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Petrography and Geochemistry of Upper Paleozoic Sandstone around Kuch Area, Blue Nile Basin, Central Ethiopia: The implication for Provenance, Paleoclimate and Tectonic

Tigist Birhanu

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Petrography and Geochemistry Upper Paleozoic Sandstone around Kuch Area, Blue Nile Basi Gentral Ethiopia: The implication for Provenance, Paleoclimate and Tectonic Setting

By

Tigist Birhanu

A Thesis Submitted to the School of Earth Sciences, Bahir Dar University in partial fulfillment of the Degree of Master of Sciences in Petrology

October 2020 Bahir-Dar, Ethiopia

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Approval of the thesis for defense

I hereby confirm that I have supervised, read, and evaluated this thesis/dissertation titled €Petrography and Geochemistryuppfper Paleozoic Sandstoneround KuchArea, Blue Nile Basin, Central Ethiopia: theniplication for Provenance, Paleoclimate and Tectonic Setting• by Tigist Birhanu prepared under my guidance. I recommend the thesis/dissertation be submitted for oral defense (mockriva and viva voce).

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Declaration

I hereby certify that the entire work to this thesis entitled €Petrography and Geochemistry of upperPaleozoic Sandstoræround KuchArea, BlueNile Basin, Central Ethiopia: theniplication for Provenance, Paleoclimate and Tectonic Setting• was done by me, Tigist Birhanu, for partial fulfillment of the requirements for the award of the Degree of Master of Science in petrology to the School of Earth Sciences, Bahir Dar University (BDW)der the spervision of Minyahl Teferi (PhD.) and Dawit Libene (P.D.).

I amounce that the entire materialmy original work and only with the use of the referenced literature and the described methods. The results embodied in this thesis have not beend submitte in part or whole to any other university or institute for assessment or award of another degree.

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Name		Signature	date

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ABSTRACT

Paleozoic sedimentary rocks in the Blue Nile or final Ethiopia are related to two major Gondwana glaciations: namely, the Late Ordovicianiurian and the Carboniferour Permian glaciation. The present study investigates sandstone sections cropping out in the Bokotabo Sentom and Daguja town, both which are foundaround the Kuch area, in the western parts of Blue Nile basin, central Ethiopia he upper Paleozois and stones are composed of mudstones, siltstones and sandstones the BokotaboSentom area and deposited as sandstituteoneand tillite in the Daguja area. The present study is aimed at investigating the petrography and geochemistry of these sandstones to evaluate the provenance, the tectonic setting, and the paleoclimate conditions under white upper Paleozoiscandstones were deptesd. The study was conducted using transmitted microscope, inductively coupled plasma mass spectrometry (ICP-MS), and inductively coupled plasma atomic emission spectroscopy A(ESP). Based on major, trace and rare earth element analysis and petrogradatia, the upper Paleozoic sandstones are dominated by Quartz (on average of 64.5% in Boketation area and 58.4%) in Daguja area) and followed by feldspars (on average of 31.0% in BokStattom area and 36.6% in Daguja area) and rock fragment (onrage of 3.2% in Bokotab6 entom area and 4.9% in Daguja area). The sandstone is medition coarsegrained, texturally immature to sub mature, and poorly to moderately sorted. The sandstone was derived from transitional continental and basement uplift rocks he sandstone could be classified as arkasic lithicarenite The chemical index of alteration, plagioclase index of alteration, and chemical index of weathering values identive the upper Paleozois and stone has moderate high weathering history in the BokotaboSentom area and w to moderate in the Daguja area Based on trace and rare earth element concentrations, its sources possibly are juvenile material, the basement nearby.

Keywords: uppePaleozoic, SindstoneBlue Nile baisn, PetrographyGeochemistry, Provenance

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ACRONYMS

ACM " active continental margin

- Afsp "alkali feldspar
- ALS "Australia laboratoryservice
- ANS, Arabian Nubian Shield
- CIA " chemical index of alteration
- CIW " Chemical Index of Weathering
- DF "discriminant function
- Gr,, granitoid
- HFSE, high field strength elements
- ICP-AES "inductively coupled plasma
- atomic emission spectroscopy
- ICP-MS " inductively coupled plasma mass

spectrometry

- IRF "Igneous rock fragment
- LILE " largeion lithophile elements
- LOI " Loss onignition
- MRF "Metamorphic rock fragment
- Mc "microcline
- Md " mudstone (for thin section)
- MST- mudstone (for thin section)
- PAAS, PostArchean Australian Shale
- PIA " plagioclase indx of alteration
- Plg, plagioclase
- PM " passive margin
- QFL- Quartz Feldspar Lithics
- Qm-monocrystalline quartz
- QmFLt " monocrystalline quirtz-feldspar

lithic fragment

Qp- polycrystalline quartz

- REE " rare earth element (HREE heavy
- REE; LREE, light REE)
- Pl- Paleozoic
- SIT "siltstone
- SRF, Sedimentary rock fragment
- SST, sandstone
- TIL, tillites
- TTE " transition trace elements
- UCC, Upper Continental Crust

1. INTRODUCTION

1.1.BACKGROUND OF THE STUDY

In the Paleozoic, who main glaciation events ave been peorted from various locations within the Gondwana continent. However, the period and the areal coverage of the glaciated areas are not completely understood ewin et al., 2018 Elhebiry et al., 2019 The lower Paleozoic upper Ordovician Silurian) glacition was depicted, relatively, as a limited, momentary (11Ma) Hirnantian events anthe upper Paleozoi(Carboniferous Permian event) lasted for tens of millions of years (>70 Mallsbell et al. 2012)During the Ordovician glaciation, a wide range of glacial deposits such as sgbacial landforms including tunnel valleys, mesgrale glacial lineation, and paleice streams have been formed, particularly in northern Gondwana (Armstrong et al., 2005 During the upper PaleozofiermoCarboniferous) glacition, the southwestward migration of the glaciogenic deposits was in response to movement of the southern pole across Gondwana from NW Africa to central Antarcascetese and Barrett, 1990; Torsvik and Cocks, 2013 Both Paleozoic glaciations are ideinetid in northern Central Africa (Niger and Chad), Horn of Africa (Eretria and Ethiopian)d southern Saudi Arabia, while Carboniferous Permian glaciogenic deposits have been well documented from southern Arabia (i.e. Yemen and Omar Elhebiry et al., 209). Theupper Palaeozoic glacio...uviatile and glacio-lacustrine deposits occur in East AfridaVopfner and Kreuser, 1986 upper Paleozoicsilici- clastic sedimentary rocks are recognized ftbersouth of the Equator, starting from Ethiopia in the nont up to South Africa in the sout Elhebiry et al., 2019) In Ethiopia, there are two types of Palaeozoic sedimentary rocks which are related to the two major Gondwana glaciations: Enticho sandstone (Late Ordovician to early Silwiniach) is exposed in the Mekelle basin and the upper Paleozois and stone (the Carboniferous) which are exposed in Mekellebasin (Edaga arbi glacials) and Blue Nile basessert, 2010; Lewin et al., 2018 They are underlain by Neoproterozoic basement rocks and a invery Mesozoic clastic and carbonate sedimeteskurie, 2010; Lewin et al., 2018). The study areaKuch area, is located in the Blue Nile Basin, central Ethiopia. The geological

1

units that cover the uch area belong to the following three major categori) the Precambrian

basement, ii) the Paleozoid Mesozoic sediments, and iii) the Cenozoic Volcanic ro(disige 2008, Gani et al., 2009.) The Paleozoic sedimentary rocks occur in the south and southeastern part of the study area, in the western pathe Nile basin(Dawit, 2014; Lewin et al., 2018) They are exposed in narrow zones and discontinuous bodies that have a general gout both trend. The present study with bvertwo key areas, covering different parts and fund Kuch area in the Blue Nile Basin: Bokotabe Sentom and Daguja area.

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The present study focused on the petrographic and geochemical characterizable nupper Paleozoicsandstone around the Kuch area, in the Blue Nile Basim tending to provide nsight into the provenance, pale involute, and tectonic setting. Petrographic and geochemical characterization of sediments is important for the implication of provenance, tectonic, setting paleoclimate conditions. Thin sections were prepared at Geological Survey of Ethiopia, Addis Ababa and then petrographic studies have been conducted using transmitted light microscopes in the petrology laboratory of the Department of Earth Science at Bahir Dar University. The analytical techniques for major, tracend rare earth elements viewabeen peformed by inductively coupled plasma mass spectrom (HCPP-MS) and inductively coupled plasma atomic emission spectroscopy (ICRES) techniques at the laboratory of the ALS in Ireland. Other aspects such as textures are studied to the additional felfillof the aim of the study.

1.2.Location and accessibility

The study area lies in the Northwestern plateau of Central Ethiopia and Southern **plate**ts of Kuch area, bounded by ⁹108,09•N to10⁹24,45•N latitudes and between ⁹300,44•E to 37⁹04,40•E longitudes overing a total area of 390 km². It is about 500 km far from Addis Ababa and is reached through two main routes. The first route is from Addis Aba**b**aebre Markos, Bure-Bokotabo road. The road from Addis Ababa to Bure is asphalted whereas a road from Bure to the study area **is**gravel road. The other one is through Addis Aba**b**aekemte, Agemsa - Bokotabo road. The road from Addis Ababa to Nekemte is asphalted and the remaining route from Nekemte the study area **is** a gravel road. It salso accessed **on** g with Bahir Dar Debre Markos, Bure Bokotabo road. The study area is accessible by a field car and motorcycle during all seasons.

Figure 1(A) The geological map of Ethiopiafter (Billi, 2015); (B) Location Map of the stuydarea, western Blue Nile basimpodified after (EMA, 1987)

1.2.1. Physiography

The physiography of the study area is characterized by subdued and rolling terrain dissected by streams which are tributaries of the Blue Nile River cross the area in a generally estas direction in the central part of the area. The altitude withins tode area ranges from about 079 m to 2044m in the Bokotabo Sentom area and 1200 to 0003 in the Daguja area. The study area, topographically, is characterized by valleys, flat aread cliff with slope gradient varying from gentle to a steep slope.

Figure 2Physiographic map of the study areacluding both areas (Bokotabentom and Daguja area)

1.3.Previous work

The recent works that have been studieeduad the study area include Assefa (1997U), so t al. (1994), Wolela (2007), Tsig(2008), Gani et al. (2009)Enkurie (2010) and Lewin et al. (2018). Assefa (1991) studied the lithostratigraphy and environment of deposition of the Late Jurassic Early Cretaceous sequence of the central part of Northwestern Plateau, Ethiopia. Assefa studied lithostratigraphy and the depositional environment of the Mugher Mudstone and the Debre Libanos Sandstone of Northwestern Plateau. Russo et al. (1994) studies etailed explanation about the formation and evolutions of every succession in the Blue Nile basin visbidower sandstone (Adigrat sandstone), Gohatsion formation, Antaleestorne, Mugher sandstone (muddy sandstone), and Debre Libanos sandstone (upper sandstone). Wolela (2007) studied the source rock potential of the Blue Nile (Abay) basin, Ethiopia. According to his study, Permian Karroo Group shale was found toobver-maturingfor oil generation; whereas algal laminated gypsum from the Middle Hamanlei Limestone Formaties owganic lean and had

little source potentialTsige (2008) studied and mathee generaGeological map and major structures ofheBure area. Gareit al. (2009) studied Stratigraphic and structural evolution of the Blue Nile Basin, Northwestern Ethiopian Plateau. They outlined the stratigraphic and structural evolution of the Blue Nile Basin based **dre**ld and remote sensing studi**Es**kurie (2010)studied Stratigraphy, Facies, Depositional environmented palynology of Adigrat sandstone in Northern and Central Ethiopia. He gaveletailed investigation of the stiggraphy, sedimentary facies, depositional environmentend palynology of the ‡Adigrat Sandstone, succession in the Mekelle and Blue Nile basinsLewin et al. (2018) studied the Provenance of Paleozoic sandstones in Ethiopia, including the study areay Tused petrographic and geochemistry (X ray ...uorescence) analysis to determine the provenance of the sandstone. According to Lewin et al. (2018), the upper Paleozois is less mature with a geochemical signatume or juvenile source materialmost likely the Arabian Nubian Shield. Howeverthey only studied one sample frorthe upper Paleozois difference of the sandstone.

1.4.Statement of the Problem

Even though the petrography and geochemistry of all sedimentary succestiverBlue Nile basin are well studied by the above authors,-destailed work has been done on the Paleozoic sandstone. General geology and major structures of the sandsetore envestigated by the Geological Survey of Ethiopia Besides, Lewin et al. (2018) studied eth Provenance of the upper Paleozoics and stones in Ethiopia, but their study more focused on Northern Ethiopia only one sample was prepared in the Blue Nile basin. Hence, its geochemistry and petrography that reveal the provenance, paleoclimated teconic setting of this sandstone have not been well studied yet.

Therefore, petrographical and geochemical studies are acquoir address the provenance, Paleoclimate, tectonic setting the upper Paleozois and stone. Furthermore, tructures and textures will provide adequate information about the deposition advisor of the upper Paleozoics and stones.

1.5.Objectives

1.5.1. General Objective

The general objective of the present study is to condupter trographical and geochemical investigation on the upper Patezoic sandstone around the Kuch area, the Blue Nile basin, Central Ethiopia, to evaluate the provenance, tectonic settimes paleoclimate during the pper Carboniferous Early Permian glaciation.

