ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL SCIENCES

SCHOOL OF EARTH SCIENCES

THE GEOLOGY AND GEOCHEMICAL CHARACTERIZATION OF TERCHA COAL, SOUTHWESTERN ETHIOPIA: INDICATION FOR ENERGY VALUE

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN EARTH SCIENCES (RESOURCE GEOLOGY, PETROLEUM AND COAL GEOLOGY).

TAKELE MENGISTIE MIHRETIE

Addis Ababa University, Addis Ababa, Ethiopia

May 2018

ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL SCIENCES

SCHOOL OF EARTH SCIENCES

THE GEOLOGY AND GEOCHEMICAL CHARACTERIZATION OF TERCHA COAL, SOUTHWESTERN ETHIOPIA: INDICATION FOR ENERGY VALUE

BY: TAKELE MENGISTIE MIHRETIE

MAY 2018

ADVISOR: BALEMWAL ATNAFU (PhD)

CO-ADVISOR: WORASH GETANEH (PhD)

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN EARTH SCIENCES (RESOURCE GEOLOGY, PETROLEUM AND COAL GEOLOGY).

May, 2018

Addis Ababa, Ethiopia

ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL SCIENCES

SCHOOL OF EARTH SCIENCES

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN EARTH SCIENCES (PETROLEUM AND COAL GEOLOGY).

By: TAKELE MENGISTIE MIHRETIE

College of Natural Sciences

School of Earth Sciences

Petroleum and Coal Geology stream

Approved by board of Examiners

Dr. Balemwal Atnafu	________________	________________
(Chairman)	signature	Date
Dr. Balemwal Atnafu	________________	________________
(Advisor)	signature	Date
Dr. Worash Getaneh	________________	________________
(Co-advisor)	signature	Date
Dr. Mulugeta Fessha	________________	________________
(Examiner)	signature	Date
Dr. Gilamichael Kidanemariam	________________	________________
(Examiner)	signature	Date

Declaration

This thesis is my original work and has not been presented for a degree in any other university and that all sources of material used for the thesis have been acknowledged duly.

____

Takele Mengistie Mihretie

College of Natural Sciences

School of Earth Sciences

Petroleum and Coal Geology stream

Approved by;

Dr. Balemwal Atenafu (Advisor)

____

Dr. Worash Getaneh (Co-advisor)

____

Abstract

Energy is critical input for different purposes. Present study deals with characterizing the energy of Tercha coal and its use. In countries, like Ethiopia, which imports almost all of their energy source, hydrocarbon, further analysis of known deposits and investigation of new area, like this, should forward in detail to decrease exchange rates, expand energy related accessibilities, factories, agricultural sector and others. The coal, in which this research conducted, is found in Southwestern Ethiopia, Dawro Zone, Tercha town approximately 550 Km distant from Addis Ababa. The geology of the area comprises two rock groups of Oligocene age; Igneous (trachyte, welded ignimbrite and volcanic glass units) and Sedimentary (mudstone, shale and coal units) rocks. NW and SE part of the study area is covered by volcanic rock while the sedimentary units are exposed along NE and SW part. The units are formed in two different swamps or lagoons. Different stratigraphic sections recorded in SW part of the study area are correlated litho-stratigraphically.

The main objective of this research is characterization of the physical and chemical properties of the coal in the perspective of its energy value for different economic scopes. The methods involved to achieve the objectives are desk studies about the area, fieldwork for mapping and sampling, laboratory analysis (Proximate, Ultimate, CV and TOC).

Four stratigraphic sections and Geological map (1:10,000) have been developed. The coal thickness in S1 and S2 stratigraphic sections, are very thin and dominated by clastic materials. The integrated analysis results confirmed that the coal which is found NE of the study area, is higher than other studied coal, in its rank (High Volatile B bituminous coal), best energy (steel-grade I) and, vitrinite and liptinite in maceral type in addition to that of it has considerable thickness. The coal which is found south of the study area, is subbituminous – bituminous in rank and Washery Grade IV in its energy value. Seam 1 and seam 4 are lowest in grade, rank and its energy value. From all studied samples, in general, the coal found southern and NE part of the study area have better quality for different economic purposes like; steam, coking, power generation, fertilizer production, in cement industry and chemical production.

Key Words: Tercha, Coal, Energy Value, Calorific Value

ACKNOWLEDGMENT

Before and above all everything I am honored when I thank the almighty God, who helped me throughout my life.

I thank my advisors Dr. Balemwal Atenafu and Dr. Worash Getaneh for their ensuing guidance, constructive inspect, constant inspiration, reviewing the thesis and providing useful comments throughout the research since the beginning.

I am thankful to Addis Ababa University, Woldia University and Geological Survey of Ethiopia, for the assistance I have received during my studies and/or research of the Master's Program. I am also greatly thankful to the Tercha town friendly people and Administration officers for their permission to do the fieldwork.

I really appreciate and thanks Fantahun, who helped me during fieldwork, for his kind support throughout my stay in Tercha. I thank all my friends (Getnet Gezahegn, Bahru Zinaye, Samuel Getachew, Abate Assen, Amdemichael Zafu, Ermias Filfilu, Million Alemayehu, Tadele Tessema, Tenaw Mengistie, Tadele Dagne, Biniyam Fentie and Teklu Bangu) for their day to day pursuit to accomplish the research.

Deepest gratitude to my family, my mother (Kerebesh Tesfay), my father (Mengistie Mihretie), siblings (Fantanesh Mengistie, Nebret Mengistie, Eyerus Mengistie, Yigermal Mengistie, Fiker Mengistie and Meron Mengistie), uncle (elderly Getachew Tesfay), sisters (Mesetewal Bitew, Alemtsehay Bitew, Birtukan Bitew and Hana Tesfahun), and Kins (Gizachew Belay, Tsegay Tamir, Misganaw Birhanu, Melkamu Sheferaw, Tsegaye Sheferaw, Yenework Limeneh and Fekadu Molalign). Great thanks are also for all other family and friends who constantly encouraged, helped and sustained me for my success. Great respect for all.

Table of Contents

List of Tables and Figures

Acronyms

ASTM – American Society for Testing Materials

CV – Calorific Value

DEM – Digital Elevation Model

FC – Fixed Carbon

GCF – Gross Calorific Value

GPS – Global Positioning System

ISO - International Organization for Standardization

LHV – Lower Heating Value

NCV – Net Calorific Value

TOC – Total Organic Carbon

UTM – Universal Transverse Mercator

VM – Volatile Matter

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Coal is a chemically and physically heterogeneous "combustible'' sedimentary rock consisting of both organic and inorganic material (Miller, 2005). It is an organic rock mostly enriched with carbon, with minor concentration of hydrogen, oxygen, sulfur and nitrogen along with few inorganic constituents, minerals, and water (Vassilev and Vassileva, 2009). It is a solid usually brown or black carbon-rich material that most often occurs in stratified sedimentary deposits (Curley, 2012). During and after deposition of plant remains in sedimentary basins the organic remains undergo a sequence of physical, biochemical and chemical changes (diagenesis and catagenesis), which results a series of coals. The series begins with unaltered plant material and peat which continues with increasing rank through brown coal, bituminous coal and finally to anthracite (Tissot and Welte, 1984). The transformation of vegetable matter into peat and then to coal is regarded as biochemical and physicochemical stage of coalification respectively (Stach et al., 1982).

The original plant (but can include animal) material has a vast morphological and chemical variety even before being incorporated into the peat. After plant materials deposited, a range of biochemical processes take place (peatification), which considerably alter the morphological, physical and chemical nature of the existing organic material with introducing new materials, precipitates. Finally, through humification, burial diagenesis (coalification) with increasing temperature has a significant effect on all the individual particles and on the coal as a whole (Scott, 2002).

