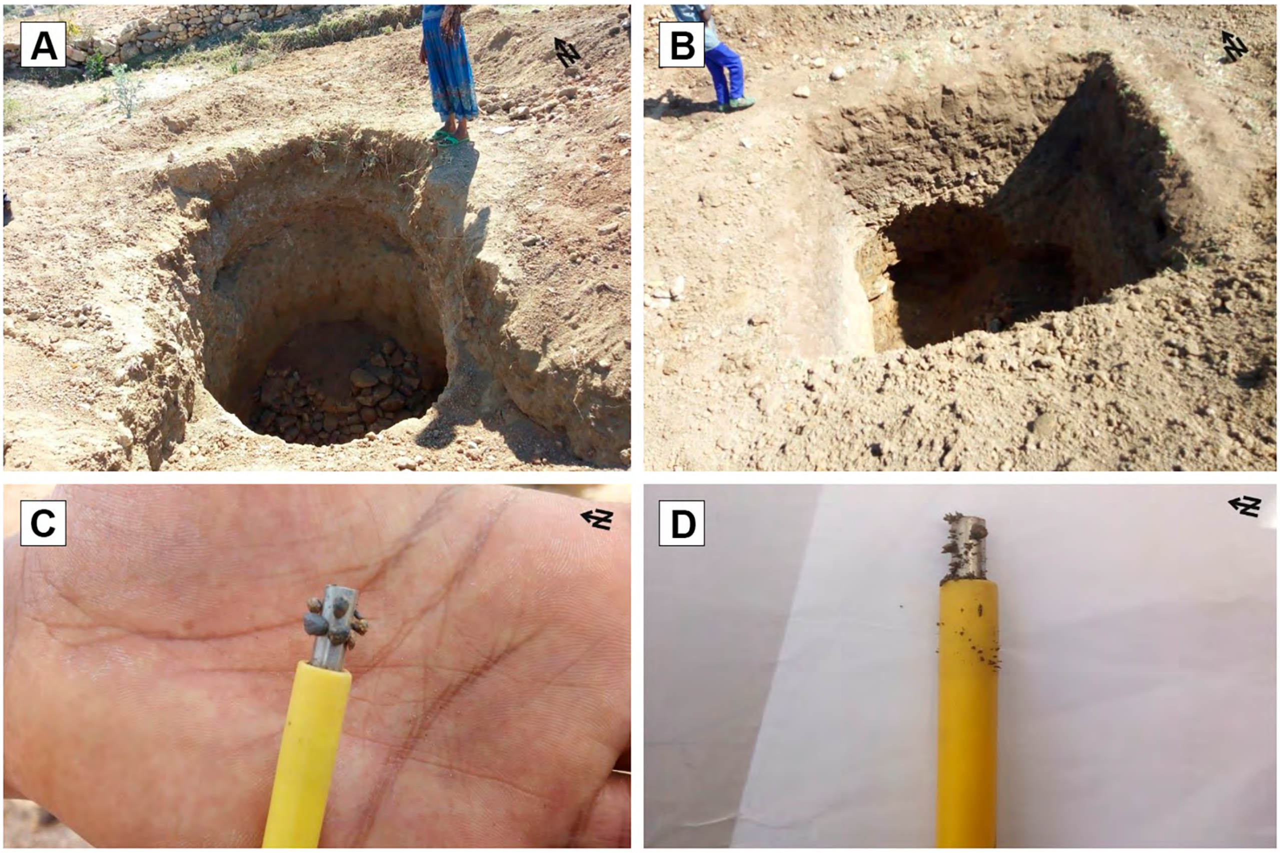


Figure 3. (A, B) Pits Excavated, (C, D) minerals associated with Sapphire detected by Magnetic pencil.