1.5.2 Specific Objectives

The specific objectives of the presenter dy include:

- conducting detailed petrographical investigation to determine the provenant dee of upper Paleozois and stone;
- conducting detailed geochemical analysis (meajor, rare and trace element analysis) to calculate geochemical proxies, such@hemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA) and Chemical Index of Weathering (CIW);
- assessing the paleoclimate and tectonic setting duringupper Carboniferouslower
 Permian glaciations by using the calculated geochempioaies;
- Attempting to conduct regional coradion with coeval deposits in Mekelle basin, in Ethiopia.

1.6.Methodology

Based on the availability and relevance, different methods and techniques are employed to accomplish the abovenentioned objections.

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1.6.1 Field methods

Forty-eight samples were collected from each lithological unit for petrographical and geochemical investigations. Two field trips were carried out duthing study to examine the upper Paleozois and stone succession in the study area. The first field trip was conducted n December 2531, 2019 for 6 days observand select well exposed lithology and stratigraphic sections around the Bokotabe Sentom area. The second field trip was conducted anuary 1-1 14, 2020 for 4 days around the Daguja area to observe and select verify bosed lithology and stratigraphic sections. Geological traverses and orientations in the field were carried out by Bure topographic maps of 1:50,000 scales produced by the Ethiopian Mapping Agency. During the field work, various sedimentary structures and textures; griate and color variations; mineral composition were examined. At the field traverse were described by GPS is matternal.

Sample collection techniques

Forty-eight representative samples were collected based on sampling intervals were 1 m to 15 m for each succession with little or no lithologic changesm1sampling intervals were selected for lithology thatapidly changed. 25 (twenfive) sandstones, 9 (nine) mudstones, 6 (six) siltstones and 5 (five) tillites were collected from various sections for petrographic and geochemical analysis. These samples were labeled as SST for sandstone; SIT for **bllsst**one; for mudstone; TIL for tillites; and Gr for granitoid. Field photographs and **sectode**re employed to document and illustrate key geological features such as sedimentary lithologies, structures, textures, and changes in exposure.

1.6.2. Laboratory methods

The analyses were done a **b** chphasizing the petrographical and geochemical aspects of the observed rocks. The collected fresh samples were placed into zip lock polythene bags marked with sample number and location and sent to the Geological Survey of Eth Addia Ababa for thin section preparation and the laboratory of ALS for Geochemistry.

1.6.2.1 Petrographic analysis

The petrographic analysis is used for determination of modal composition and textures of sandstones and it gives insight into the source national the processes involved in the formation of the rock(Aleali et al., 2013)17(seventeen)samples which include; 11 (eleven) sandstones, 4 (four) siltstones, 1 (one) mudstormeds one tillite are prepared for thin section. The selected samples werens for thin section preparation the Geological Survey of Ethiopia, Addis Ababa. They were evenly cut into rectangular slabs and either side being polished for soft, flat surface then adherence to glass specimen plates. Later than, the samplerelabs we trimmed and polished to get an even surface (~0.03mm thickness) that allowing maximum light distribution through the specimen plates. 17 (seventeen)setations were prepared and analyzed by using petrographic microscope. Then petrographic studies wonducted using polarized transmitted light microscopes in the mineralogy and petrology laboratothe of Department of Earth Science at Bahir Dar University. Rock compositions, size indegree of sorting and roundness, and other features wereestudie modal analyses were carried out by counting more than 300 points per thin section, using the Dirkinson pointcounting method(Gazzi, 1966; Dickinson, 197.0After that, rooted in the modal composition, sandstone classificationwasmade usinghe McBride schemeMcBride, 1963. Sandstone composition and tectonic discrimination were recognized by QFL and QmFLt plots proposed data and Suczek (1979)

1.6.2.2 Geochemical analysis

Out of the 17 (seventeen) rock samples, 8 (eight) representative samples are selected for geochemical analysis These samples are 3 (three) sandstones, 3 (three) siltstones, 1 (one) mudstone and one tillite. The analytical techniques for major, traced rare earth elements has been performed by inductively coupled plass mass spectrometry (ICMPS) and inductively coupled plass mass spectrometry (ICMPS) and inductively coupled plass mass spectrometry (ICMPS) and inductively coupled plasma tomic emission spectroscopy (ICMPES) techniques Before, weathered part of the samples removed; split into significant several to 76.9% less than 2mm, ruffle split off 0.75 gand then pulverized split to 91.4% passing 75 µm before analysis. This preparation is done in ALS services plc, Nifas silk subity. These pulp samples were analyzed by-ACHS for major oxides together with trace elements analyzed by-ACHS and ICPMS. These analyses

were performed at the laboratory of the ALS Loughrea locat Dulatin Road, Loughrea, Co. Galway, Ireland. The process was accomplished by dissolution of the pulpes dryp ithium metaborate or tetraborate (LiB/Di₂B₄O₇) fusion method. This mixing lithium metaborate or tetraborate fusion with a prepared sample (0.75g) was fused in a furnace at 1000°C. After that, an acid mixture (nitric, hydrochlor, icand hydro..uoricacids) was used to cool and dissolve the mixture. The solution was then analyzed by HQIES and ICPMS. For samples that are high in sulfides, a NgO₂ fusion may be substituted to obtain better result. Loss of ignition (LOI) represents the total volatilcontent of the rock that is determined by igniting the rockwals measured after heating the samples overnight at 100°C to remove water, at 550°C for four hours to remove organic matter, and at 1000°C for two hours to remove carbornates and trace element on centrations were recalculated b 100% volatile free.

After geochemical analysis, the ØN-K diagram, the CIA, CIW, and Pl,Aand elemental ratios were calculated to quantitatively measure the source rock composition and degree of weathering. The relative mobility of certain oxides has helped many researchers in developing some paleoclimate proxies such as the Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA), Chemical Index of Weathering (CIW), ØN-K ternary diagramand elemental ratios. In this studythese paleoclimate proxies were approv Beetsides, the pattern of REE may give some indication of the weathering intensity. Correspondingly, the pattern of REE, major and minor element abundanceand their ratios have elem used for the interpretation of the provenance. Bivariate, ternangund multiple plots have been created by using the Øreemical Data toolkit (GCDkit)(Janou€ek et al., 2006).

No	Analysis methods	No of samples	Examination
1	Petrographic analysis	17	Modal and source rock composition a texture
2	Geochemical analysis (ICP-AES and ICPMS)	8	trace and major element for discrimination tectonic setting and provenance

.6.2.3	Summary of	petrographic and	geochemical	methods
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Figure 3- The flow chart showing the methodology of this thesis work

1.7.Expected Outcome and Significance of the Study

The outcome of this thesis work will to contribute the understanding of the provenance, tectonic setting and paleoclimat of the upper Paleozoiscandstone in the Bure area, Western part of Blue Nile basin, Central Ethiopia. Additionally, the output will be;

- a detailed petrographical investigation that determines the provenant determines the provenant determines paleozoics and stone;
- detailed geohemical analysis (i.e., majorare and trace element analysis) that calculate geochemical proxies;
- a detailed evaluation of the paleoclimate and tectonic setting during upper Carboniferous lower Permian glaciations by using the calculated geochempioaries;
- Regional correlation with coeval deposits Minekelle basin, in Ethiopia.

The Significances of this research tos give comprehensive information othe provenance, tectonic setting, paleolimate, and depositional condition othe upper Paleozo is and stone around the Kuch area, western Blue Nile Basin

2. REGIONAL GEOLOGICAL SETTING

2.1.Introduction

The final assemblage of Gondwana was an extended process during the Neoproterozoic between 650 Ma to 600 Ma. During this time, the East idan Orogen was formed which is one of the largest accretionary orogens in Earth's hist do and Pisarevsky, 2005; Abate al., 2015). At the end of the Precambrian time the accretion and dismantle of the East African Orogen occurred, which was foolwed by a long period of erosig Mogessie al., 2002; Dawit, 2014) In Northern Africa, a vast peneplain developed after the consolidation of the newly formed continent, on which a blanket of Paleozoic sandstone was dependent al., 2005) Between Paleozoic and Triassic, the Precambrian tectonic structures reactivated as extensional faults that guide the deposition of eolian and glacial deposits (Edaga Arbi Glacials and Enticho Sandstones), and successively of alluvial plain sediments (Adisparid stones) (Dawit, 2014; Abate ea al., 2015 and Sembroni et al., 2016) From three major transgression and regression cycles, the first cycle was responsible for the formation of the majority of Mesozoic sediments in Ethiopia/Kazmin, 1972;Mogesse et al.2002)In Cenozoic, around Eocene, the impingement of the Afar plume starts to deform the lithosphere causing a regional broad uplift and the emplacement of the flood basalts on the Palebase ozoic sandston (Dawit, 2014; Sembroni et al., 2016).

2.2.Stratigraphy of the Blue Nile Basin

The Blue Nile Basin is situated in the northwestern Ethiopian plateau, between latitudes 08⁴⁵, to 10³⁰, N and longitudes 36³⁰ to 39⁰⁰, E and covers an area of 55,000 square kilometers (Enkurie, 2010). It is one of a series of NE and NW trending intracontinental rifts and extensional basis, which were subsequently led with about 2000 meter section of Paleozoic Mesozoic sediment Mogessie et al., 2002Gani et al., 2009) The stratigraphy of the Blue Nile Basin is characterized by the Precambrian crystalline basement, Palaeozoic apado Mesozoic sedimentary successions of the Tertiary continental flood basalts (Trap series). Paleozoic Mesozoic sedimentary rocks unconformably overlying on the Neoproterozoic basement rocks and unconformably overlain by Eagly ate Oligocene and Quaternary locanic rocks (Gani et al., 2009).

2.2.1. The Precambrian basement

The Neoproterozoic basement rock, ranging from 850 to 550 Ma, lies on the base of the Paleozoic Mesozoic sedimentary succession in the Blue Nile Basimi et al, 2009; Enkurie, 2010). It consists of low-grade metavolcano-sedimentary succession and matitramatic complexes of the Arabian Nubian Shield (ANS) and the -byinghole metamorphosed and deformed Mozambique Belt (MB), produced between West and East Gondwana by the closure of the Mozambique Ocean T(adesse et al. 2000; Stern et al. 2004) hese are overlain unconformably by a Permoriassic €Karroo• succession around 450 m t(hit/balela, 1997).

2.2.2. Paleozoic sedimentary successions (pAedigrat sandstone)

The Palaeozoic units comprise sedirtsenof one of the two major Gondwana glaciations, Late Carboniferous to Early Permian glacial.uvio/ lacustrine deposit(Sussert and Schrank, 2007;Bussert, 201)0According to(Russo et al., 1994)P;reAdigrat sediments are considered as a single unit but after (Enkurie, 2010), Paleozoic sedimentary rocks are classified into three sections: PreAdigrat I, PreAdigrat II, and PreAdigrat III sediments

2.2.2.1. Pre-Adigrat I

PreAdigrat I sediments are the oldest sedimentary succession in the Blue Nile biblishan w thicknessof up to 50 m(Enkurie, 2010) This rock is composed of poorly sorted, massive to crossbedded medium to coarsegrained white sandstones and conglomer (Herekurie, 2010). Different structures such as ductile solution subtractures, largescale trough crossbedding, crude horizontal bedding nd channelype cut and fill structures have been found (Enkurie, 2010) These structures lead to correlate this succession with the lower glaciogenic part of the Enticho Sandstone in Ethiopia. It overlies the crystalline basement anist exposed in small isolated outcro (besides and conglom)

2.2.2.2. Pre-Adigrat II

PreAdigrat II sediments are extensively exposed in the Blue Nile basin and reach a maximum thickness of 400 m in the Finchalkey of central Ethiopia and it reaches up to 200 m in the northwest of Blue Nile basin (in Bokotabo area, which is the parts of the **strody**)rie, 2010). These successions are composed of lateral accretion deposits, floodplain fines, crevasse splays playa-lake, and eolian dune sedimer(Bawit and Bussert, 2009; Enkurie, 2018)ased on the

age of the overlying unit, the age of these successizeronsidered to be private carboniferous. It is unconformably overalineither preAdigrat I or the Precambarn basemer(Enkurie, 2010).

2.2.2.3. Pre-Adigrat III

PreAdigrat III sediments have a thickness of 350 m in Fincha and Dedu areas and 100 m in Fuliya and Dejen area (Enkurie, 2010) It consists of three successive cycles of stacked, multi story sheet sandstoneodies that are capped by overbank fines and crevasse splay deposits. These successions can be interrelated with Karoo sediments (fluvial and lacustrinife syn sediments) which are widespread in eastern and southern AlEridaurie, 2010). Based on palyndogical dating, the lower part of these successions are late Carboniferous to Early Permian age (which is also the parts of the study) rice, 1983; Stephenson et al., 20,000 the top of the succession indicate a Middle Triassic (Gereletu & Wille 1998). These successionare underlain by PreAdigrat sediments and overlain by Adigrat sands (Erinekurie, 2010).