The coal deposits have specific plant precursors that are marked by the regional history followed by depositional condition. This causes enrichment or depletion of different elements, phases or minerals that giving rise to a unique fundamental code which characterizes a coal. The mineral composition and association between mineral matter and organic matter mark the genetic code. Then, the composition can be interpreted to infer the type, quality, and genesis of a coal (Vassilev and Vassileva, 2009).

Therefore, the geochemistry of coal deals with the origin, evolution and environmental effects of organic and inorganic substances in the coal. The geochemistry also deals the formation, evolution and appraisal of the mineral deposits relating to coal (Zeng, 2009). Coal is characterized into four main ranks; lignite, sub-bituminous, bituminous and anthracite. These different types of coals had a certain set of physical and chemical characteristics distinguished by different approaches including; proximate, ultimate, total organic carbon (TOC), calorific value (CV) and maceral analysis.

The proximate analysis of a coal determines moisture, volatile matter (VM), ash and fixed carbon (FC). The ultimate analysis is the chemical approach to characterize coals according to the amount of principal chemical elements as carbon, hydrogen, oxygen, nitrogen and sulfur (Rasheed et al., 2015). The TOC is the amount of organic matter present in the unit and CV indicate the energy value in the coal whereas the maceral analysis is the petrography approach to identify the maceral types.

1.2 General Information about the Study Area

1.2.1 Location and Accessibility

The study area is found in southern nation's nationalities and peoples region (SNNPR), Dawro zone in and around Tercha town. It is bounded by Shata river in the NW, Shata and Tabeno in the SW and Zo-A in the NE and SE. The study area is located 507kms southwest of Addis Ababa to Jimma and then to Tercha. It is accessed through Addis Ababa –Jimma asphalt road and extends further southeast of Jimma to Tercha gravel road. There are further local gravel road and foot trials which connect rural local peoples from their home area to the town. This helps to search and easily access possible exposures far from the main road (Fig. 1.1).

According to the Geological Survey of Ethiopia, the area lies on Jima map sheet, typically in Waka sub sheet. Geographically, the area is bounded by the coordinates of (295000-305000) m Easting and (785000 -793000) m Northing that covers approximately 80 Km^2.

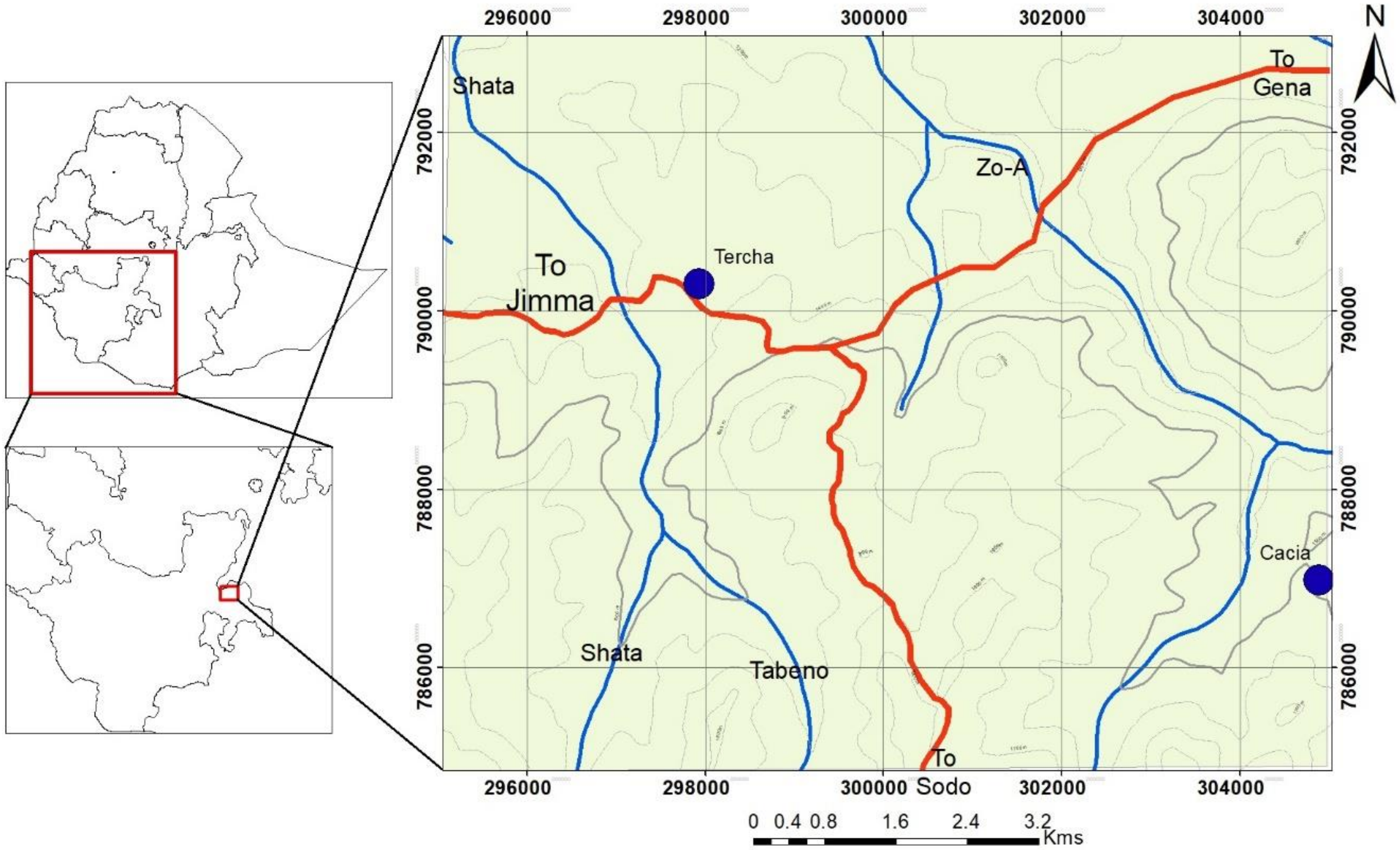


Fig. 1.1 Location and Accessibility map of the study area.

1.2.2 Physiography and Drainage Patteren

The study area is found in southwestern Ethiopia nearby the western flank of Main Ethiopia Rift. It is dominated by rugged topography with desiccated gorges, minor flat land and multiple ridges including Sheba, Bodi Ara, Gulale Agara, Ando and Dud Mountain. Extensive fracturing in Early Cenozoic rocks and major displacement along the fracture zones in the Late Tertiary, together with widespread volcanism, determined the forms of landscapes in the southwestern Plateau of Ethiopia (Mohr, 1962). The elevation of the study area ranges from 1200m to 1800m above mean sea level as shown in Fig. 1.2.