Geology of Chilla area

Chilla area mostly characterized by low grade metamorphic rocks, granitoids, and tertiary volcanic rocks. The basement rocks observed in the area includes graphitic phyllite and phyllitic quartzite (Figure 5). The graphitic phylite is fine grained, shiny to dull, gray color, shows schistose and strongly deformed rock unit. The phyletic quartzite rock unit comprises alternating bands of phyllite and quartzite. The Chilla Granitoid is composed of granodiorite, diorite, syenite and granite. This Granitiod rock units are coarse grained, dark gray to light gray which mainly consist of quartz, plagioclase, k-feldespar, and biotite with some garnet and zircon as accessory minerals (Tadesse, 1998). Presence of dark colored, angular to sub-rounded, mafic microgranular enclaves up to 20cm is also common. Granite in Chilla area is medium- to coarse-grained, weakly weathered, light gray to pink color and considered syn tectonic (Tarekegn et al., 2000). It is composed mainly of quartz, K-feldspar with minor amounts of biotite and muscovite. The other rock unit is the tertiary volcanic rocks and contains aphanitic, porphyritic (olivine and plagioclase phenocryst) which intercalates with vesicular and amygloidal basalts (Hagos et al., 2010b). The aphanitic basalt is characterized by massive, fine grained and black to gray color. The phenocrysts found in poryphyritic are olivine and plagioclase which has irregular to euhedral shape with mm to 10 mm diameter size.

RESULT

Host rock composition

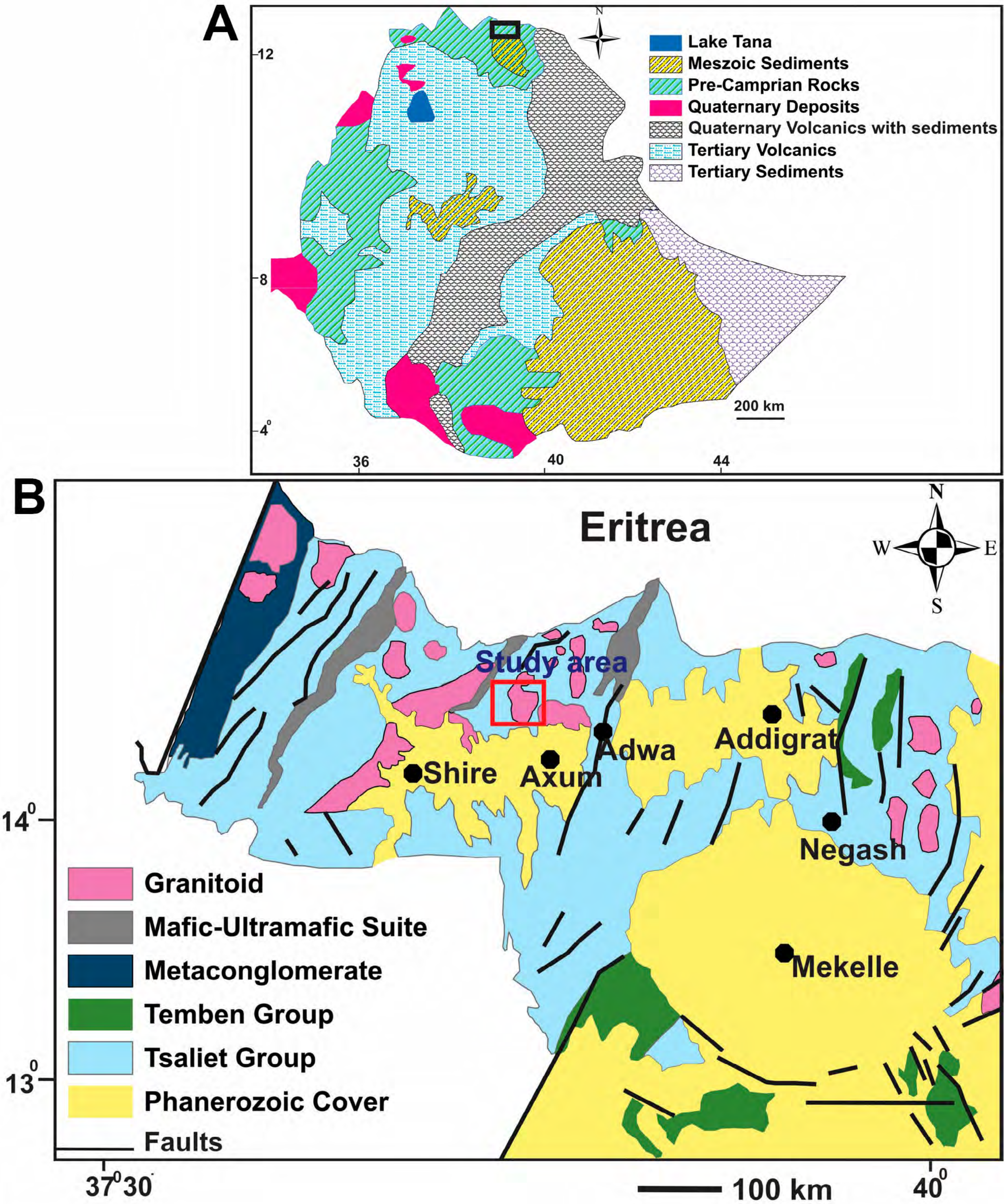
Rock samples have been analyzed for whole rock geochemistry. The rock samples include ten from tertiary basalt and three from granitoid rock. The results are listed below in table 1.