2.2.3. Mesozoic sedimentary successions

2.2.3.1. Adigrat sandstone

Adigrat Sandstones have thickness of ~300 m and deposited above the partially peneplain Triassic surface that unconformably developed above the Perfinitassic sediments as well as of the basement and overlain by Early, Middle Jurassic Lower Limestone un(Eani et al, 2009, Abbate et al., 2015)Based on some biostratigraphic data and cationel with adjacent areas that providing fossil ages, this succession is assigned as "TeadyicJurassic in age (Russo et al., 1994).

2.2.3.2. Gohatsion formation

The succession has thickness of 450 m and It is assigned as E, Migdle Jurassic age (Toarcianto Bathonian) (Assefa, 1981) It consists of a cyclic repetition of facies successions that are composed of alternating dolostones, marlstones and shales, bioturbated mudstones with thin siltstone intercalations, fingerained coquinoid crostaminated sadestones and thick beds of gypsum (Assefa, 1981; Russo et al., 19914) is underlain by the Adigrat sandstone unit and overlain by a Middle Jurassic Antalo Limestone u(Genani et al., 2009).

2.2.3.3. Antalo Limestone

This unit is a carbonate successionthood Middle-Late Jurassic age, based on the Callovian to Kimmeridgianbenthic foraminifers and macrofaun(Resusso et al. 1994 and Atnafu, 20018) is found in the SW...owing segment of the Blue Nile basimuch comprises thinly bedded to massive limestone whith a thickness of ~400 mQ (ani et al., 2009). This unit is sandwiched between the Gohatsion Formation and eithmer Mugher mudstone unit or the Debrie alnos Sandstone unit or the volcanic rock (San (ni et al., 2009; Enkurie, 2010)

2.2.3.4. Mugher Mudstone

This unit is named by Assefa (1991) after the unit was found alongside the Muger River in the eastern part of the Blue Nile basin. It is believed to **provide the Blue** based on stratigraphic position (Assefa, 1991) This unit is dominantly reposed in the canyons of Mugher, Ega, Wodem, Dersena, Beresssa, Adabai, Zhema, Waemoch Othennli rivers (Mogessie et al., 2002) It is conformably underlain by the Antalo Limestone and overlain by eitherthe Debre Libanos Sandstone unit or the volcaroid (Enkurie, 2010)

2.2.3.5. Debre Libanos Sandstone

Its thickness varies from west to east; from ~200 up to ~500 mawiadverage thickness of 280 m (Gani et al., 2009; Enkurie, 201.0) Based on its stratigraphic relationship with overlying and underlying units, its age is assigned to be of Late Jura Staidy Cretaceous ag(Assefa, 1991; Russo et al., 1994) is underlain by Mugher mudstones and unconformably overlain by the Early, Late Oligocene volcanic rock \$\$ (sefa, 199,1) Gani et al., 2009 and Enkurie, 2010)

2.2.3.6. Trap series

The basalt series with subordinate trachytes and rhyolites envelop most of the Northwestern Ethiopian Plateau and overly the Debre Libanos sandstone or Antalo limestone, i(Galaicet al., 2009; Enkurie, 2010)Based on Arage datingnd magnetostratigraphy, these units assigned as ower "Upper Oligocene age (26, 29.4 Ma) and var in thickness from 500 to 2000 m(Hofmann et al., 1997)

3. GEOLOGY OF THE STUDY AREA

The studied area is bounded between 8,009•N to 10²24,45•N and 3700,44•E to 3704,40•E and are grouped into two sections; the Bokot **Sec** to and the Daguja area (f) g

3.1.The Bokotabo-Sentom area

The upper Paleozois and stone sections are located from the northeast of the Bokotabo village t the southeast of the Sentom village. It covers 10⁶22,55•N to10⁶24,45•N and 37⁶00,44•E to 37⁶04,40•E. The upper Paleozois and stone sections in this area reach about 150m. It is unconformably underlain by the Neoproterozoic basement and unconformably overlain by Adigrat sandstone. This work categorizes the studie paleozois and stone into three units based on lithology and mineralogical composition. This succession is composed of sandstone, siltstone and mudstone unit.

The sandstone units

This sandstone unit is found anterbottom of the formation and exposed in the northeadsteof Bokotabo are. This unit is unconformably underlain by Netwoterozoic granitoid rockst is approximately, 0m in thickness. This massive sandstone formation is fine to meghained, sub-angular tosub-roundin shape, and moderately sorted with variable color (pale purple, white and red). This unit is mostly composed of quartz and feldspar minerals. At the bottom, this unit contains soft sandstone with essized clasts (fig4-E). The whitesandstone is spotted by red color minerals which may indicate feaside minerast such as hematite. The pepterple sandstone is relative fine-grained in size. Some structures are observed in this section such that: graded bedding and trough crossding(fig-4-B & C) which arealsothe characteristics of glacial sandstones.

The siltstone units

This laminated stistones unit is approximately04 in thickness. It has a white and redcolor (fig-4-D). The white siltstone intercalated with mudstone is laminally composed of fine quartz with some pinkish minerals which may be feldspar minerals. The oriended siltstone may be due to Feoxide minerals. This formation is fine to medium grained randed erately sorted. It is overlain by laminated mudstone the Sentom area and overlain by digrat sandstone in the Bokotabo area.

The mudstone unit

This mudstone unit is only exposed the Sentom area and has roughly 50m thickness. It is entirely reddish which may indicate the composition is dominated byokkede mineral such as hematite, as cementing materials. Two types of mudstone are observed in this area. The upper part is highly laminated and friable, while the bottom one is hard and massive mudstone. Thi hard and massive mudstone overlies the siltstotheeiß entom area.

Adigrat sandstone

This sandstone is fine to coargreained, medium sorted with variable color (yellow, pwhete and red sandstones). Its thickness reaches about 100m. Differetutrets are observed in this section; graded bedding, herringbone cross-dding trough and plan-terbular cross-bedding and hummocky cross-bedding (fig 4F&G). Tabular and herringbone cress-edding are common in this unit. It is overlain the siltstone units the Bokotabo are, and mudstones it he Sentom area

В С D Е G F

Figure 4- The outcrops view of sandstone units and show (A) partial view of siltstone and mudstone units overlying by Adigrat sandstone, (B) hd(C) the sandstne unit showingrough crossbedding, (D) thin white and dark red laminated siltstone, (E) outsized clasts in sandstone, (F) herringbobeddings, (G) hummocky crossbedding.

3.2.The Daguja area

This area is bounded between \$108,09•N to 10°19,49•N and 37°01,00•E to 37°03,10•E. The thickness of this section is approximatebachel to 130 metes. It consists of two sections; the tillite and sandstone and siltstone section-\$fig.).

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The tillite unit

The tillite unit is unconformably underlain by Netwoterozoic granitoid rocks. Its thickness reaches up to 50m. It consists of rounded clasts with white and pinkish colorD() igThe grain size of these clasts ranges from fine rocks to boulder size. Most of these clasts are granitoids. The matrixes inthis unit have whitis hyellow color and medium to coarse grain sized sub angular shape. This tillite is overlain by palayellow sandstones its to unit.

The sandstonesiltstone unit

This massive sandstonsiltstone unit has a thickness reaches up0mo. It has yellow and pale yellow color (fig-5-B). The siltstone unit is hard and composed of fine yellowish grains. The sandstone unit is both soft and hard massive sandstone. It consists of fine to medium grains, sub angular to sub-round in shape, and moderately sorted grainsOnly normal graded bedding structure is observed in this unit (figC).



Figure 5- Field photographs of the outcrops from Daguja (A)apartial view of tillite and sandstone in the study **a**;e(B) a cliff showing massive yellow sandstone, (C) normal graded bedding in sandstone (D) tilliteoulder outcrop that composed of medium to coagreeined clasts

A geological mapwas prepared at scale of 1:50,000, based on their lithologichange. The vertical exaggeration between the geological map and the sceotion is 1:1A normal fault is found in the northwestern parts of the Bokotabo area. This faultissects all sedimentaryunits (including Adigrat sandstone) cept the upper Pleozoic sandstone which underlain the siltstone unit. A-B crosssection was chosen to show all lithological units be upper Pleozoic sandstones in both areas are underlain by the Neoproterozoic granitic basement and overlain by Adigrat sandstone and tienty basalt.

Figure 6 (A) Geological mapand lithostratigraphic columof BokotaboSentom and Daguja area with samples for petrography and geochemistaryalyses; LP (late Paleozoic), M (Mesozoic). (B) Geologic crossection of BokotaboSentom and Daguja area.

4. PETROGRAPHIC AND GEOCHEMICAL RESULTS

4.1 Petrography

The mineralogical composition of the upper Paleozois and stones as determined by using Gazzi, Dickinson, s point counting method and plotted in a Qabd QuFLtternary diagam for sandstone classification ectonic setting discriminatio (fig-18 & 19). Petrographic descriptions are presented in (Table). According to the classification scheme of McBride (1963), based the modal composition the upper Paleozois and stone in both areas is dominated by arkos et al.

4.1.1 Bokotabo-Sentom area

17 (seventeen) this sections were prepared and analyzed unadepolarized microscope. The major constituent minerals in these samples are quartz, plagioclated space, the mica minerals (muscovite and biotite), carbonate (calcated) accessory mines (zircon, tourmalie, garnetand FeTi oxide), respectively. Framework grain components dominate 807. % of the rock samples with matrix and cement constitute about of. %. Based on the overall analysis, the upper Paleozoic and stone has an average modal composition of vol. % quartz, 30.1 vol. % feldspar, 3.7 vol. % lithic fragments and 0.5 vol. % accessory minerals. The saccessory ranges from fineto coarsegrained, subangular to subounded, and moderately to poorly sorted sandstones (table). In the sampled thin section, theock (lithic) fragments are composed of metamorphic, sedimentary, and plutonic rocks (fig.)7 In thin sections heavy minerals are dominated byzircon, tourmaline, rutile, garnet, iron oxides (magnetite, and hematite), few opaque bases and minor orthopyroxene, while most of theave occurred as inclusions (fig 7 E & F). Grains of heavy minerals are very fine and rounded to rovel ded grains. All analyzed samples contain cement such as silica, calcite, and mica Inica Sandsone samples for instance Sst3bok and Sst&bok are strongly cemented with silica; Sbt#k and Sst&bok are strongly cemented with calcite and Sstak is strongly cemented with hematite. In some samples, quartz, plagioclase and some lithic fragments and tered to hematite and calcite. Sandstone samples (Sst5bok, Sst6sen and Sst10bok) are differentrom their compositionsfrom the rest samples; they are related to Adigrat sandstones.

Quartz is the principal constituent mineral in the studied samplies three varieties; monocrystalline (Qm), polycrystalline (Qp), and stretched quartz (19).7 The quartz grains

are generally subangular tosubround in shape. Along with quartz grain monocrystalline quartzis leading overpolycrystallinequartz with an average modal volume percentage of 43.3 vol. % and 21.2vol. %, respectively. The majority of the Qm grains showing to slightly undulatory extinction and some quartz grains contain inclusions such as guartz, zircon, tourmaline and garnet (fig 7-A & H). Feldspar is the second most dominant constituent minerals with subangular shapes. Plagioclase, orthoclase, microcline, and perthite are the major common varieties, respectively (fig-A&K). Plagioclase dominates over-feldspar with the average modal composition of 23.4 ol. % and 4.1 vol. % respectively. Among Keldspar, microcline is dominantiver orthoclase and microerthite. Rock (lithic) fragments are the least framework grain withan average modal composition of 73 ol. %. In general, the fragments are subangular in shape. They are abundant with siltstone, metamorphic lithodadtsplutonic lithoclasts, respectively. Metamorphic lithoclasts are slates, sahistmetæedimentary rocks which show foliation (fig 7-E&I). The sedimental lithoclasts are ne sandstone and siltstones. Cementing materials occurrings pore fillings are composed of silica, carbonate (calcite), iron oxides (hematite), and mica (muscovite and biotite) minerals, respectivel **7**-(fig) J). Fluid, lithic fragment and heavy mineral inclusions are observed in the analyzed thin section skiftig E & H).

4.1.2. The Daguja area

The analyzed samples in this section have the major components of **64ardd** (%), feldspar (30.7 vol. %), lithic fragments (**4** vol. %), and accessory minerals (0.5 vol. %). The samples vary from fine to coarsegrained, subangular, and moderately to poorly sorted sandstones (Table3). The lithic fragments are metamorphic, sedimentary, and plutonic in origin. Framework grain compontenaccount for **6** vol. % of the rock samples with matrix and cement constitute about **4** vol. %. Accessory minerals are zircon, tourmaline, rutile, garnedx. The samples, and minor orthopyroxene (Table). Types of cementare silica, calcite, and mica (muscevitand biotite). Siltstones sample (Sittlag) is strongly cemented with calcite followed by muscovite, Sst1-dag strongly cemented with hematite and muscovite without calcite cement Sst2dag and Sst2dag are moderately cemented with silica, hematite lixtte calcite (fig-7-1, J& K). The quartz grains are generally sautigular tosub-round monocrystalline (Qm) is dominated over polycrystalline (Qp) with an average of 40.5 vol. % and 23.5 vol. %, respectively-(5) able
The majority of the Qm grainsalare undulatory extinction and some quartz grains contain mineral inclusions such as rutile, zircon, tourmalianted garnet.