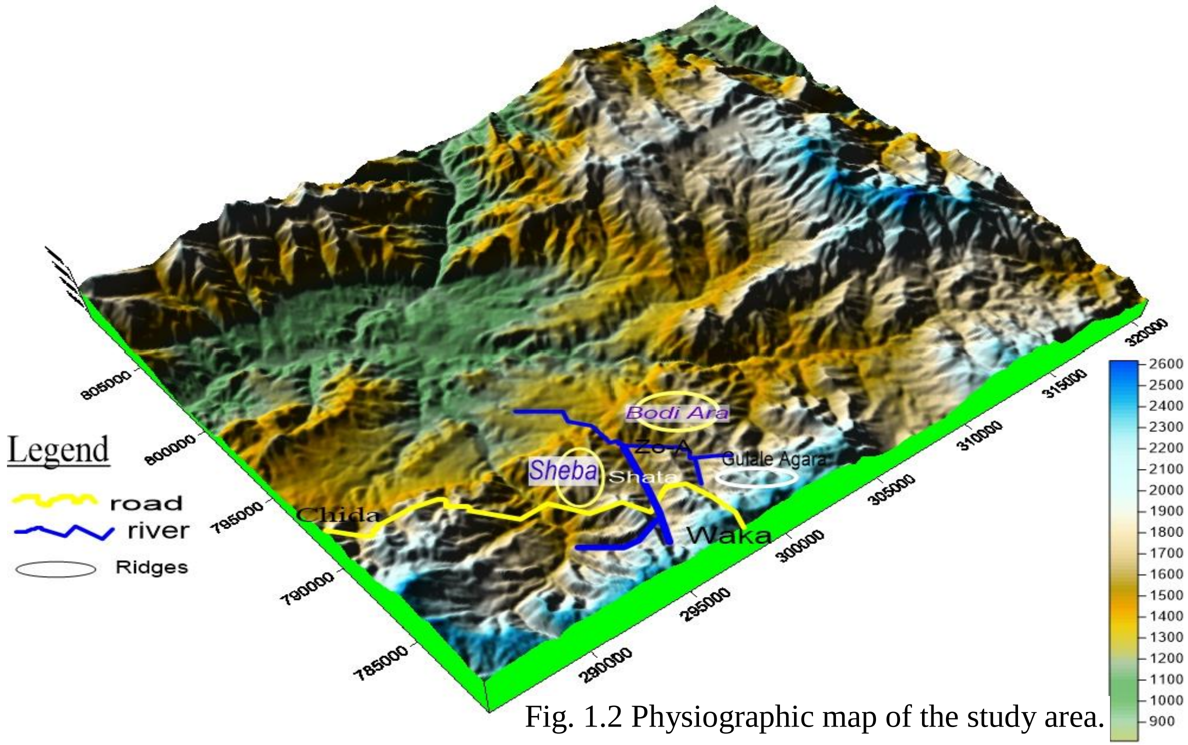


Fig. 1.2 Physiographic map of the study area.

The study area is located in between different ridges composed of volcanic rocks that have high resistance of weathering. Hence, the flow of water is mainly controlled by the ridges. The drainage pattern shows dendritic feature (Fig. 1.3). The two main rivers, Zo-A and Shata, are the major ones that have a number of tributaries. Most tributaries are intermittent.

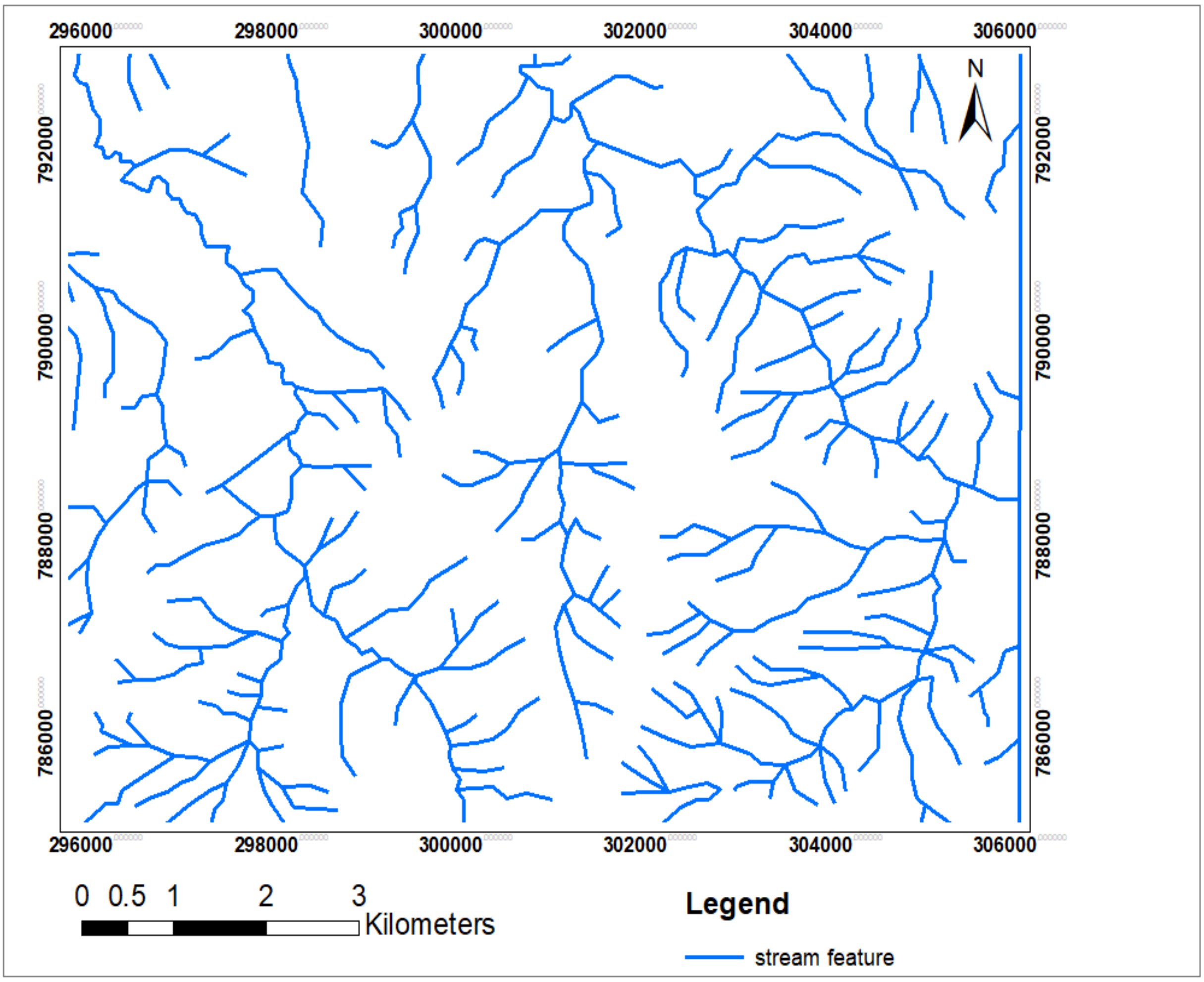


Fig. 1.3 Drainage map of the study area.

1.2.3 Climatic Condition and Vegetation Coverage

The study area receives rainfall almost throughout the year, for 9 months**.** Heavy rain comes between June and September. The mean annual rainfall is 1705.4mm at Gasa Chere Station while 1424.9mm at Tercha station. The maximum and minimum mean annual temperature is (22.3^{0}C and 12.4 ^{0}C) and (29.3^{0}C and 16.8^{0}C) in Gasa Chere and Tercha stations respectively (Mathewos et al., 2013). Based on the 18 recently classified agroecological zones, the area consists of sub-humid types of agroecological zones containing deciduous woodland with elevation 550 – 2820 meter having *Boswellia papyrifera*, *Combretum mole, Terminalia browni, Acacia senegal, Balanites aegyptica, Lannea fruticose* and other varities along the Omo and Gojeb river valleys (Engedasew Andarge et al., 2014).

The major economic activity of the people in the study area is mixed agriculture, rearing of animals and growing of crops. The main food crops grown in the area are enset, maize, taro, sweet potato, sorghum, millet, teff, pulses and yam. Dawuro is a naturally gifted land with rugged topography, diverse climate and varied ecology. The ecology is home to a wide range of fauna and flora diversity in wildlife and botanical resources. The fauna includes vertebrates such as reptiles, mammals, birds, bee, snake, insects and domestic animals while the flora diversities are kosso, korerima, timez, gesho and others (Tamirat Solomon et al., 2014). The Chebera-Churichura national park is a natural habitat for many wild animals in Dawro zone. The forests are the basis for the lives of respondent households through provision of different goods and services **(**Engedasew Andarge et al., 2014).

1.2.4 Population and Settlement

According to the Central Statistical Agency of Ethiopia (CSA) (2007) Census Dawro zone has a total population of 489,577. Out of this 249,263 men and 240,314 women live in an area of 4,814.52 Km^2. This zone has a population density of 101.69 per Km^2. While 7.16% (35,044) are urban inhabitants, a further 14 individuals are pastoralists. A total of 89,915 households are counted in this Zone, which results in an average of 5.44 % to a household, and 86,642 housing units. There are two largest ethnic groups which include the Dawro (97.32%), and the Hadiya (1.3%); all other ethnic groups are 1.38% of the population.