According (Cox et al., 1979; Le Bas et al., 1986), the mafic rocks of Chilla area fall in the basaltic, basanite tefrite, trachy basalt and trachy andesite fields (Figures 6 and 7). Therefore these rocks are classified under alkaline rock series. Using same method, the granitoid rocks of the area are grouped in syenite and syenite-granodiorite under alkaline sires (Figures 6 and 7).

DISCUSSION

Host rock characteristics and Occurrences of the sapphire

Chilla area mainly comprised by Precambrian basement rocks, intrusive bodies, and tertiary volcanic rocks



Source: modified from (A) Merla et al., 1973; (B) Tadesse et al., 1999.

Figure 4. (A) Geological map of Ethiopia, (B) Simplified regional geological map of the northern Ethiopia.

(Figure5). The sapphire mineral is dominantly observed as sandwich between tertiary volcanics (basalt) and granitoid rocks (Figures 5, 8 and 9). Most of the sapphires are exposed along the river channel as alluvial deposit and at the contact of tertiary volcanics (basalt) and grantoids as eluvial deposit. Field and test pits investigation shows sapphire is found at the bottom of tertiary volcanics (basalt) and above grantoids.

Geochemical result indicates the volcanics (basalt) of Chilla area are alkaline character. The sapphire deposits

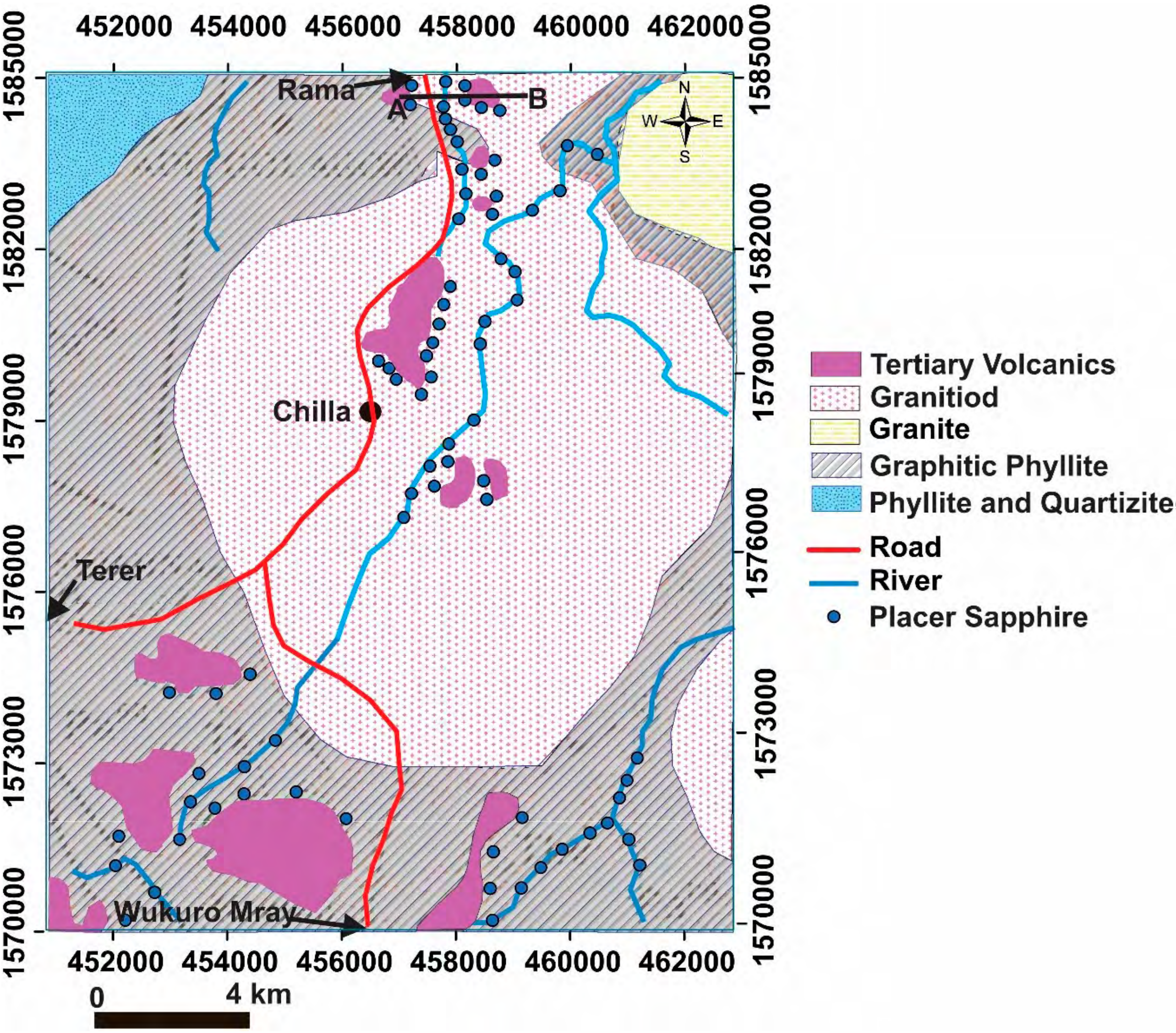


Figure 5. Geological Map of Chilla Sapphire deposit.

found as primary magmatic deposit associated with alkaline basalt and as secondary deposits with eluvial, colluvial and alluvial. According (Levinson and Cook, 1994; Simonet et al., 2002) alkali basalts are most host rock for sapphire. The host rock (alkaline basalt) and the associated sapphire mineral may have been derived/produced by partial melting from considerable depths (Cox et al., 1979; Le Bas et al., 1986; Levinson and Cook, 1994; Giuliani et al., 2014) (Figures 1 and 2). From field observation and pits excavated the model of the sapphire mineral is shown in figure 9.

Comparison of Chilla sapphire host rock with other sapphires host rocks

There are many sapphire deposits in the world which has similar characteristics like Chilla area. Some of them are listed and compared in the Table 2.