Feldspar is the second dominant constituent with **angu**lar grains. Plagioclase, orthoclase, microcline, and microperthite are thenajor constituent minerals. Plagioclase dominates over K feldspar(22.9 vol. % and 7.8 vol. %, respective(Table3). Among K feldspar, microcline is dominantover orthoclase minerals.

Rock (lithic) fragments are the least framework grain withhaverage of 4.9 vol. %. In general, the fragments are subungular in shape. They are abundant with plutonic lithoclasists, claystone, and metamorphic lithoclasts respectively. Metamorphic lithoclasts are composed of slates, micaceous schist, and metamorphic rocks. The sedimentary lithoclasts are sandstone and siltstones.



С

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Figure 7- Photomicrographs of the upper Paleozois and stones showing (A) and (B) monocrystalline and polycrystalline quart $\mathcal{A}(\mathbb{R})$, plagio dase and microcline (xpl and ppl, $4\mathcal{A}(\mathbb{C})$) and (D) mudstone, monocrystalline quartz and microcline (xpl and ppl, $4\mathcal{A}(\mathbb{C})$), and (F) mineral inclusion in kyanite (red, blue and black arrow), pore space (green arrow) (xpl and ppl, 10x)

Н

G

ι J κ L

(G) monocrystalline and polycrystalline quartz with stretched grains cemented by silicas with hematitemicro-crack on the quartz crystal pl, 10x); (H) monocrystalline quartz with inclusion(Qin) and undulatory extinction (Qu) (xpl, 10x);) cements such as calcite(a, yellow arrow), muscovite flakes (green arrow), biotite (red arrow) and hematite (blue arrow) (xpl, (4)); cements hematite (green arrow), calcite (red arrow), and siltstone rock fragment (blue arrow), muscovite (yellow arrow) (xpl, 4x); (K) micro-perthite grains (xpl10x); (L) fluid inclusion in quartz (xpl, 4x).

4.2.Geochemistry

4.2.1. Source rock compositions

The major and trace element concentration and their ratios of all analyzed samples are given in (Table 4&5). The sandstones were measured upthe average composition office upper continental crust(UCC) (McLennan, 2001) and PAAS (Taylor and McLennan, 19\$5 The selected major and trace elements normalized bet primitive mantle(Sun & McDonough, 1989) are plotted in (fig 9&11). Besides, REE and a were plotted on REE primitive mantle spider plots (McDonough & Sun, 1995). The entire samples show comparable patterns with upper continental crust and Post Archean sediments that display LREE enrichment and moderatety HREE pattern (fig 9& 11).

4.2.1.1 Bokotabo-Sentomarea sandstone

8 (eight) samples were prepared and analyzed by inductively coupled plasma mass spectrometry (ICP-MS) for trace and rare earth elements and inductively coupled platsmaic emission spectroscopy (ICFAES) techniques for an interpretation of the signature of in this sample is an indicator dfie abundance of all silicate minerals present in the sandstone mainly quartz, feldspars, and clay minerals, while quartz is the important mineral. It adocunts the highest concentrations in all samples (7,496 wt. %). Other major element are relatively have low concentration: AD₃ (3- 14.05 wt. %, mean 8.50 wt. %), NaO (0.01 4.14 wt. %, mean 1.62 wt. %), 50 (0.41-4.37 wt. %, mean 1.73 wt. %), 16 (0.04 2.01 wt. %, mean 0.93 wt. %), TiQ (0.11- 0.75 wt. %, mean 0.30 wt. %), CaO (0.00267 wt. %, mean 0.23 wt. %), MgO (0.04 0.49 wt. %, mean 0.18 wt. %) \mathcal{O}_{5} (0.01- 0.18 wt. %, mean 0.05 wt. %), and MnO (0.01 0.05 wt. %, mean 0.02 wt. %). Some samples this area show nearly negligible concentrations of some major elements such as CaO, MnO, MOQ, and TiQ. The ratios of SiO₂/Al₂O₃ values are range from 5.31 to 32.00. All the studied samples show low Ca02/Al values (0.007 to 0.06). Moreoverhe low concentrations of TiQ(<1wt. %) that show low abundances of Tbearing opaque minerals such as rutile. When compared with UCC (McLennan 2001)PAAS (Taylor and McLennan, 1985 the studied samples are characterized by high SiO contents and low in AO₃, FeO₃, CaO, NaO, MgO, KO. However, siltstones (SIT5) & SIT6) have a higher value of NaO than the UCC and PAAS. The depletion of Ω a < 1 wt.

%) in mudstone can be attributed to a relatively smaller amount **-oficN** aplagioclase in them (Table 4). According to K₂O and N₂O contents and their ratios the mudstone sample has the highest ratio (K₂O/Na₂O =18). Al₂O₃ content is relatively high in all samples except sandstones sample # SST5 (3 wt. %). The sandst **sae** mple(SST5) has the highest value dD₂ (96 wt. %), and it has the lowest value of other major oxides such 200₈, Att₂O, Fe₂O₃, CaO, MgO, Na₂O. Depend on all geochemical vasue hesandstones ample(SST5) might be different from other samples during their formation, it is possibly from grad sandstone

The correlation between Si@and other major elements is negative for the studied samples that indicate much of the Si@s present as quartz grains. The Si@ontent of the studied samples shows a strong negative correlation with₂@y, TiO₂, Fe₂O₃and P₂O₅, and a weak negative correlation with MgO, N₂O, and CaO (Table). Exceptfor SiO₂, all major elements have positive correlation with A₂O₃ (fig-8); P₂O₅, Fe₂O₃, TiO₂, and K₂Ostrongly correlated while Na₂O, MgO, and CaO weakly correlated and MnO exhibit no correlation. Mudstone has, relatively, high concentration of TiOthat indicates Trich opaque mineralsuch asrutile. Additionally, it has increased trace element concentrations (Th, Y, Zr, and REEs like Ce, Dy, Gd, La, SmandTb), that indicate heavy minerals such as zircon (Table)

Figure 8 - Multiple plots of all major elements $against_2 \Theta_{s}$; (A) $AI_2O_{3vs} SiO_2$, (B) $AI_2O_{3vs} CaO$, (C) $A_2O_{3vs} MgO$, (D) $AI_2O_{3vs} Na_2O$, (E) $AI_2O_{3vs} K_2O$, (F) $AI_2O_{3vs} TiO_2$, (G) $AI_2O_{3vs} P_2O_5$, and (H) $A_2O_{3vs} Fe_2O_3$; all major elements are measured by w.%

Large-ion lithophile elements (Rb, Ba, Pb, Cs, and Sr)are relatively mobile and incompatible elements. BaRb, Pb, Sr, Cs concentrations in all samples well below the values for the UCC, except siltstone amples that are enriched in Ba compared to the UCC-9 (Fig). These mobile elements are enriched in mudstone and siltstone than the sandstones. Cs, Rbd Sa show a strong positive correlation with $_2$ (Table 9). All studied samples are enriched in Pb that indicates arkosic sandstone, except sandstones (SST3 and SST5) whieh heging ible amount of Pb (< 2 for both samples).

High field strength elements (Th, U, Ti, Hf, Zr, Nb, and Ta)are incompatible and mobile elements that reenriched in felsic rather than mafic root Bauluz et al., 2000) They are used as an indicator of provenance due to their immobil(taylor and McLennan, 1985) II HFSE in the studied sample, except mudstone, are well below at the UCC (fig)-A). The studied mudstone shows higher concentrations of **heid** strength elements (HFSE) such as Zr, and Hf compared to UCC. The lower sandstone (SST3) shows depletion in high field strength elements such as Ga, Ta, Hf, Nb, STrh, U, Zn, and Zr. The deletion of Hf (2.1-4.5 ppm) in all samples except mudstone (9.1 pmiss) due to the depletion of mafic minerals in the frable 5). This hows weak positive correlation with $\partial \Theta_k$ (r= 0.6447) and strong positive correlations with elements, such as Tigand Nb (r = 0.985788 and r= 0.998344, respectively) (Table). Transition trace elements (Sc, Cµ and Ni): All transition trace elementare depleted compared to the UCC (fig-A). Mudstone is relatively enriched by Cu and Sc, while is enriched in siltstone. Medium correlations between Cu and Ni and selected major elements have been observed (Table). The depletion of Sc and Ni in all studied samples indicates the depletion of mafic rocks in these formations. Sc correlates stroppossitive with AbO3 (r=0.879816), TiQ (r=0.934036), Zr (r=0.884455) and the REEs (r=0.859301; r=0.915178 for HREEs) (Table7&9).

Rare earth elements (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb and Luarethe least concentration, insoluble and relatively immobile element during weathering, and have the most important application for provenance in sedimentary rollokesLennan, 1989; Rollinson, 1993). The presence of heavy minerals such as zircon, monazite possibly cloar siderable effect on the RE pattern of individual sample Rollinson, 1993). The total REE concentration of the

30

studied samples SREE) is 103.88 ppm, whichs lower than the average PAAS (183 ppm) and UCC (145.72 ppm) concentrations (Table CI-normalized REE patterns are similar the PAAS and UCC with slightly enriched LREEs, flat HREEs ad a slight negative Eu anomaly (fig-9-B). The Eu anomaly latter was calculated according (MocLennan, 1989):

Where N = chondriteormalizedvalues.

The Eu anomaly values of greater than inducatea positive anomaly while values of less than 1.0 indicate the negative anomaly.

Similar to other LREE, Eu is an incompatible element, however is specially incorporated into plagioclase. Accordingly, the average UCC exhibits Eu depletion thromagnion attemption effects (McLennan, 1989) In all studied samples, the Eu shownsegative anomaly (Eu/Eu*<1) with an average of 0.82, except sample SIT6 (1.03). The mean and median Eu/Eu* is slightly lower than the PAAS and UCC (Table). The (La/Yb) value, which describes the total slope of the Cl normalized REE trend, is higher than the PA(Ara) value, McLennan, 1985) n all samples. The chondritenormalized (La/Sm) ratios which indicate the LREE enrichment in this sample ranges from 3.54.0 and have an average of 3.7. The (Gd/Yb) values range from 1.2.1 with average ratios of 1.8 (Table)., that indicate...at HREE pattern (fable).

LOI values for all samples are range from 0.9% (SST3) to 5.15% (MST1). Mudstone sample (MST1) has the highest value of LOwhich is expected in felsic rocks. Sandstone sample (SST3) from Bokotab&entom area has the lowest value of LOI that indicates it is enriched in mafic minerals rather than felsic.

А

В

Figure 9 - (A) The selected major and trace element concentrations normalized to the primitive mantle after (McDonough and Sun, 1989)(B) Rareearth element concentrations, chondrite normalized after (McDonough and Sun, 1995) atterns for PAAS from Taylor and McLennan, 1985) and UCC from (McLennan, 2001) ave been plotted for comparison.

4.2.1.2. The Daguja area sandstone

The selected major and trace elements normalized to upper continental crust and shale, and chondritenormalized REE are plotted in (fig1). SiQ concentrations in the Daguja area range from 65.3, 76.5 wt. %. The relative enrichment of ${}_{2}\Theta_{B}$ (12.2, 13.95 wt. %, mean 12.97 wt. %), NaO (1.96 4.81 wt. %, mean 3.7 wt. %), and OK (1.014.1 wt. %, mean 2.28 wt. %) in this area, is possibly due to elevated levels of feldasp It is also, relatively, enriched in CaO (0.42-5.94 wt. %, mean 2.34 wt. %), De (1.27-3.09 wt. %, mean 1.91 wt. %), MgO (0-12 1.85 wt. %, mean 1.03 wt. %), T₂00.15 0.47 wt. %, mean 0.32 wt. %)₂ Θ_5 (0.04 0.17 wt. %, mean 0.09 wt. %), and Mn(0).02-0.11 wt. %, mean 0.05 wt. %) when compared with BokotaboSentom areaThe siltstone samples in this area are relatively enriched in CaQ. SiO Al₂O₃ ratio values of the studied samples range from 5.12 to 6.32. All samples show low CaO/ Al₂O₃ values (0.034 to 0.466), but relatively highhen compared with Bokotabertom area sandstones. All samples generally have low concentrations of (₹iOwt. %) which indicates low abundances of Tbiearing opaque minerals such as rutile (T-ab) Te be studied as mples show high contents of SiQand NaO and low in FgO3, Al2O3, MgO, and TiQ contents, when compared with UCC (Mclennan, 2001) and PAAS (Taylor and McLennan, 1985). Siltstone (sampled as SIT1) hashigher value of CaO (5.94%) and enriched in Obsecontent. The tillite (TIL1) has a higher value of KO (4.1%) than the UCC and PAAShich is mainly controlled by the presence of Keldspar (Kmica) (Wedepohl, 1978)

The SiQ concentration shows strong negative correlation with f_{20} , MnO, CaQ and P₂O₅, while Al₂O₃ and K₂O exhibit no correlation with SiQ(Table6). Al₂O₃ shows a strong negative correlation with MgO and TiO₂, a strong positive correlation with f_{20} , and weak positive correlation with NgO, and no correlation with CaO, f_{20} , Fe₂O₃, and SiO₂(fig-10). The enrichment of NgO (1.96 4.81 wt. %, average3.7%) in these samples can be attributed to a relatively higher amount of Ngich plagioclase in them. The f_{20} and NgO contents and their ratios (K₂O/Na₂O) in all samples are <1. The tillitensples are relatively enriched in f_{20} and K₂O content. All samples have correspondingly increased concentrations of trace elements (Zr, Th, Y, and REEs like La, Ce, Sm, Gd, Tabd Dy) (Table5).