Dawurtsho is spoken as a first language by 97.44% of the inhabitants, and 1.3% speak Hadiya. The remaining 1.26% people spoke their primary language. The peoples in this Zone follows different religions; Protestants, Orthodox, traditional religions and Catholicism. Dawro is one of the ethnic groups in Ethiopia that uses its own character set of the Ethiopic syllabary (CSA, 2007). In center of the study area, Tercha town in this Zone, there are small villages found around the vicinity. The population settlement in these small villages is low relative to the town.

1.3 Statement of the Problem, Expected Outcome and Research Relevance

Fossil fuel is indeed one of the critical and very basic entity in different aspects like industry, agriculture, mining, construction, transportation and verities of service-giving organizations in the world. This is not only for economic development but also to progress the day to day human survival activities. For a long period of time the need of domestic fuel in the country, Ethiopia, is the major factor which triggers deforestation that cause soil degradation later. In addition, to increase the supplement amount of this resource for different industries like cement industry, agriculture sector, steel factory and chemical industries to reduce the currency that is paid for importing such needs. The country, like Ethiopia, which import much of this inputs gets loss of much economy. In this regard, detailed geological investigations on available energy resources can contribute a great deal to solve the problem.

Further investigations and researches (e.g. Getaneh and Saxena, 1984; Getahun Belay et al., 1993; Kibre and Gashawbeza, 1997; Wolela Ahmed, 2006, 2007, 2008) conducted up to now inferred that inter-trappean coal and oil shale deposits are distributed on the South-Western and Central Plateau of Ethiopia (Delbi-Moye, Yayu, Lalo-Sapo, Sola and Chida, Chilga, Nejo, Mush Valley Basins). The coal found in those areas is characterized in terms of CV, proximate and ultimate analysis, sedimentology, palynology, depositional environment, mapping the surface and subsurface of the resource, structural orientation and relative position using geophysical methods and drilling (Getaneh and Saxena, 1984; Getahun Belay et al., 1993; Wolela Ahmed, 2007, 2008).

According to Workineh Haro et al. (2012) report, there is coal resource along NE direction of Tercha at Bodi Ara locality. However the resource is not yet investigated in any one of such analysis except its occurrence. Therefore, this research is designed to investigate the coal deposit in detail and present data on the coal including TOC, CV, proximate and ultimate analysis. Then the rank, grade, energy and the utility scope in which such coal is used for will be described in detail.

1.4 Objectives of the Study

1.4.1 General Objective

The main objective of this research is characterization of the physical and chemical properties of the coal resource found around Tercha area in Southern Nations Nationalities and Peoples region of Ethiopia.

1.4.2 Specific Objectives

The specific objectives of the research are;

- ✓ Preparing geological map of the study area.
- ✓ Assessing the Proximate and ultimate analysis of the coal.
- ✓ Quantifying TOC value.
- ✓ Determining the type, rank and Grade of the coal.
- ✓ Estimate the coal resource in the area.

CHAPTER TWO

2. LITRATURE REVIEW AND REGIONAL GEOLOGY

2.1 Literature Review

2.1.1 Coalification

Coal is an organic sedimentary rock which contains carbon, hydrogen, nitrogen, oxygen and sulfur as well as trace amounts of other elements including mineral matter in varying amount (van Krevelen, 1961; Gluskoter, 1975; Speight, 1994; Miller, 2005; ASTM D-121). It is a solid, brittle and combustible carbonaceous rock formed as a result of the accumulation (in a specialized environment), decomposition and chemical alteration of vegetation debris by compaction and temperature over geologic time (Thomas, 2013; Speight, 2004). The depth, temperature, degree of acidity and natural movement of water in the original swamp are important factors in the formation of coal (Mitchell, 1997; Van Krevelen, 1993).

For the accumulation of the vegetal matter which eventually gives rise to coal seams there are two main theories (Moor, 1922; as cited in Miller, 2005). The first theory, the one most accepted as it explains the origin of most coals, says the coal originated and formed from in situ peat bogs (i.e, where the vegetation grew and fell), is said to be autochthonous (Fettweiss, 1979; Miller, 2005). Some coals appear to have been formed allochthonously, which is the second theory. This is through the accumulation of vegetal matter and fragments of plants that has been transported by water and deposited on the bottom of the sea or in lakes. These, wherein they deposited and build up strata, later becomes compressed into solid rock (Miller, 2005). Allochthonous formation is possible only under the additional prerequisite of a transport under non-oxidizing conditions between the places of plant growth and those of the deposition (Fettweis, 1979).

Coalification is the process of chemical and physical change by biochemical interferences, temperature, pressure and time imposed on the organic components that survived the peat formation until it becomes organic rock (Tissot and Welte, 1984; Miller, 2005). The change includes decaying of the vegetation, deposition and burying by sedimentation, compaction, and transformation from a plant material to a solid rock. It is continued initially biochemically and then very complex geochemical process continues (Fettweis, 1979).

Geochemically, the process consisting of three steps: the microbiological degradation of the cellulose of the initial plant material, the conversion of the lignin of the plants into humic substances, and the condensation of these humic substances into larger coal molecules (Miller, 2005; Tissot and Welte, 1984). Coal has different physical and chemical properties which can be related with various factors which in turn reflects the quality and grade of the deposit. According to World Coal Institute (2001) temperature, pressure, the length of time in formation (organic maturity), kind of decaying vegetation, conditions of decay, depositional environment and movements of the Earth's crust are important factors in determining the nature, quality and relative position of the coal seams. Different rank and structurally complicated coals are formed hence accumulations have been affected by syn- and post-sedimentary influences, variations in the environments of deposition, differences in the kinds of the original plant material (coal type), degree of coalification (coal rank) and range of impurities (coal grade) (Thomas, 2013; Curley, 2012; Schobert, 1987; Van Krevelen, 1993). There is also considerable diversity due to the differing climatic and botanical conditions that existed during the main coal-forming periods along with subsequent geophysical actions (Miller, 2005).

Major coal deposits are formed in geological period since the Upper Carboniferous Period, 350 to 270 million years ago (Miller, 2005). In the geological periods (Carboniferous, Cretaceous, Paleogene and Neogene Periods) the episodes of coal development are given together with the principal coal occurrences worldwide (Thomas, 2013). Coal deposits are known to have been formed more than 400 million years ago even most anthracite and bituminous coals occur within the 299 to 359.2 million-year-old strata of the Carboniferous Period, the so-called first coal age. The formation of coal deposits continued through the Permian, Triassic, and Jurassic periods into the "second coal age", which includes the Cretaceous, Paleogene, and Neogene periods. Coals of the Cretaceous Period, 145.5 million to 65.5 million years ago, are generally in the high- volatile to medium-volatile bituminous ranks. Cenozoic coals, formed less than 65.5 million years ago, are predominantly of the subbituminous and lignitic ranks (Curley, 2012).

2.1.2 Coal Petrography

The particles of organic matter, optically homogeneous, discrete and microscopic constituents of the organic fraction, are inherited from the remains of the original plant parts called as "macerals" (Miller, 2005; Karr, 1978). They are the building blocks of coals analogous to minerals of rocks. Maceral composition and petrography-based parameters are used for the identification of the original plant part, which result individual maceral types. This helps in many studies on coal deposits for the characterization of the depositional environment, in determining coal quality and the peatification of land plant material (Bechtel et al., 2003; Bechtel et al., 2014; Calder et al., 1991; Diessel, 1986; Kalkreuth et al., 1991; Karayigit et al., 2015; Markic and Sachsenhofer, 1997; Petersen and Ratanasthien, 2011; Stock et al., 2016; Miller, 2005). Macerals are classified into three major groups on the basis of source material (woody versus non woody tissues), morphology, nature of formation (biochemical degradation versus charring by fire), similarity in chemical composition, internal structures, level of reflectivity and degree of coalification (Karr, 1978). The composition can be interpreted to infer type, properties, quality and genesis of coal (Vassilev and Vassileva, 2009).