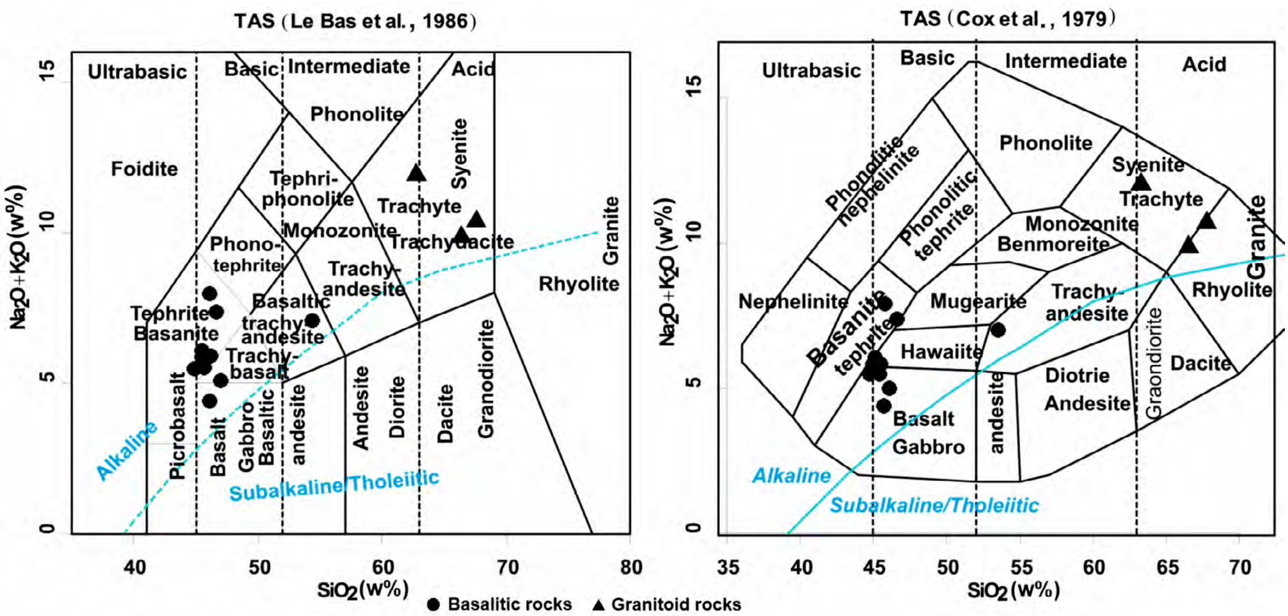
CONCLUSION

The outcomes described here are very limited and must be measured as only preliminary. Many gemstone deposits in Tigrai have never been described, let alone studied in detail. In Chilla area, most of sapphires are found in alluvial or eluvial deposits in which high concentrations of sapphire are found in the centre of the valley near the river bed. The ore of the sapphire is found in the contact between mafic basalt and intrusive granite rocks. The sapphires have been released from their basalt host rock by weathering.

The sapphire Sapphires have also been found on top of the basalt hills, indicating that the basalts are sapphire bearing. Using the limited data on the geology and geochemistry of sapphire mineral host rock, the sapphire mineral is hosted with alkaline basalts and occurred in the contact b/n alkaline basalt and intrusive granite rocks.

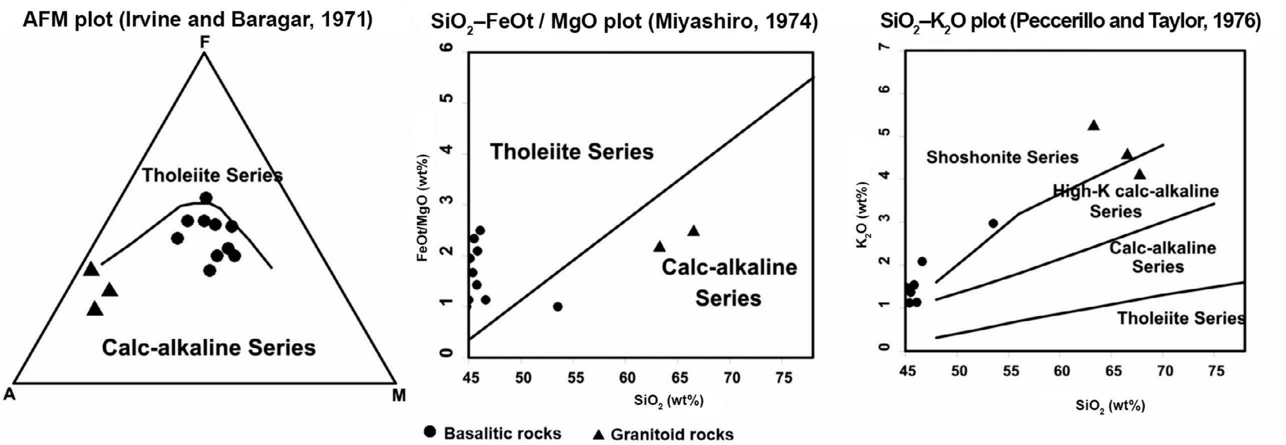
Table 1. XRF analyses of the host rocks of sapphire in Chilla area.