All sandstone and siltstone samples have higher LOI value values, which is expected in felsic sediments, while the tillite has esser value (0.67%).

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Figure 10 - Multiple plots of Al₂O₃ against all major elements the Daguja area(A) Al₂O_{3vs} SiO₂, (B) Al₂O_{3vs} CaO, (C) Al₂O_{3vs} MgO, (D) Al₂O_{3vs} Na₂O, (E) Al₂O_{3vs} K₂O, (F) Al₂O_{3vs} TiO₂, (G) Al₂O_{3vs} P₂O₅, and (H) Al₂O_{3vs} Fe₂O₃; all major elements are measured by (w.%).

Large-ion lithophile elements: Rb, Sr and Csconcentrations in all samplessewell below the UCC values, whe all samplesenriched in Ba compared to the UCC except sandstone samples (SST1).Rb, Cs and Baconcentrations relatively enriched in the tilliteit while Sr enriched in siltstone samples Cs, Rb and Ba show a strong positive correlation with QI (Table 9). High field strength elements: Th, U, Y, Hf, Nb and Ta inall studied samples are well below UCC (fig-11-A). Sandstone sample (SST1) relatively enriched in elements such as Hf, Sm, and Zr, and depleted in Ga, and V (Table 5). Siltstone (SIT1) is elatively enriched in Y, V, Zrand Ta, while depleted in Th. And the tillite relatively enriched in Ga, and depleted in Zr, Sm, Y. Th shows a strong positive correlation with ΔD_3 (r=852818) and strong negative correlations with elements, such as Tj and Nb (r =-0.97709 and r=0.99785, respectively) (table).

Transition trace elements: All transition trace elementare depleted in the studied samples as compared to the UCC value. Sample SIT1 is enriched in Sc and Ni while the tillite is enriched in Cu (Table5). Strong negative correlations between Cu and Ni(74543) have been observed. Sc correlates strongly positive with Ti(7=0.827788) and correlates weakwith Al₂O₃ (r= - 0.20968), Zr (r=0.13618) and the REEs (r= 0.140108) (Table9).

Rare earth elements: The average total REE concentration R(EE) 87.34667 ppm, much lower than the average PAAS and UCC concentrations (Tabble I-normalized REE patterns are similar to the PAAS and UCC with enriched LREEs, flat HREEs-1(fleB). In all Daguja samples, Eu is well above the UCC values, extreeptilite unit sample which indicates NgO enrichment (fig11-B).

The (La/Yb)_N value, which describes the total slope of then Qilmalized REE trend, is higher than the PAAS(Taylor & McLennan, 1985) in all samples. The chondriteormalized (La/Sm) ratios which indicate the LREE enrichment in this samples from 2.53.1 and have an average of 2.9. The (Gd/Yh) values are range from 0.52.3 with average ratios of 1.94, hich indicate... at HREE pattern (Table

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Figure 11- (A) selected major and trace element concentrations normalized to the primitive mantle after (McDonough and Sun, 1989)(B) Rareearth element concentrations, chondrite noized after (McDonough and Sun, 1995)? atterns for PAAS from (Taylor and McLennan, 1985) nd UCC from (McLennan, 2001) ave been plotted for comparison.

Classification of the upper Paleozoicsandstones

The chemical classification of sandstone was psepdoby (Lindsey 1999) based on major elements (Table). Though, it is controversial to differentiate arkose and lithicarenite. Using the geochemical classification diagram (Refttijohn et al., 1972) the log (SiQ/Al₂O₃) vs. log (Na₂O/ K₂O), all siltstones and mudstone from BokotaSentom areaand tillite unit form Daguja areaare classified as arkosic, while sandstone and siltstone from Daguja areae classified as sub lithicarenite(fig-12). Based on the classification diagram (Herron, 1988) the log (SiQ/Al₂O₃) vs. log (FeO₃/K₂O), mudstone and andstone from BokotabeSentom arefall on Fesand field, while sandstone and siltstone and siltstones and tillite unit form bokotabeSentom arefall on Fesand field, while sandstone and siltstone and siltstones and field on tillite unit form bokotabeSentom arefall on Fesand field, while sandstone and siltstone and siltstones and field on tillite unit form bokotabeSentom arefall on Fesand field, while sandstone and siltstone from bokotabeSentom arefall on Fesand field, while sandstone and siltstone from bokotabeSentom arefall on Fesand field, while sandstone and siltstone from bokotabeSentom arefall on siltstones and tillite unit form bokotabeSentom bokotabeSentom arefall on Second field, while sandstone and siltstone from bokotabeSentom arefall on Second field, while sandstone and siltstone from bokotabeSentom arefall on Second field, while sandstone and siltstone from bokotabeSentom arefall on siltstones and tillite unit form bokotabeSentom arefall on Second field.

Classes	log (SiQ ₂ /Al ₂ O ₃)	log (K ₂ O/N ₂ O)	log ((Fe ₂ O ₃ +MgO)/(K ₂ O+Na ₂ O))
quartzarenite	>= 1.5	_	_
greywacke	> 1	< 0	_
Arkose(sub arkose)	< 1.5	>= 0	< 0
Lithic-arenite (subgraywack and protoquartzite)	>1.5	< 0	>0

Table 1Chemical classification of upper Paleozoiscandstonebased or (Lindesy, 1999)

Samples	Log (SiO ₂ /Al ₂ O ₃)	Log (K ₂ O/Na ₂ O)	Log ((F&O ₃ +MgO)/ (K ₂ O+N&O))	Chemical classification
SIT5(BOK)	0.86	-0.37	0.77	
				Arkose
SIT6(BOK)	0.84	-0.31	1.50	
				Arkose/Lithicarenite
SST5(BOK)	1.51	0.60	0.41	
				Quartzarenite
SST3(BOK)	1.49	-0.14	1.02	
				Arkose/Lithicarenite
SIT1(DAG)	0.71	-0.44	0.89	
				Arkose
SST1(DAG)	0.80	-0.29	0.16	
. ,				Arkose



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Figure 12- Geochemical classification (A) the log (SiQ/Al₂O₃) vs. log (NaO/ K₂O) (Pettijohn et al., 1972), (B) the log (SiQ/Al₂O₃) vs. log (FeO₃/K₂O) (Herron, 1988) for upper Paleozoic sandstone, in both Bok tabo Sentom and Daguja area.

The Al₂O₃/TiO₂ vs. (SiQ₂) plot of (Le Bas et al., 1986)was used to determine the sample whether is felsic or mafic in composition (fig 3A). The geochemical differences between elements such as Th and La (felsic igneous constant of and V, Sand Cr (mafic igneous sources indicator) are used ansindicator of contrasting felsic and mafic provenanceusing ternary plots such alsi-V-Th*10 plots (fig-13B) (Condie and Wronkiewicz, 1990)/cLennan and Taylor, 1991 and facciali et al., 2007).Based on both diagrammente upper Paleozoic sandstone in both sections is felsic in composition to the mafic field because it has higher amount of V.The granitoid boulders sampled from tillite have similar compositions to those in the granitoid which is underline the the tillite

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Figure 13, (A) The Al_2O_3/TiO_2 vs. (SiQ) relationship to determine whethepperPaleozoic sandstone is felsic or mafic (Le Bas et al., 1986)(B) Ternary Ni, V, Th*10 diagrams for source rock discrimination after (Bracciali et al., 2007)

4.2.2. Paleoclimate condition

- 4.2.2.1. Major Oxide€s climate proxies
 - 4.2.2.1.1. CIA, CIW , and PIA

Chemical weathering affects the meralogy of rocks and sediments that leads to affecting their major element composition. The degree of chemical weathering possibly acquirted by chemical index of alteration (CIA), plagioclase index of alteration (PIA), and chemical index of weathering(CIW) on a molecular basis of the major element oxides to evaluating how these processes have affected the rocks and sediments, propose by the advector of the track of the trac

$$CIA = \frac{1}{(1 + 1)^{n}} + 10 f \mathcal{D} f f f f. Equati \qquad on (1)$$

$$PIA = \frac{1}{(1 + 1)^{n}} + 10 \mathcal{D} f f f f f f Equation (2)$$

$$CIW = \frac{1}{(1 + 1)^{n}} + 10 \mathcal{D} f f f f f f f Equation (3)$$

CaO* represents CaO incorporated in silicate **nails**eand accepted when CaONa₂O (Fedo et al., 1995)CaO was low in all measured samples. Therefore, CaO* was considered as equal to CaOHigh CIA, PIA, and CIW values (7,5100) shows intensive weathering history in the source area, while low values (60 bess) indicate low weathering in the source area. The CIA CIW and PIA were calculated and presented in (Table

Bokotabo-Sentom area

The calculated CIA values for studied Bokotaßbentom samples range from 63.4 (sample SIT6) to 94.5 (sampleMST1), with an average of 3.9. The PIA values range from 52.1 (sample SIT6) to 89.7 (sampleMST1), with an average of 4.8. The CIW values range from 71.5 (sample SIT6) to 99.4 (sampleMST1) with an average of 1.0. The mudstone sample (MST1) has relatively the highest value of CIA, PIA, and CIW that shows the highest the mical weathering history. Wile the siltstone sample SIT6 has the lowest values of the lowest weathering history.

Daguja area

The CIA values for these samples are range from 60.5 (for tillit) to 78.3 (sample SST1), with an average value of 68.3. The PIA values range from 42.8 (for tillite unit) to 71.8 (sample SST1), with an average of 57.2. The CIW values range from 54.3 (sample SIT1) to 83.7 (sample SST1) with an average of 70.5. The tillite sample(TIL1) has the lowest value of CIA and PIA and CIW while the sandstone sam(355T1) has the highest value of CIA, CIVAIND PIA.

4.2.2.1.2. The A CN K diagram

Paleoweathering conditions can also be identified using the AI(CaO*+NaO) - K₂O (A-CN-K) ternary diagram of Nesbitt and Young (1984), where unweathered rocks are crowded together alongside the -feldsparplagioclase join (Nesbitt and Young, 1984; Holail and Moghazi, 1998) All the studied samples examined here in both area plot parallel to-Che A line (Fig-14). The Bokotao-Sentom sections show mediuton high weathering conditions while the Daguja section shows low to edium weathering conditions.

A bivariate plot of SiQ against total AlO₃+K₂O+NaO as proposed by Suttner and Dutta (1986) was used o classify the maturity of sandstone **Z**a(id and Al Gahtani, 2015) and all samples in both areas lie on seminid fields, except sandsto (SEST3) which lies on seminium fields (fig 15).

Figure 14 - A, CN, K ternary diagram $[Al_2O_3 - (CaO^* + N_2O), K_2O]$; for both study area Bokotabo Sentom area Daguja area af (blesbitt and Young, 1984).

Figure 15 Chemical maturity of the upper Paleozois and stones tated by bivariate plots of Si Ω Al₂O₃+K₂O+Na₂O after (Suttner and Dutta, 1986)

4.2.3 Tectonic setting

Based orthe Petrographic approacDickinson and Suczek (1979), and Dickinset al. (1983) worked on the relationship between sandstone compositions and tectonic setting. Dickinson and Suczek (1979) proposed that tectonic settings of depositional basins are recognized by plotting the detrital framework modes of sandstone suites QFL and QmFLt ternary diagrams (Dickinson and Suczek, 1979; Dickinson et al., 1983) QFL (Quartz-Feldspar, Lithics) diagram is grouped into three main fields that are representative of three different tectonic regimes, named: €continental block€magmatic arcs,• and €recycled orog€Dickinson et al., 1983),and plotted on (fig19-A). The QmFLt diagram is comparable to the QFL diagram, except that it plots exclusively monocrystalline quartz (Qm), and total lithics(Dickinson et al., 1983) and plotted on (fig19-B).

For selected major elements, trace elements and REEs, valuable comparison can be made with sandstones derived from known tectonic settings. Various authors have depicted that the effectiveness of major element geochemistry endingnentary rocks to identify tectonic setting based on discrimination diagramBhatia, 1983; Roser and Korsch, 1986) mstrong Altrin and Verma (2013) proposed two new discrimination functionsed diagrams fosiliciclastic sediments from 3 main tectorsettings; continental rift, arend collision. These diagrammere used to distinguish the tectonic setting of siliciclastic sediments by employing major elements and optimized for both low silica (35% to 63% SiQand high silica rocks (63% to 95% SiO₂). They are tested on NeogeOceaternary as well as Precambrian sediments with success rates of 75% to 100% Verma and Armstrong, 2013; Bassis, 2017) these diagrams, three different tectonic settings were considered: (1) €Ainded (Continental and occan island arcs), (2) €Collision•field (continental collision)and (3) €Rift•field (continental rifting leading to the development of passive margins and intratonic basins Verma and Armstrong, 20)1.3 The $([(SiO_2) = > 63 \% \text{ to } <=95 \%]$ sediments) and ksikica $(SiQ_2)adj =>35\%$ - <=63 %) sediments (Verma and Armstrong, 2013). excludes all samples with (Sigadi>95% and (Sig <35% as suggested by the originauthors (Verma and Armstrong, 2013) ince the silica content the upper Paleozois and stones is >= 65, high bilica sediment equations were used for this thesis. Samples with (Sigadi > 95 % are excluded, for the reason that they possibly characterize

relatively high analytical errors in the determination of the major eleméhesma and Armstrong, 2013).