Because of the unique properties of the coal that sometimes formed from putrefying marine biota or massive accumulations of plant spores and pollen grains in lakes or open offshore waters, coal type is also described as humic and sapropelic. Humic coals are developed from terrestrial plant debris that was at least transiently exposed to the atmosphere and consequently passed through a recognizable peat stage (Francis, 1961). Sapropelic coals (or sapropels), resulted from plankton, algae, and/or terrestrial vegetation by putrefaction in entirely anaerobic lacustrine or shallow marine environments (Berkowitz, 1979).

2.1.2.1 Macerals Group

There are three major maceral groups found in coal which can be identified by petrography approach. This includes vitrinite, liptinite (exinite) and inertinites. Vitrinites are coalified woody tissues and the most abundant and important maceral in coals which is derived from stems, roots, and vascular tissues of leaves. They accounting for the major percentage of any given coal bed or coal seam with the exception of some Gondwanaland coals and certain cannel/boghead coals (Karr, 1978). Because of their reflectivity and composition, vitrinite group is subdivided into collinite, tellinite and vitrodetrinite. Vitrodetrinite is used to designate a maceral when the type challenges to distinguish between collinite and tellinite (Berkowitz, 1979).

The macerals of the liptinite group are derived from resinous and waxy material of plants (resins, cuticles, spore and pollen exines) and algal remains (resinite, cutinite, sporonite and alginate). Liptinites appear to be light to dark yellow in transmitted light and dark gray to gray in incident light. Liptinites have the highest hydrogen content among all macerals (Karr, 1978). Depending on refelectivity and composition types liptinite group is subdivided into sporinite, cutinite, resinite, alginite and liptodetrinite. Liptodetrinite is used when it is impossible to differentiate between sporinite and cutinite on morphological grounds (Berkowitz, 1979).

Inertinites are a group of macerals that are opaque to transmitted light and bright to extremely bright in incident light. It is thought that they are derived from charring of plant tissues in which certain inertinites may also be the result of intensive biochemical processes (Teichmüller and Teichmüller, 1966). Depending on their shape, size, degree of preservation of cellular structure and intensity of charring inertinites are subdivided into fusinite, semifusinite, macrinite, micrinite, sclerotinite and inertodetrinite (Teichmüller and Teichmüller, 1966).

2.1.3 Geochemical Variability, Classification and Utilization of Coal

2.1.3.1 Geochemical Variability in Coal

Compositionally coal is mostly enriched with carbon, making up 50 - 95%, with minor concentration of hydrogen, oxygen, sulfur and nitrogen along with few inorganic constituents and water (Rasheed et al., 2015). In most coals, in addition to the main constituents of the organic matter, trace elements occur in minor amounts which are derived from the original plants. However, the majority is implaced either during the initial stage of coalification or during the second stage of coalification. During the initial phase these are introduced by wind or water to the swamp whereas in the second stage those becomes after consolidation of the coal by movement of solutions in cracks, fissures and cavities (Miller, 2005).

These elements (e.g. heavy metals including arsenic and mercury) are either concentrated within the minerals or disseminated within macerals (Speight, 2004; Serendin and Dai, 2012; Serendin and Finkelman, 2008). Their presence plays an important role in terms of coal processability, but also causes environmental hazards, during coal production, processing and utilization (Dai et al., 2012; Conko et al., 2013; Panov et al., 1999; Speight, 2005; Swaine, 1990).

Coal also contains low levels of uranium, thorium and other naturally occurring radioactive isotopes. But, their release into the environment may lead to radioactive contamination. Although these substances are trace impurities, when a great deal of coal is burned, releasing significant amounts of these substances (Speight, 2004).

Three analyses are used in classifying coal, two of which are chemical analyses and one is a calorific determination. These analyses do not yield any information on coal structure but do provide important information on the coal behavior and are used in the marketing of coals. The chemical analyses include proximate and ultimate analysis. The proximate analysis gives the relative amounts of moisture, volatile matter, ash (i.e., inorganic material left after all the combustible matter has been burned off), and, indirectly, the fixed carbon content of the coal. The ultimate analysis gives the amounts of carbon, hydrogen, nitrogen, sulfur and oxygen comprising the coal. The third important analysis, the calorific value, also known as heating value, is a measure of the amount of energy that a given quantity of coal will produce when burned (Miller, 2005).

For most coals containing 90% or less carbon, the hydrogen content is generally in the range of 5% and it drops to nearly 2% for coals having 95% carbon. The nitrogen content of almost all coals is in the range of 1 - 2%. The oxygen content is inversely related to carbon for instance, the coals of 65% carbon, may contain 30% oxygen, while coals of 95% carbon may contain only 2 -3 % oxygen. Sulfur content of coal is seen to be less variable (Rasheed et al., 2015).

2.1.3.2 Classification and Utilization of Coal

2.1.3.2.1 Coal Classification

Coal classification is the grouping of different coals according to certain qualities or properties such as; coal type, rank, carbon–hydrogen ratio and volatile matter (Speight, 2004). Mostly, coal producing countries, importers and exporters, coals are classified according to ASTM standard. These standard need the calorific value and a proximate analysis (moisture, ash, volatile matter, and fixed carbon by difference) of a coal. To calculate these values to different basis (as received (ar), air dried (ad), dry (d), Dry ash free (daf) and dry mineral-matter-free (dmmf) basis), the Parr formulas are used American Society for Testing Materials (ASTM D-388) (Speight, 2004; Miller, 2005).

2.1.3.2.2 Utilization of Coal

Originally coal was used as a source of heat and power in homes and industries (Fettweiss, 1979; Miller, 2005; Thomas, 2013). It accounts for 29% of the world's consumption of primary energy and, importantly, provides fuel for the generation of around 42% of the world's electricity (Thomas, 2013). The use of coal as an energy source has been known from ancient times, although it was a minor resource until the Industrial Revolution (Miller, 2005). As it is one of the most important of the primary fossil fuels, coal can be used as a source of energy, a chemical feedstock from which numerous synthetic compounds (e.g., dyes, oils, waxes, pharmaceuticals, and pesticides) can be derived and in the production of coke for metallurgical processes (Curley, 2012).

The principal uses of traded coals worldwide is for electricity generation and steel manufacture, with other industrial users and domestic consumption making up the remainder (Thomas, 2013). Coal finds most of its use in combustion or in conversion into useful solid, gaseous, and liquid products. By far the most important use of coal is in combustion, mainly to provide heat to the boilers of electric power plants, metallurgical coke is the major product of coal conversion. The uses for coal did not stop with coking and solid fuel combustion which then continues up to gases released from the coal during the coking process. This gases could be burned, which in turn led to the establishment of the manufactured gas industry to exploit the illuminating power of coal gas (Thomas, 2013).

Additionally, gaseous and liquid fuels produced through gasification and liquefaction can be transported (e.g., by pipeline) and conveniently stored in tanks (Curley, 2012). Further to techniques for gasifying and liquefying coal into fuels or into feedstocks for the chemical industry are well developed but their commercial viability depends on the availability and price of the competing fossil fuels, petroleum and natural gas (Curley, 2012).

2.1.4 Resource Classification and Reserve Estimation

Coal resources categories range from the general evaluation of a coal basin to the calculation of specific reserves located within mine workings. The final result of geological investigation of a coal deposit will be to calculate all categories of coal resources (Thomas, 2013). Different countries have their standard for the classification of coal resource and reserve. But, a committee of the Council of Mining and Metallurgical Institutions of different countries use a provisional agreement for the use of standard definitions and method of calculation for mineral resources (inferred, indicated and measured) and ore reserves (probable, proven and marketable) which is approved by Combined Reserves International Reporting Standards Committee (CRIRSCO), (1998).