	CH-01	CH-02	CH-04	CH-05	CH- 06	CH-07	CH-08	CH-09	CH-10	CH-12	CH-03	CH-11	CH-13
SiO_2	44.96	45.81	45.51	44.76	45.76	46.62	53.54	45.4	45.14	46.09	67.77	63.3	66.56
Al_2O_3	13.61	11.14	10.6	13.82	14.06	11.36	8.58	14.82	14.89	16.35	12.05	12.04	10.34
Fe_2O_3	11.27	11.03	10.61	10.33	12.09	11.66	8.43	12.57	12.92	14.53	6.48	4.38	5.02
MgO	8.94	4.73	4.08	9.3	7.61	9.24	7.59	6.77	5.98	5.23	0.57	1.83	1.83
CaO	10.78	15.38	17.08	12.27	12.1	10.67	10.72	9.92	10.17	6.87	1.52	6.28	5.32
Na_2O	4.34	6.38	4.46	4.36	2.85	5.3	4.01	4.36	4.58	3.86	6.6	6.8	5.32
K_2O	1.47	1.54	1.37	1.12	1.53	2.08	2.97	1.12	1.47	1.14	4.1	5.23	4.56
TiO_2	2.05	1.58	3.97	2.95	2.57	2.12	1.85	3.5	3.1	3.34	0.46	0.6	0.78
P_2O_5	1.3	1.53	0.6	0.76	0.57	0.8	0.66	0.76	0.89	0.43	0.56	0.23	0.32
MnO	0.24	0.25	0.18	0.2	0.2	0.21	0.17	0.24	0.21	0.17	0.14	0.16	0.17
H_2O	0.3	0.22	0.4	0.32	0.12	0.1	0.11	0.5	0.6	0.65	0.11	0.12	0.22
LOI	1.04	1.25	2.72	1.36	1.87	0.65	1.56	1.73	1.51	1.53	1.45	1.98	1.52
Total	100.3	100.84	101.58	101.55	101.33	100.81	100.19	101.69	101.46	100.19	101.81	102.95	101.96
Rock type	Tephrite Basalt	Tephrite Basalt	Tephrite Basalt	Tephrite Basalt	Trachy Basalt	Tephrite Basalt	Tephrite Basalt	Tephrite Basalt	Tephrite Basalt	Trachy Basalt	Syenite--granodiorite	Syenite	Syenite--granodiorite



Source: Le Bas et al., 1986; Cox et al., 1979.

Figure 6. SiO_2 Wt. % versus total alkali (Na_2O+K_2O Wt. %) On the diagram.



Source: Baragar, 1971; Miyashiro, 1974; Peccerillo and Taylor, 1976.

Figure 7. Discrimination diagrams of the high-K calc-alkaline rock series further into low-K tholeiite series.

Table 2. Comparison of Chilla Sapphires host rock with other sapphires deposits host rocks.

Characteristics	Chilla sapphire	DakNong sapphire , southern Vietnam (Garnier et al., 2005)	Turkana sapphire deposit, Kenya (Simonet et al., 2002)	Siebengebirge sapphire deposit, Germany (Baldwin et al., 2017)	Montana sapphi-re deposit (Guylaine,1995)
Host rock	Alkaline basalt	Basaltic fields	Tertiary volcanic rocks	Alkaline basalt	Alkali province
Age	Tertiary	~6.5 Ma followed by another one at ~1 Ma.	Tertiary	Cenozoic	48.2-1.3 Ma
Associated minerals and elements	Corundum, zircon, magnetite and iron	Fe, Cr,Ti, V and Ga		Fe, Ti, Mg, Mn, Ga, V, Nb, W	Corundum, Mg_ Al_Fe, Ca, Cr, Sr
Mode of occur-rences	Alluvial or eluvial deposits	Eluvial and alluvial placers	Alluvial or eluvial deposits	In situ megacrystic	As dike
Type	Blue	Blue, green and yellow	Blue	Blue	Violet, purple and blue
Quality	Medium to high	Medium to high	Medium to high	Medium to high	High