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$$\begin{split} \mathsf{DF1}_{(\text{Arc-Rift-Col}) \,\text{ml}} &= (-0.263 \, ^* \,\text{ln} \,(\text{TiQ}_2/\text{SiQ}_2)_{\text{adj}}) \, + \, (0.604 \, ^* \text{ln} \,(\text{A}_2^{\text{L}}\text{O}_3^{\text{J}} \, \text{SiQ}_2)_{\text{adj}}) \, + \\ &\quad (-1.725 \, ^* \,\text{ln} \,(\text{F}_{\Theta} \text{O}_3^{\text{I}} \, \text{SiQ}_2)_{\text{adj}}) \, + \, (0.660 \, ^* \text{ln} \,(\text{MnO}/\text{SiQ})_{\text{adj}}) \, + \\ &\quad (2.191 \, ^* \,\text{ln} \,(\text{MgO}/\text{SiQ})_{\text{adj}}) \, + \, (0.144 \, ^* \text{ln} \,(\text{CaO}/\text{SiQ})_{\text{adj}}) \, + \\ &\quad (-1.304 \, ^* \,\text{ln} \,(\text{M}_2^{\text{O}}/\text{SiQ}_2)_{\text{adj}}) \, + \, (0.054 \, ^* \text{ln} \,(\text{K}_2^{\text{O}}/\text{SiQ}_2)_{\text{adj}}) \, + \\ &\quad (-0.330 \, ^* \,\text{ln} \,(\text{P}_2^{\text{O}_5}/\text{SiQ}_2)_{\text{adj}}) \, + \, (0.054 \, ^* \text{ln} \,(\text{K}_2^{\text{O}}/\text{SiQ}_2)_{\text{adj}}) \, + \\ &\quad (0.303 \, ^* \,\text{ln} \,(\text{P}_2^{\text{O}_5}/\text{SiQ}_2)_{\text{adj}}) \, + \, (1.064 \, ^* (\text{ln} \,\text{A}_2^{\text{O}}\text{O}_3/\text{SiQ}_2)_{\text{adj}}) \, + \\ &\quad (0.303 \, ^* \,\text{ln} \,(\text{F}_{\Theta} \text{O}_3^{\text{I}} \, \text{SiQ}_2)_{\text{adj}}) \, + \, (0.436 \, ^* (\text{ln} \,\text{MnO}/\text{SiQ})_{\text{adj}}) \, + \\ &\quad (0.838 \, ^* \,\text{ln} \,(\text{MgO}/\text{SiQ}_2)_{\text{adj}}) \, + \, (0.407 \, ^* (\text{ln} \,\text{CaO}/\text{SiQ})_{\text{adj}}) \, + \\ &\quad (1.021 \, ^* \,\text{ln} \,(\text{N}_2^{\text{O}}/\text{SiQ}_2)_{\text{adj}}) \, + \, (-0.407 \, ^* (\text{ln} \,\text{CaO}/\text{SiQ})_{\text{adj}}) \, + \\ &\quad (-0.126 \, ^* \,\text{ln} \,(\text{P}_2^{\text{O}_5}/\text{SiQ}_2)_{\text{adj}}) \, - 1.068 \, \end{split}$$

The subscript adj in (Signadj refers to the Signalue obtained after volatilities adjustment of the ten majorelements to 100 wt.%.

The tectonic setting discrimination diagram of Verma and Armst Addrign (2013) based on major oxide concentrations are plotted on -(fig). All samples form the Daguja area and SIT5 from the BokotaboSentom area plotted in the €continental rift• and all samples from BokotaboSentom area, except SIT5, plotted in the €ateded. In the tectonic discrimination diagram of (Roser and Korsch, 1986) ased on major oxides, all samplexcept mudstone, are allocated toan active margin setting (fig 7). A passive margin setting is distinct by silicarich sands (SiQ=70%) with (K₂O/Na₂O) ratio of more than unit (Bhatia, 1983) and FeO + MgO content of less than 5% Taylor and McLennan, 1985) Depend on these; mudstone from Sentom area is correlated with passive margin setting

Figure 16 Tectonic discriminant function diagrams fibre upper Paleozois and stone proposed by (Verma and Armstrong, 2013).

Figure 17 Tectonic setting discrimination diagrams based on majoresxARC- Oceanic island arc, AM- active continental margin, PApassive margin, afteR(oser andKorsch, 1986)

5. DISCUSSION

5.1.Implications for provenance

The most relevant features that are used to interpret the provenance of sandstone are the chemical corposition of the rocks, which helps to interpret source rock lithology and the direct observation of features (sedimentary structures and grain size and shape) in the transport 2009)

Sandstones with less abundant quartz and riched inunstable minera (lithics, feldspar) have resulted from short transport distances that will allow less stable materials (such as lithic fragments) to survive and get deposited ckinson et al., 1983; Johnsson, 1953 aight to slightly undulate extinction of monocryatiline quartz grains in the sampled thin sections point towardsthe granitic source (Pettijohnet al, 1987) Inclusions of heavy minesalike zircon and tourmaline in monocrystalline quarize the studied samplesirect evidence of the granitic source. However, some monocrystalline quartzis excluted these heavy mineral inclusions and shows slight undate extinction indicates that the source might be older gneiss or schist rocks (Pettijohn, 1975) Polycrystalline guartz with stretched grains and seat boundaries are derivate from metamorphic source, apparently schigeset, 1967; Folk, 1980)Therefore, the whole quartzanalysis in the studied samples points toward granitic and schistose provenance. Feldspar is more significant to offer infortion about primary source rocks composition than quartz because they are chemically and mechanically less stable and less likely to be recycled (Boggs, 2009)A high abundance of feldspars in the sampled thin sections proposed the origin from crystalline ocks (Folk, 1980) Microcline, in the studied sample indicates the origin of felsic igneous or metamorphic rock Boggs, 2009) According to Pittman (1963) unzoned plagioclase is to be likelyrom a metamorphic origin(Krainer & Spotl, 1989). Unzoned plagioclase in the sampled thin sections probably is sourced from the metamorphic rocks, such as slate he presence of microperthitic intergrowthis the sampled thin section uggestist sourcedfrom an igneous rockgranites(Folk 1980). The presence of zircon and rutile in the sampled thin section indicate an acid igneous sour (Pettijohn, et al., 1987) ased on feldspar in the studied samples the upper Paleozois and stone is feldspar rich arkosic lithology which indicates that local deposits deerd from low to medium grade metamorphic rocks (slate and schistose) and ranitic basement rock Pettijohn et al., 1972; Miall, 1984 Based on feldspar

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content,the upper Paleozoiscandstone is compositionally immature time Daguja area) to sub mature(in the BokotaboSentom area).

Rock fragments are also givintige best clue tothe provenance of rocks. The presence of siltstone and sandstone rock fragments in the sampled thin section indicates sedimentary origin, while, plutonic lithic fragment inclue clasts of quartz and feldspar are granitoid in origin. Clay minerals are excellent for provenance studies because individual clay minerals are typically formed by the weathering of particular bedrock type att 1985 Nichols, 2009. The presence of mica (muscovite and biotite) in the sampled thin section robably indicates lovgrade metamorphic rocks origins like schist, gne att granite (Ghazi, 2009).

According to the QFL triangular diagram (McBride, 1963), the classification of the upper Paleozoic sandstones is arkosic.

Figure 18 The QFL triangular diagram shows the classification the upper Paleozois and stones after (McBride, 1963).

The SiQ contents and SiQAI₂O₃ ratio and the alkali content (NQ+ K₂O) are the most used geochemical criteria for sedimentary maturity. They are reflecting the quantity of silica (quartz), clay, and feldspar contents of the state of SiO₂ and Al₂O₃, indicating that much of thei \mathfrak{G}_2 is present as quartz grainskarish and El Gohary, 2008; Ahmad and Chandra, 2018) enrichment signifies the abundance of feldspar and clay minerals which is related to lower maturAtypositive correlation of A_2O_3 with K_2O_3 and NaO indicates that AI distribution considerably influenced by the concentrations of the feldspars and suggests that the abundance of these elements is mostly controlled by plagioclase and Feldspabearing minerals such as clay mineral (mica and muscovite) concentrations (McLennan etal., 1983; Akarish and -Elohary, 2008)Al₂O₃ and K₂O concentration in the studied samples possibly associated with the presence feed spars (orthoclase and microcline), and mica. The relative enrichment of Na over K₂O in all samples can be attributed to a relatively higher amount of -Niah plagioclase in them, while depleted in mudstone due to relatively small amount of Naich plagioclase. The 1/O and NaO ratios (K₂O/N₂O) in all samples (except mudstone) are <1% that perhaps according to clase feldspar dominates over-feldspar. Some samples (typically, siltstonethe Daguja area) are relatively enriched in CaO which ossibly due to the presence of diagenetic calcite cement. Somesamples (typically, mudstone and siltstone) areched in FeO3 content that is possibly related to the abundance be oxide heavy minerals The geochemical classification diagram proposed by (Herron 1988) and (Pettijohn et al., 1972) shows that the upper Paleozoic sandstones are arkosindLithicarente. Based on the RN-K ternary diagram, all Formation in both areas was derived from plagioclassenitic-smectite source terrain. The Al₂O₃/TiO₂ vs. (SiO₂) ratios proposed b(Le Bas et al., 1986) ndTernary Ni, V, Th*10 diagrams(Bracciali et al., 2007) implies the whole the upper Paleozois and stone is felsic in composition. The tillite unit is enriched in AI that signifies the abundances of feldspar and clay minerals which is related to lower maturity. It has slightly higher amount of No than the KO indicates controlled by the presence of plagioclase thafeled spar (Kmica) (Wedepohl, 1978) The most important elements for provenance indiscatore REE, Sc, Th, and lesser Cr, Co. These elements are unaffected by diagenesis and metamorphismt bleie tow concentration in sea and river, and low residence time in the ocean and element ratios. Accondingly

reflect their source rock chemistr () (Ilinson, 199). Immobile elements such as Zr,, Hafnd Sc are possibly controlled by the distribution of heavy minerals and dispersed according to grain size. Co, Cr, Fe, Sand Tathat controlled by ferromagnesian mineralse low concentrations in the studied sample (Culler, 1988) Most formations (on average, mudstone in Sentom and sandstones in the Daguja area) have correspondingly increased concentrations of trace elements (Zr, Th, Y, and REEs like La, Ce, Sm, Gand Dy), which are indicative f heavy minerals like zircon.

The concentrations of Bach, and Cs are controlled by feldspar. The emieht of Ba and Rb in mudstone and siltstone is strongly influenced by the presence felds par and mica (biotite and muscovite) Strong positive correlation of Cs, Rb, Srand Ba with A2O3 in the studied samples show phyllosilicate (alay minerals and micas) as a controlling factor of LILE concentrations Etemad Saeed et al., 2011 The enrichment of LILEs in the upper Paleozoic sandstones is possibles a result of less weathering and metamorphic processes and controlled by K- feldspar and mica. As high field strength elementare incompatible and immobile elements, they arregood indicator of provenan@aylor and McLennan, 1985, Pb, Ti, and Zr enriched in most sandstones and mudstones that indicates felsic source rather than mafic rocks. Th sows strong positive correlations with elements, such as a right which indicates that it is possibly controlled by clays or -Tand Nb bearing phases associated with clay minerals. Sc correlates strongly positive with TagOhis may indicate heavy menals as controlling factors for Sc concentration (Etemad Saeed et al., 2011) he depletion of Sc, V, Co, Nand Cr in most samples is due to the depletion of mafic minerals in tthem ow concentration of these elements in the studied samples related to felsic provenance rather than mafic composition. Although rare earth elementare the least concentrad, they are an excellent indicator of provenance due to their immobility during weather indicLennan, 1989; Rollinson, 1993). Chondritenormalized patterns show moderate LREE enrichment and HREE segments. LREE enrichment indicates the sourcess felsic crust. Eu which is mostly incorporated in plagioclases relatively enriched in siltstones in both areas.

5.2.Implications for paleoclimate

Climate is one of the factors that has an intense impact on the composition and maturity of siliciclastic sediments and the climatic signatures are well preserved in the deposited sediments (Suttner and Dutta, 1986)

Based on Petrographic evidence, paleoclimateditions of the upper Paleozois and stone can be determined. For instance, less abundance of rounded quartz, grained feldspars and subangular grain sizes are related to a **townoderate degree of chemical weather** Besides angularities of quaz grainsand detrital components, textural immatuing icate the first cycle of erosion sediments or short distance of transportation before depositions which havea high amount of feldspar are immatu@sae et al., 2006 The high propertion of feldspar and the dominance of chemically unstable plagioclase ovields par in the upper Paleozoic sandstones suggest that the source was exposed to low to moderate weatheringAlmistory. abundance of unaltered feldspars and lithics in thesetstames suggested that it is sourced from moderate to high relief and rapid erosion and deposition in nearby basints evints ignificant alteration. Color also can givehelpful information on lithology, depositional environmenfor instance ferric irons frequently occuras the mineral hematited providea red color to the rock. Hematite formed under oxidizing conditions and these areften found within sediments originated undersemiarid environmentsMudrocks formed underthese environments (e.g., desers, lakes and rivers) are repeatedly reddened through hematite pigmentation he dominance of unstable grains (feldspar and other rock fragments) latigety low percentage of monocrystalline quartz (especially it he Daguja area), and the lest exation of feldspar grains implied that the source area experienced a shoat moderate period of chemical weathering(Pettijohn et al., 1987; Amireh, 1991).