The basic formula to calculate coal resources is (for each defined resource/reserve block):

Coal thickness (m) × area × RD = total metric tonnes,

Where, RD stands for relative density.

2.2 Regional Geology

The Main Ethiopian Rift bordering Southwestern Ethiopia plateau consists of thick succession of flood basalts, alkaline to tholeiitic in composition, and lower amounts of rhyolites emplaced during Eocene to Middle Miocene (Woldegabriel et al., 1991). Trachybasalt and rhyolites which cover most part of the southwestern Ethiopia is collectively named as Jimma volcanics (Merla et al., 1979). These are considered analogues with the main sequence provided by Davidson (1983). These forms a thick successions of basalt and felsic rocks with basalt dominating the lower part of most section (Workineh Haro et al., 2012) (Fig. 2.1).

The Jimma volcanics, which represent most of the effusives in SW Ethiopia with minor outcrops east of the Ethiopian rift, rest directly on the basement or on the Omo basalts (Abbate and Sagari, 1979). According to the Geological Survey map sheet distribution, most of the Southwestern part lies in Jimma map sheet. The area is covered mainly by Tertiary lava flows, pyroclastic flows, pyroclatic fall-outs, ash-flows and to a lesser extent by Quaternary ash-falls and quaternary alluvial deposits consecutively (Workineh Haro et al., 2012).

According to Mengesha Tefera et al. (1996), the geology of the area comprises Cenozoic volcanic rocks of Early Tertiary rocks that are the Lower Jimma volcanic (mainly basalt flows) and upper Jimma volcanic (mainly silicic rocks; trachytes, rhyolites, ignimbrites and rare tuffs) rocks. Different workers (Kazmin, 1972; Merla et al., 1979; Davidson 1983; Mengesha Tefera et al., 1996) marks the lower volcanic flows, Omo trachyte flows, lower basalt flows, lower trachyte flows and lower pyroclasts are pre-Oligocene. The middle basalt flows and middle trachyte flows may correspond to Oligocene Period.

The younger flows are Miocene-Pliocene in age. While, Kazmin (1975) classified the volcanic rock hosting the fluvio-lacustrine sediment as the Ashangie group.

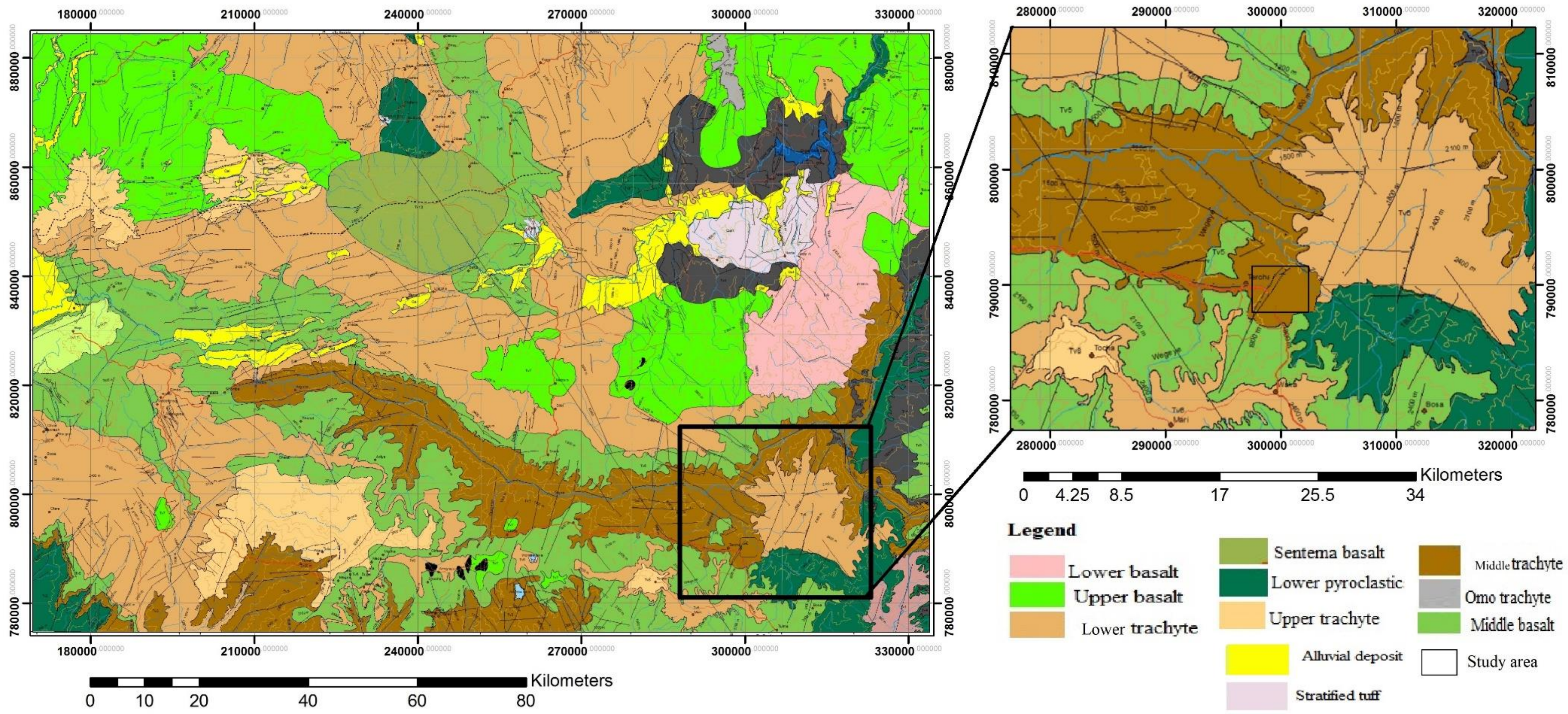


Fig. 2.1 Geological map of Jimma map sheet, Southwestern Ethiopia modified from Workneh Haro et al. (2012).

2.3 Coal Deposits in Ethiopia

The Early Cenozoic volcanics (trap series) of the southwestern Ethiopian plateau are known to contain fluvio-lacustrine and volcanic clastic (tuffaceous) sediments (Workineh Haro et al., 2012). Different authors recognize these fluvio-lacustrine sediments as coal and oil shale bearing sediments (Getahun Belay et al., 1993; Kibrie and Gashawbeza, 1997; Wolela Ahmed, 1991 a & b, 2006, 2007, 2008).

Coal and oil shale-bearing sediments are widely distributed not only in the southwestern but also in the Central, NNE, and Northwestern Plateau of the country (Fig. 2.1). The presence of these sediments is well known as intervene in between the Tertiary volcanics (Jelenc, 1966; Mengesha Tefera and Seife Michael, 1982; Getaneh Assefa and Saxena, 1984; Bae et al., 1989; Wolela Ahmed, 1991 a & b, 2006, 2007, 2008; Tesfaye Lemma et al., 1992; Getahun Belay et al., 1993, Kibrie and Gashawbeza, 1997; Miniye Betru 1992). The coal deposits of Ethiopia are classified into inter-trappean and pre-trap volcanic geological setting (Wolela Ahmed, 1991a, b; 1992a, b). Inter-trappean coal and oil shale deposits are distributed on the South-Western and Central Plateau of Ethiopia (Delbi-Moye, Yayu, Lalo-Sapo, Sola and Chida, Chilga, Nejo, Mush Valley Basins) (Wolela Ahmed, 2008).

According to Wolela Ahmed (2007), there are two types of coal-bearing sedimentary successions identified in Ethiopia which include: (i) sandstone–coal–shale facies (The coal seams hosted in this facies are thicker and persistent than those in the second) and (ii) siltstone/mudstone–coal–shale facies. Significant amounts of coal deposits are found in the Delbi-Moye, Chilga, Yayu, Lalo-Sapo, Nejo, Wuchale and Mush Valley Basins (Wolela Ahmed, 2007, 2008).