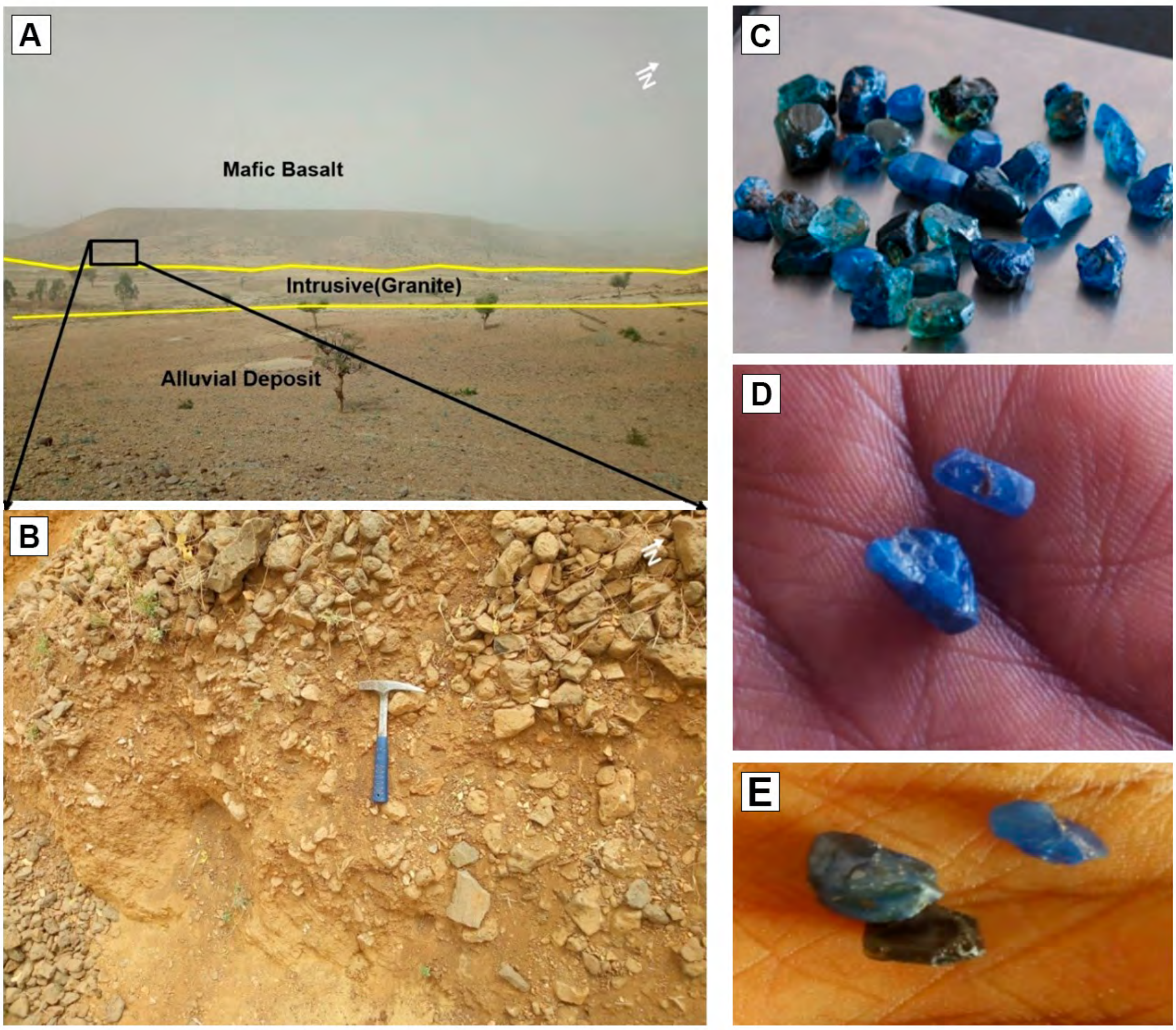


Figure 8. (A, B) Outcrop of occurrence of sapphire mineral in contact between tertiary volcanics and granitoid; (C, D, E) Sapphire mineral from Chilla area.

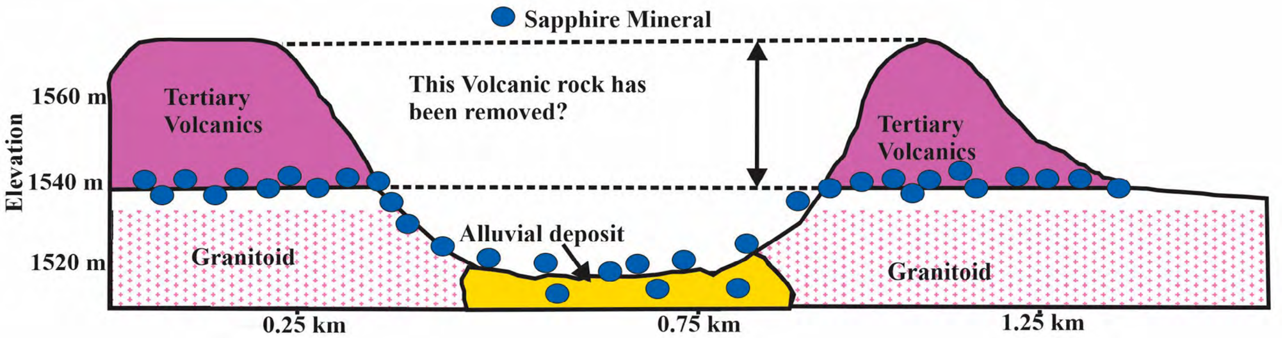


Figure 9. Schematic cross sectional model of the sapphire deposit at Chilla area from point A to B in figure 5 (0456382mE to 0457824mE and 1584171mN to 1584773mE).

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