The degree of chemical weathering can be achieved by calculation of the chemical index of alteration (CIA), plagioclase index of alteration (PIA), and chemical index of weathering (CIW) (Nesbitt and Young, 1982) hese CIA and PIA values indicate moderate degrees of weathering of the source, or during transport before deposition, which may réinistic stage recycling in semi-arid and semi-humid climate conditions in the source ar(elacclennan et al., 1993; Osea et al., 2006; Bakkiaraj et al., 2010) The studied sample (MST1 in Sentom and SST1 in the Daguja area) has the highest value of CIA, CIW and PIA which may indicate higher

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weathering history. The highest values of chemical proxiestime mudstone are due to high chemical weathering such as oxidizing he rest studied samples alues indicate low to moderate degrees of weathering of the seu Generally chemical weathering values the upper Paleozois and stone shows noderate to high weathering history in the Bokotabe Sentom area, and low tomoderate degrees of weathering in semiarid and semi-humid climate conditions in the source area or during transport (McLennan et al., 1993; Osea et al., 2006)

A, CN, K ternary diagram of molecular proportions of 2013- (CaO*+Na2O), K2O proposed by after (Nesbitt and Young, 1984) o determine the perto-weathering of the upper Paleozoic sandstone falls between plagioclags anite smectite fields. ACN-K- diagram shows low medium to high chemical weathering conditions in both areas. A bivariate plot of a state total Al₂O₃+K₂O+Na₂O as proposed by Suttner and Dutta., 1986) vas used to identify the maturity of the upper Paleozois andstone as note of climate. This plot show that the upper Paleozoic sandstones fall in the semantial climatic conditions exceptor sandstone from the Bokotabo Sentomarea which falls on semi-humid field.

The tillite unit has the lowest value of CIA and PIA that indicates low weathering history, or direct input of immature continent detrital minerals into the depositional system iaraj et al., 2010).

5.3.Implications for tectonic setting

A variety of ternary diagram Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Dickinson, 1985) were applied to construct the relationship between detrital mineralogy and tectonic setting. Sandstone compositione related to major provenance types such as stable cratons, basement uplifts, magmatic arcs, and recycled or Detakinson et al., 1983). Sandstones enriched in lithics and less abundant in quartz resulted from short transport distances that decrease physeil sediment sorting and chemical weathering and characterized by magmatic arc depositional system Dickinson et al., 1983; Johnsson, 1993).

The upper Paleozois and stone was plotted on the QFL and QmFLt ternary diagra (Deixide son et al., 1983) to interpret the tectonic discrimination source fiel(fig-19). In the QFL plot (Dickinson, 1985) the selected samples are plotted in transitional continental region of continental block provenance field bis indicates the detritus derived from transitional are between craton interiors and basement uplift masses. The detritus sediments derived from this field have intermediate compositions between craton (pure quartzose sand) and uplifted basement (arkosic sands). the QmFLt plot (Dickinson, 1985) most of the samples from the Daguja area, fall in basement uplift fields while most of the samplest free bookotabe Sentom area plotted inthe transitional continental region.

Figure 19 The QFL and QmFLtternary diagram fortectonic discrimination of the upper Paleozoic sandstonefter (Dickinson et al., 1985).

Different tectonic environments do have distinctive geochemicalsignature, therefore, geochemical data can be used to extract important environmental information froms sound that assign tectonic environmen(Maclennal et al., 1990; Rollinson, 1993) e, Mg, Ti, and Al are more abundation Arc-derived sediments rather than cratonic and recycled sediments. Most of the studied samples from both areas are enriched in Al FændSediments derived from transitional recycled sources are moderately enriched in the light rare earth elements (REE) and flat HREE slopes, without the pronounced flattening seen in other cratonic sediments. All studied samples from both areas show matterly enriched in the light rare earth elements (REE) and flat HREE slopes.

The discriminant function diagram which is used to evaluate the tectonic settithge for pper Paleozoics and stones suggests that upper Paleozois and stone possibly derived of the continental arc and continentalift. Based on major oxides, on active versus passive margin diagram of (Roser and Korsch, 1986) for any setting. Mudstone is derived from passive margin setting.

Comparision of the upper Paleozoicsandstone in Blue Nile Basin and Mekele Basin The upper Paleozoicsandstones it the Blue Nile Basin consist of tillite sandstone and siltstone, around the Daguja area and sandstone, silts to aned mudstone around the Bokotabe Sentom area. In Mekelle basin, it consists of tillite at the base overlain by laminate chold ysiltstones (Edaga Arbi Glacials) and basal tillite, a lower glaciogenic sandstone unit and an upper shallow marine sandstone unit (Entic Scandstone) Lewin et al., 201)8

The upper Paleozoiscandstone in Blue Nile Basin and Edaga Arbi Glacials in Mekele Basin has similarity in source composition and provenance, based on petrographic and geochemical results. Both show juvenile, crustal sources such as the Arabian Shield. The upper Paleozoic sandstones in the Blue Nile Basin are arkanse lithicarenite while subarkose to arkose in the Mekele Basin. Accessory minestabuch as zircon, tourmaline, rutile, gainethd opaque minerals are observed in both formation Both formations show ANa, and K enrichment that indicates a low maturity of the rock-lowever, there is a slight difference between their CIA values which indicates paleweathering and tectonic setting discrimination.seta on CIA value, the upper Paleozois and stones in the Blue Nile Basin show low to medition weathering history while the Mekele Basimas low weathering history. In the tectonic setting discrimination diagram of Verma and ArmstreAttrin (2013) based on major oxide concentrationsthe upper Paleozoiscandstones in the Blue Nile Basin shows €continental rift• and €arce while in the Mekele Basin it shows €continental rifter and €collisiteneds. In the active versus passive margin discrimination upper Paleozois and stones in the Blue Nile Basin are assigned in the passive margin setting with the Mekele Basin are assigned in the active and passive margin setting.

6. CONCLUSIONS AND RECOMMENDATION

Based on the petrological and geochemical analysist host upper Paleozoissand stones (Permo Carboniferous), the following conclusions can be drawn:

- ðŒThe upper Paleożco sandstone has a provenance transitional continental and basement uplift with a mixture of acid igneous, messædimentary and low-grade metamorphic rocks. It is compositionally immature to surbature and heabeen classified as arkosic and lithicarenitein composition. Additionally, some euhedral heavy minerals (zircon and tourmaline grains) show short transport distances. Therefore, it was derived hereon basement rocks nearby, possiblyeo-Proterozoic granitoid rocks and bw-grade metamorphic rock (ste and schist). Based dhe above statement and trace element geochemistry the Neoproterozoic basement of the nearby ANS is almost certifiely source.
- ð• The upper Paleozoiscandstone hassoderateto high weathering history in the Bokotabo Sentom area, ned low to moderate weathering history in the Daguja areaPaleoclimate data for the upper Paleozoiscandstone suggests seannid climate conditions for all sandstones in both aseand semihumid climate conditions for sandstone from the BokotaboSentom as a.
- ðŽ The tectonic setting discriminant diagram suggests that deposition of the sediments is in the continentalarc and continental rift fields. Based the active and passive diagraal, sediments are derived frothe active margin and mudstine is derived from the passive margin

Recommendation

Isotopic analysis (that reductive influence of sedimentary sorting on provenance studires) required to have a better understanding of the provenance, tectonic, settingaleeweathering history.

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<u>Appendix</u>

Table 2- Locations of the upper Paleozois and stones sampling sites and outcrompth GPS coordinate.

Sampl	LocationNorthingEasting Positio	nLithologycolor	size	considerable features
Mst1-s	eSnentom 1023.65237°01.72t2op	mudstonered	-	Laminated silty mudstone
SST2-	b Bkoko Tablo0°22.16377°00.82b7ottom	sandstonberown	medium	Soft, friable sandstone
SST3-	B koko Tablo [°] 22.23397°00.95b4ottom	sandstonwahite	coarse	Hard, massive Sandstone wi
SST4-	B koko Tablo ^{0°} 22.00357°01.19b6ottom	sandston e inkish v	vnhietoelium	Sandstone with muds
SST5-	b B koko Tablo0°23.07327°01.38t2op	sandston\#/hite	medium	Massive, hard sandstone
SST6-	senentom 10°23.88387°02.55t7op	sandstonwahite	fine	Slightly crumbled sandstone
SST8-	B koko Tablo ^{0°} 22.23307°00.96b4ottom	sandston e ale gre	emnedium	Hard Sandstone with speckle
SST9-	B koko Tablo [°] 22.29327 [°] 00.97b2ottom	sandstonwahite	coarse	Oxidized sandstone
SST10	5.e kn.tom 10°24.38827°00.77t2op	sandstonneed	coarse	Massive sandstone with sec
Sit2-b	B oko Tablo0°22.53317°00.99m6iddle	siltstoneDark red	fine	laminated Silty mudstone
Sit5-b	oµBoko Tablo0°22.73377°00.91m3iddle	siltstonewhite	coarse	Black and white lamination
Sit6-b	B oko Tablo°22.81317′°01.02mliddle	siltstonered	midium	laminated siltstone
SST1-	olpojaguja 10°18.92397°02.92t2op	sandston@ale pin∤	kcoarse	Massive, crumbled (soft) sa
SST2-	o∣Dogaguja 10°18.93327°02.93t9op	sandstonyeellow	fine	Massive hard
SST3-	o∣Dogaguja 10°18.69327°03.13t2op	sandstonberown	medium	Soft sandstone
Sit1-d	ajb)aguja 10°18.53327°03.07t2op	siltstonePale yell	omwedium	Hard sandstone
til1-da	gDaguja 10°18.54877°03.17mliddle	tillite pink	-	

Table 3 Point-counted data and the derived QFL indice **the**fupper Paleozois and stonezi (zirconium), tou (tourmaline), ru (rutile), gar (garnet), opx (orthopyroxene), hem (hematite), cal (calcite), mosc (muscovite), bio (biotite), sit (siltstone), sst (sandstone), FS (fine size), MS (medium size), CS (coarse size), PS (poorly sorted), MS (moderly tsorted), WS (well sorted).

		Quartz	(%)		Fel	dspar ((%)		Rock	Fragei	nt (%)	total ac	, U M	0.0	anmont	Doundo	Crain	Corti
Sampl	e MQ	ΡQ	Q-tot	al M	0	Plg	F-tota	SRF	MRF	PIRF	RF-to	tal	ПМ	Opt	, cement	Koulluli	Glain	30111
SST2-	bol&6.4	44.3	70.7	8.8		19.5	28.3	0.3		0.7	1	307	2zi,1tou,1ru	J 2	hem,musc,	csalibangu	l a rM S	ΡS
SST3-	bok42.9	27.2	70.1	6.4	1.9	19.1	27.4	0.8	0.3	_	1.1	357	2tou,1 ru	2	qrtz,hem,c	aslu b a n g u	larCS	WS
SST4-	bo189.9	23.5	63.4	6.4	0.77	25.6	32.77	0.26	2.8	_	3.06	391	3zi, 2tou	3	cal,hem	angula	r M.S	ΡS
SST5-	bok70.8	28.6	99.4	0.3	_	0.3	0.6	_	_	_	_	339	2zi,1tou,2ru	2	sit,sst	subroun	d MS	MS
SST6-	sen80.7	15.6	96.3	0.3	0.3	_	0.6	_	_	1.3	1.3	301	5zi,3tou,1ru	2	sit	subroun	ıd FS	ΡS
SST8-	bok41.7	23.4	65.1	7.4	0.5	23.7	31.6	0.5	_	_	0.5	393	3zi, 1ru,1tou,1	o p2x ,	2garqr,hem,ca	lsub ang	ulaMS	ΡS
SST9-	bok47.3	20.4	67.7	7.5	0.3	23.2	31	0.3	0.6	_	0.9	319	3zi,2tou,1ru,1	gâr	cal,musc,h	e snubang	ulaCS	MS
SST10	-b <i>ō</i> 16.1	23.3	99.4	0.3	_	0.3	0.6	_	_	_	_	305	4zi,3tou, 1ru	J 1	qr,sit,hem,	caslubrou	nd CS	MS
Sit2-b	ok50.7	11.1	61.8	3.7	3.4	24.4	31.5	2.3	3.4	_	5.7	353	6tou,1ru	1	cal, hem,bio	, manışını la i	r FS	ΡS
Sit5-b	ok36.8	20.2	57	5	3	29.5	37.5	_	2.7	_	2.7	302	5zi,2tou	1	musc,he,c	alangula	r CS	ΡS
Sit6-b	ok42.5	17.5	60	5.3	1	22	28.3	9.6	1.5	_	11.1	395	5zi,1tou	3	hem,musc,	caalngula	r M.S	ΡS
SST1-	daĝ7.6	31.1	48.7	15.4		26.7	42.1	5.3	3.8		9.1	318	1zi	_	hem,musc	subangu	larCS	MS
SST2-	daĝ1.9	35.3	57.2	11	3.5	22.2	36.7	2.1	4		6.1	374	5zi,3tou1ru	2	cal, hem	subangu	larFS	MS
SST3-	da@(9.5	30.7	60.2	14.2	1.8	21.1	37.1		2.7		2.7	332	1zi,4tou	_	cal,musc,	subangu	l a rM S	MS
Sit1-d	ag24.8	42.6	67.4	6.1	2.9	21.6	30.6		1.9		1.9	310	2zi,3tou,1ru,1	o p4 x	musc,cal	subangu	l a rM S	ΡS

Table 4- Major element composition with CIA, CIMand PIA values of Late Palaeozoic sandstones Element concentrations were measured-ACHS are given in weight%.