The specific area where this research was conducted is not described by the above authors except Workineh Haro et al. (2012) reported as there is coal indications during their geology, geochemistry and gravity survey of Jimma area. But, any analysis like CV, TOC, proximate and ultimate analysis and further geological interpretation about its sedimentology, structural orientation, detail mapping depositional environment, quality in terms of rank, type and grade is not known yet. From this all the CV, TOC, proximate and ultimate analysis results are described in this research mainly by focusing on energy value. Palynology studies confirmed that the Ethiopian coal and oil shale-bearing sediments range in age from Eocene to Miocene (Wolela Ahmed, 1991; 2004).

The chemical characteristics of Ethiopian coals shows different characteristic in their volatile matter, ash, moisture and calorific values which infers as they are different in rank, type and grade that guides their utility scope. The Delbi sapropleic coals are characterized by high-medium VM, medium-low ash content, low moisture content medium to high CV, and classified as lignite to high-medium volatile bituminous coals with weak coking properties whereas; CV and FC of the Moye humic coals are characterized by sub-bituminous to high volatile bituminous B coals with strong coking properties (Wolela Ahmed, 2008). The coal deposit of Moye area is the best type of coking coal deposit in Ethiopia (Wolela Ahmed, 2008). The humic coals in Yayu, Chilga, Chida, Mush Valley, Nejo and Wuchale Basins classified under low-medium ash content, medium volatile matter, moderate calorific values and lignite to bituminous rank (Wolela Ahmed, 2008).

Fig. 2.2 Location map of Ethiopian coal deposits modified from Wolela Ahmed, (2008).

CHAPTER THREE

3. METHODOLOGY

3.1 Introduction

In order to overcome the objectives of the present research different methods have been followed. They are mainly divided into three phases; pre-field work, field work and post-field work activities. During each different phases, a variety of tools were used including; topographic (1:150,000) and geological maps (1:250,000), standard field sampling and measuring equipment (such as GPS, Brunton compass, Camera, geological hammer, meter, sample sack and 10× hand lens) and ArcGIS, surfur, DEM, Global mapper and Google Earth software's.

The pre field work phase, that is desk study, has been conducted by concentrating on searching and review literatures which guide the researcher. This starts from the background of the study and study area through problem statement to methodology cope with schedule to progress the work. The literature papers (like organic geochemistry of coal, advance inorganic geochemistry of coal, maceral groups of coal and, minor and trace elements in coal) are collected by asking concerning authors or organizations, advisors, libraries and persons who have knowledge about the subject of study. Secondary data collection (including literature searching, vegetation and climate condition), logistic plan, physiographic situation assessment is done using Google Earth, Surfur, Global mapper and DEM and, drainage pattern by ArcGIS software's have been also completed in this phase. The base map for the development of geological map of the study area is extracted from DEM. By identifying different rocks and their contacts the geological map of the study area is produced. On the map the sedimentary units, where they found, are located also as a point (units which are exposed and have one observation point, S_1 and S_2 stratigraphic sections) and plane (the coal and coal bearing mudstone).

During fieldwork, primary data are collected (like collection of samples and describing different units found in the study area, the geology of the area, stratigraphic nature of sediments according to their physical characteristics as explained in detail in section 4.1) by using measuring tools that are listed above. Hence the study area is one of the inter-trappean sedimentary units found, different stratigraphic sections development (section 4.2), mapping (section 4.4) and structural data (section 4.3) collection have been done.

The main purpose of sample collection during fieldwork depends on the purpose of the study, geochemical characterization of the coal unit. The representative samples (TS_1-1, TC-1, TS_2-1, TS_3-1, TS_3-2, TC-2 and TC-3) are collected from the outcrop and stratigraphic sections exposed on the surface. As it is descried in chapter 4, the study area geology comprises two rock groups. Even from different Sedimentary units the coal deposit is the target of this study. From the coal found as exposed in the study area at different places (southern, SW, SWW and NE), representative samples are collected in accordance to variation in physical characteristics and existence in different stratigraphic sections (stratigraphic sections Fig. 4.10, 4.11 and 4.12). The geological map has been developed by following selective traverses and visible outcrops. The resource estimation is calculated based on the coal which is only exposed in the area, the average thickness of the coal seam and the relative density of coal rank.

After the fieldwork activities were completed, post fieldwork step forwards to analyze and integrate those different relevant data for further interpretation, recommendation and presentation. The analysis part depends on the sections that has been developed and samples of coal for geochemical characterization by synthesis proximate, ultimate and TOC values from laboratory. Finally the data, that are primary and secondary, could come up together through interpretation and then present in the form of text, tables, graphs and map. The text states about descriptions of lithologies, stratigraphic sections and laboratory results (geochemical analysis such as proximate, ultimate, CV and TOC). These also present in table and graphic form.

3.2 Laboratory and Data Analysis

The main purpose of coal sample analysis is to determine the quality or rank, grade and type of the coal along with its intrinsic characteristics for the indication of energy value. Furthermore, these data will be used as the fundamental consideration for coal trading and its utilization. Standardization of the procedures and conditions is essential for obtaining results that are precise. The standard test methods used in routine laboratory analyses of coal will be presented in the following sections.

The variables of all analyses are expressed as a percentage mass fraction (%) calculated in several different bases (as received, air dried, dry and dry mineral matter basis). As received (ar) basis puts all variables into consideration and uses the total weight as the basis of measurement. Air dried (ad) basis neglects the presence of moisture other than inherent moisture while dry basis (d) leaves out all moisture, including surface and inherent moisture. Dry, ash free (daf) basis neglects all moisture and ash constituents in coal while dry, mineral matter free (dmmf) basis leaves out the presence of moisture and minerals in coal, for example: quartz, pyrite and calcite.

3.2.1 Proximate Analysis Procedures

The proximate analysis of a coal determines the moisture content, volatile matter (VM), ash and the fixed carbon (FC), which is within the coal sample.

3.2.1.1 Moisture

The moisture, in the proximate analysis, determines the total and/or residual moisture content of the coal. The total moisture of a coal consists of surface and inherent moisture. The surface moisture is the moisture which adheres on the outside of a coal sample whereas; the inherent moisture is the moisture occur in the microscopic structures of the coal which do not be visible in large scale fractures. Residual moisture is the moisture that remains in the coal after drying the sample in air and minor heating in oven. Moisture determination depends on the extent of sample preparation and the condition of the coal sample. The extraneous moisture liberated readily in the laboratory while the residual is expressed quantitatively.

For determining the total moisture in coal, after collecting the gross sample, the procedure begins with preparing the sample in the following way for analysis. The nature of samples, whether it is dry or wet, factor the procedure of preparing the sample. If the gross sample is dried sufficiently, it may be reduced immediately and then air dried. However, if the sample is too wet, it should be weighed and air dried before size reduction. The size that the coal sample to be reduced and divided is according to the standard specified for the test method (ASTM or ISO). While air drying removes most of the surface moisture of coal, a temperature of approximately 107°C is needed to remove inherent (residual) moisture. The moisture content of coal can be determined by an indirect gravimetric method. This method involves oven-drying of a known mass of coal sample to a constant mass at a temperature of 105 - 110°C in an atmosphere of either air (ASTM, ISO) or nitrogen (International Standardization for Organizations, ISO). ISO recommends that drying in a nitrogen atmosphere is suitable for brown coals/lignites and all hard coals, while drying in air is only suitable for hard coals not susceptible to oxidation (Zhu, 2014).