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SAMPL £ iO2	A 2 O 3	Fe2O3C	caO Mg	O Na20) K20	TiO2	MnO	P205	Sum %LO	I CI	A CI	W PI	A
SIT1(DAG)65.	3 12.7	75 3.09	5.94	1.11 4	1.81	1.73 0	.47 0	.11 0.	17 95.488	4.94	66.1	54.26	57.
SIT5(BOK) 80	11.	1 1.22	0.67	0.49 3	3.19	1.35 0	.22 0	.01 0.	02 98.272	2.84	68.06	74.2	59.
MST1(74.	6 14.0)5 4.37	0.05	0.14 (0.04	0.72 0	.75 0	.01 0.	18 94.918	5.15	94.55	99.36	89
SIT6(BOK)78.	7 11.2	25 1.98	0.34	0.13 4	1.14	2.01 0	.26 0	.050.	05 98.915	1.22	63.42	71.52	52.
SST1(DAG76.	5 12.	2 1.38	0.42	1.85 1	.96	1.01 0	.33 0	.03 0.	04 95.723	4.95	78.26	83.68	71.
SST5(BOK)96	3	0.41	0.02	0.040.0	1	0.04 0	.15 0	.01 0.	01 99.68	1.23	97.72	99.01	96.
SST3(BOK)95.	1 3.0	9 0.68	0.09	0.09 ().74	0.53 0	.11 0	.03 0.	01100.473	0.9	69.44	78.83	57.
TIL1(DAG)74.	8 13.9	95 1.27	0.66	0.12 4	1.33	4.1 0	.15 0	.020.	05 99.453	0.67	60.55	73.65	42.

Table 5-	Trace	elements	composition	of	Late	Palaeozoic	sandst &hes nent	concentrations	were
mæsure	d with I	CFMS and	ICPAES are g	jive	n in p	pm.			

SAMPLEEa Ce	Сr	Сs	Dу	Er	Eu	Ga	G d	Ηf	
SIT1(DAG)608	34.3	40	0.24	4.07	2.8	1.42	11.7	4.64	4.
SIT5(BOK)727	20.7	10	0.89	1.2	0.77	0.49	9.6	1.47	4.
MST1(536	104	50	1.17	6.73	3.58	1.96	15.6	8.82	9.
SIT6(BOK)607	19.5	30	0.31	1.65	1.11	0.68	10.5	2.01	3.
S S T 1 (D A G)2 9 8	47.1	10	0.64	3.1	1.61	1.36	11.4	4.33	6.
SST5(BOK)22.6	24.5	10	0.09	1.29	0.64	0.44	2.4	1.78	3.
S S T 3 (B O K1)8 8 . 5	18.2	10	0.21	0.81	0.51	0.34	2.3	1.16	2.
TIL1(DAG)914	14.7	10	2.46	1.36	0.88	0.33	13.9	1.24	2.
SAMPLEIo La	Lu	Nb	N d	Рr	Rb	Sm	Sn	Sr	
SIT1(DAG)0.81	17.7	0.34	5.9	19.6	4.68	34.9	4.37	3	3 1
SIT5(BOK)0.24	10.4	0.12	3.4	9.5	2.47	34.2	1.64	2	110
MST1(1.24	57.2	0.48	15.9	54.9	13.8	28.4	9.81	5	29
SIT6(BOK)0.36	11.3	0.2	3.5	11.2	2.78	39.6	2.01	2	14
S S T 1 (D A G) 0 . 6	28.5	0.23	5.7	28.1	7.05	25.5	5.59	2	53
SST5(BOK)).24	12.3	0.12	2.9	11.3	3.06	1.5	2.06	2	6.
SST3(BOK)0.16	9	0.06	1.8	8.6	2.13	11.6	1.63	1	27
TIL1(DAG)0.28	7.4	0.14	4.8	6.5	1.64	132.5	1.52	1	22
SAMPLEa Tb	Τh	Τm	U	V	W	Y	Υb	Z r	
SIT1(DAG)0.6	0.66	2.28	0.39	1.01	75	2	26.8	2.36	15
SIT5(BOK) 0.3	0.16	2.42	0.12	0.43	1 3< 1		6.3	0.85	17
MST1(1.1	1.2	12.7	0.51	2.2	67	3	30.2	3.4	33
SIT6(BOK) 0.4	0.25	2.1	0.18	0.65	38	1	9.8	3.4	12
S S T 1 (D A G) 0 . 4	0.57	3.35	0.24	0.74	17	1	15.7	3.4	28
SST5(BOK)0.2	0.22	2.64	0.12	0.6	6	1	6.8	3.4	13
S S T 3 (B O K) 0 . 3	0.14	1.46	0.08	0.2	12	1	4.1	3.4	8:
TIL1(DAG) 0.4	0.18	6.65	0.15	1.52	19	2	8.2	3.4	7 !

Table 6 -Values of Pearson,s coefficient of correlation of major elements oftuidized samples(A) for BokotabeSentom area, (B) for Daguja area.

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SiO2 TiO2 Al2O3 P2O5 Fe2O3K2O Na2O CaO MgO MnO Eu/I	Eu*(La/Yb)(NGd/Yl
SiO2 1	
TiO2 -0.73627 1	
A I 2 O 3 - 0 . 9 9 8 4 .17 5 9 9 1 6 1	
P2O5 -0.71020.99350.7299 1	
Fe2O3 -0.8140/1978666827584984261 1	A
K 2 O - 0.6750/104810/163630/505280/2225122 1	
Na2O -0.44466.2660.1404650.276907.10 <mark>508938</mark> 276 1	
[CaO - 0.43399.2192.1419996.28540.1410/695505814287 1	
[MgO - 0.45934.014064656450.1010.002.0444830653170.917079]	
Fu/Fu* -0.322-0.30369282402.20090.2010000240.20090.00000000000000000000000000	1
(la/Yb)N 582703060386 550670784430 0760 92120 93780 71796 44339 51966	90782 1
(Gd/Yb)N 390364330220 35440335316 18962 88746 98950 85756 58660 51766	99305932167 1
(La/Sm)N 25000 03701257126 09736 025022100 03262701605688865670 30950	2575.0 19860 24
	2070-0.10004.24
SiO2 TiO2 A12O3 P2O5 Fe2O3 K2O Na2O CaO N	/lgO MinO
SiO2 1	
TiO2 -0.74053 1	
AI2O3 0 0698-90 72214 1	
	В
Fe203 - 0.98 10.1856 820.26 207992 434 1	
K2O 0.1570907.78 <mark>002996</mark> 1488.227866.34569 1	
Na2O - 0.733080857936272404.682166.587202556533 1	
CaO -0,9940/2805590/17 19299950/9995 736/2576/4659394 1	
ΜαΟ 0.05800/6627 <mark>926.9918</mark> 201406713673-10.976-80.721630447	53 1
MgO 0.058026627 <mark>926.99</mark> 1820140671367340.97680.721630447	53 1

	Cs	Rb	Ва	Sr	Th	U	Y	Zr	Ηf	Nb	Та	Sc	Cu	Ni	SR E E	SLREE	SHREE
Cs		1															
Rb	0.5	63737	1														
Ва	0.7	01904.196	4581	1													
Sr	0.8	467 0 664	310.46	44501	1												
Th	0.7	6 6 2 6 .11 8	4 4 0 32	3 1 0 0 58 6	68211	1											
U	0.7	2 1 0 3 42 3	77032	5 3 5 603. 8	8900498	86112	1										
Y	0.7	4230929	2 6 9 83	0 1 6 0 49 1	8 3 6 49 8	3 5 1 809. 9	99531	1									
Zr	0.8	6 7 4 9 93 1	7 3 8 63	988 0 389	380/396	6 4 9 6 39	585 0 69	51539	1								
Ηf	0.8	6700731	04053	91404889) 4 3 Q 29 6	6 9 2 8 79	6060479	546 9 69	99787	1							
Nb	0.7	8 7 8 0 52 6	0 5 6 62	98204390) 5 1 Q .49 9	6 7 6 89	8 9 3 6 79 9	932 6 89	6 9 3 0 .19	73096	1						
Ta	0.7	742 0 434	65483	5540293	8 5 0 6 99 6	6 8 8 0 39	6 0 9 0 49	8 2 3 Ø 79	2 0 2 6 69	26007.79	81513	1					
Sc	0.7	653 2 366	3 2 6 .16 .	29607998	8780/583	310 0 78	764 9 59	0 3 1 502.8	3 5 3 208 8	523078	725 8 89	05855	1				
Cu	0	.85 8 .50	56 9 85	4 2 7 0 39 5	59104891	7 9 9 .19	4 3 1 6 .19 4	4 5 7 0 59	6 9 2 004. 9	667059	4060789	160 6 29	45984	1			
Ni	0.0	8300685	7 7 6 97	6 3 1 6 81 9)613 0 .3	8096 9 .	2224 6 .	176907.	1734 0 .	18380.	2331 6 .	1 4 2 0 22 (6 1 8 902. 0	5324	1		
SREE	0.7	46204218	18 0 22	1730/786	6 9 2 Q .19 9	8 5 8 99	856089	8769 2 .	95106.9	566 6 39	960 6 49	76204583	347605.9	081-50.3	30895	1	
SLREE	0.7	449405.1	742082	11104286	6 5 2 706. 9	986019	8 4 5 0 29 8	8 6 2 8 69	507069	5 5 9 6 49	954059	749 0 .182	2 9 9 205. 9	0 5 1-70 . 3	3 1 6 907. 9 9	996 1	
SHREE	0.7	5 8 4 0 22 9	0 5 6 93	0 6 4 6 .19 1	9 1 Q 29 8	8 9 0 6 49	929059	9 9 2 0 69	549 0 29	5 8 5 6 .19	9640298	368 2 88	981 0 994	4352 8 .	1 8 8 0 .19 9 1	3 6 5990	154 1

Table 7 - Values of Pearson,s coefficient of correlation tbe selected trace element of the studied samples

Table 8- Selected rates for the upper Paleozoiscand stones

SAMPLSEREE SL	REE SH	REESL	RESEH/REEu	/ E u * (L	a/Yb (N a	a/Sm()06J	d/YI
SIT5(BOK)50.1	46.7	3.5	13.5	1.0	8.3	4.0	1.
MST1(267.6	250.5	17.1	14.6	0.6	11.4	3.7	2.
SIT6(BOK)54.5	49.5	5.0	9.9	1.0	6.2	3.5	1.
SST3(BOK)#3.3	41.1	2.2	18.3	0.8	12.7	3.5	2.
SST5(BOK)58.8	55.4	3.4	16.5	0.7	11.5	3.8	2.
SIT1(DAG)94.9	83.5	11.4	7.3	1.7	5.1	2.5	0.
S S T 1 (D A G1)2 9 . 9	122.0	7.9	15.5	0.8	12.6	3.2	2.
TIL1(DAG)37.2	33.3	3.9	8.6	0.7	5.6	3.1	1.

Selected e	lemceonttelatio	on coe	Selected e	lem eot relation	ı coe
TiO2-Zr		0.972	TiO2-Zr	0.4	4308
T i O 2 - T h	A	0.985	TiO2-Th	B _ (0.977
T i O 2 - S c		0.934	TiO2-Sc	0	. 8 2 7
TiOSREE		0.925	TiO SREE	0.6	7148
A I 2 O 3 - V		0.575	A I 2 O 3 - V	- 0 . 1	798
Al2O3- La		0.419	Al2O3- La	-0.9	748
A12O3- Yb		-0.17	A12O3- Yb	0.0	3759
A I 2 O 3 R-E E		0.43	A I 2 O 3 R-E E	-0.9	975
Al2O3 -Th		0.64	Al2O3 -Th		0.85
A 2 O 3 - S c		0.879	A 2 O 3 - S c	- (0.209
A 2 O 3 - C s		0.763	A 2 O 3 - C s	0	. 8 8 5
A 2 O 3 - R b		0.794	A 2 O 3 - R b	0	. 972
A 2 O 3 - S r		0.870	A 2 O 3 - S r	0	. 4 8 2
A 2 O 3 - B a		0.821	A 2 O 3 - B a	0	.976
P 2 O § R E E		0.73	P 2 O § R E E	0.0	7133
Zr- La		0.908	Zr- La	0.9	9245
Zr-Yb		0.024	Zr-Yb	0.1	3618
Cr-V		0.954	Cr-V	0.9	9953
Th-Nb		0.918	Th-Nb	- (0.997

Table 9 - Linear correlation coefficients for selected lement distribution in the analyzed samples (A) for Bolotabo, Sentom area, (B) for Daguja area