3.2.1.2 Ash

Ash is the residue remaining after the combustion of coal in air and is derived from inorganic complexes present in the original coal substance and from associated mineral matter (Zhu, 2014; Speight, 2012). Therefore, the result of the determination is 'ash' and not 'ash content' as coal does not contain any ash. Ash, the main factor in the energy value of coal, is made up of minerals such as iron, aluminum, limestone, clay, and silica, as well as radioactive elements like thorium and trace elements such as arsenic and chromium. It is determined by weighing the residue remaining after burning approximately 1g of coal under rigidly controlled conditions of sample weight, temperature, time and atmosphere, and equipment specifications. The standard methods set by ASTM and ISO are similar but differ in detail. The samples ash value is determined by the approach described in ISO 1171:2010.

A general analysis test procedure for ash determination is in the way, first, accurately weighing the sample and reduce to pass a sieve of 212μm aperture. Then it is heated at a uniform heating rate in a furnace from room temperature to 500°C over a period of 60 minutes. This held at this temperature for 30 minutes (60 minutes for brown coals/lignites). Again the sample heated to 815°C ± 10°C and maintained at this temperature for a minimum of 60 minutes until the sample is constant in mass. When the incineration period is complete, the sample is allowed to cool and then weighed. Then, the result is directly measured by the oven which heat the sample. It is important to ensure that after incineration the sample is cooled under conditions which minimize moisture pickup. Variations in the amount of ash arise from the retention of sulfur that originates from the pyrite. The amount of sulfur retained in the ash is in part dependent on the conditions of ashing and therefore, in order to obtain values for the ash on a comparable basis, it is necessary to adhere strictly to the conditions specified in the relevant standard (Zhu, 2014).

3.2.1.3 Volatile matter (VM)

The VM is usually a mixture of short and long chain hydrocarbons, aromatic hydrocarbons and some sulfur. The VM obtained consists mainly of combustible gases such as hydrogen, carbon monoxide, hydrocarbons, tar and ammonia as well as incombustible gases like carbon dioxide and steam. It is determined by establishing the loss in weight resulting from heating a coal sample under rigidly controlled conditions. The methods for determining the VM content of a coal described in ISO and ASTM standards are based on the same principle and are similar.

Approximately 1 g, for general analysis, of coal sample with size of 250µm (ASTM) is heated to 950°C ± 25°C in a vertical platinum crucible for a total of exactly 7 minutes. After that, the result is determined by the oven and reported. ASTM D3175 applies to coals of all rank but provides a modified procedure for 'sparking' coals: the sample of a sparking coal is subjected to a preliminary gradual heating such that a temperature of 600°C ± 50°C is reached in 6 min. After this preliminary heating the sample is heated for exactly 6 minutes at 950°C ± 20°C. If sparking is then observed, the determination should be rejected and the test repeated until no sparking occurs either during the preliminary heating or during the 6 minute period at 950°C. 'Sparking' coals are defined as those coals that do not yield a coherent cake as residue in the VM test but do evolve gaseous products at a rate sufficient to carry solid particles mechanically out of the crucible when heated at the standard rate. Such coals normally include all low-rank non-caking coals and lignites but may also include some higher rank coals (Carpenter, 2002).

The test is empirical. The variations in 1) the size, weight and material of the crucibles used, 2) the rate of temperature rise, 3) the final temperature, 4) the duration of heating and 5) modifications that are required for coals which are known to decrepitate or which may lose particles as a result of the sudden release of moisture or other volatile materials can significantly affect the test results (Speight, 2012). In order to ensure reproducible results, it is essential that the standard procedures be followed closely. It is also essential to exclude air from the coal or coke during heating to prevent oxidation. Therefore, the fit of the crucible lid is critical. The moisture content of the sample is determined at the same time as the volatile matter so that the appropriate corrections can be made (Zhu, 2014).

3.2.1.4 Fixed carbon (FC)

Fixed carbon in coal is the carbon that remains in the coal sample after volatile matter is driven off. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with volatiles. The ratio of FC to proximate VM, the fuel ratio, is used as a measure of combustion reactivity and burnout. FC is not determined directly, it is calculated by subtracting the resultant summation of moisture, VM and ash in percent from 100 (Zhu, 2014).

3.2.2 Ultimate Analysis

Ultimate analysis provides a convenient method for reporting the major organic elemental composition of coal in percent in different basis. For this analysis, a coal sample is combusted in an ultimate analyzer, which measures the percent of carbon, hydrogen, nitrogen, oxygen and sulfur from a coal sample in a weight fraction. The total carbon, hydrogen and nitrogen are determined at the same time from the same sample in the analyzer. Total oxygen is calculated from the other values, usually by difference, while; sulfur is determined separately.

3.2.2.1 Carbon, Hydrogen and Nitrogen

Carbon and hydrogen account for 70–95% and 2–6%, respectively, of the organic substance of coal. They are thought to be the most important constituents of coal. The carbon determination includes carbon present as organic carbon occurring in the coal substance and any carbon present as mineral carbonate (Speight, 2005). The hydrogen determination includes hydrogen present in the organic materials and hydrogen in the free moisture accompanying the sample as well as hydrogen present as water of hydration of silicates. Almost all of the carbon and hydrogen in coal occurs in combined form in the complex organic compounds that make up coal. But carbon also occurs in the mineral carbonates, with calcite being the principal component. The original source of nitrogen in coal may have been both plant and animal protein (Speight, 1994).

The methods for determining carbon and hydrogen involve combustion of an exact amount of the coal in a closed system impervious to gases. All the hydrogen is converted to H_2O and all the carbon to CO_2. These products are absorbed by suitable reagents and determined gravimetrically. The combustion is usually accomplished by placing the coal in a stream of dry oxygen at specified temperatures. Complete conversion of the combustion gases to CO_2 and H_2O can be achieved by passing the gases through heated copper oxide. Chlorine (which may be released in significant amounts) and oxides of sulfur are usually removed from the combustion gases by passage over lead chromate and silver while nitrogen oxides is removed by manganese dioxide. The sample size may vary from as little as 1 – 3 mg (microanalysis) to 100 – 500 mg (macro-analysis) with combustion temperatures from 850 – 900°C (Liebig method) to as high as 1350°C (high temperature combustion method) (Speight, 2012).

The products of incomplete combustion are further burnt over copper oxide to ensure complete conversion of all the carbon and hydrogen to CO_2 and H_2O, respectively. When coal is combusted the carbon is liberated as carbon dioxide (CO_2) and as hydrocarbons (CH_4). CO_2 comes from the organic compounds in coal, but can also be liberated from carbonate (e.g., calcite – $CaCO_3$) minerals in the inorganic fraction of a coal, if they are present. Hydrogen is liberated from coal during combustion as water vapor (H_2O), which comes from the organic compounds in coal and the breakdown of clay minerals in the inorganic fraction of the coal (Thomas, 1992). Hydrogen values from an ultimate analyzer then need to be corrected to factor out hydrogen derived from moisture. This is especially important in low rank coals which have higher moisture contents.

The high temperature combustion method involves burning around 0.5 g of test sample of coal in a stream of pure oxygen at a temperature of 1350°C. ASTM D5373 – 08 which recommends instrumental determination of carbon, hydrogen and nitrogen in laboratory samples of coal. The quantitative conversion of the carbon, hydrogen and nitrogen into their corresponding gases (CO_2, H_2O and N_2/NO_x) occurs during combustion of the sample at an elevated temperature in oxygen. Combustion products which would interfere with the subsequent gas analysis are removed. Nitrogen oxides (NO_x) produced during the combustion are reduced to N_2 before detection. The carbon dioxide, water vapor and elemental nitrogen in the gas stream are then determined quantitatively by appropriate instrumental gas analysis procedures. Nuclear reactions have been applied successfully to the determination of nitrogen in coal. Coal is irradiated with fast neutrons from a 14 – MeV generator to produce nitrogen-13, which decays via positron emission and has a 10 minute half-life. Standard deviation for the nitrogen determinations was 0.07% (Zhu, 2014).

3.2.2.2 Sulfur

Sulfur occurs in coal in three main forms: inorganic sulfates or sulfate sulfur (sulfate minerals), pyritic sulfur (sulfide minerals) and organic sulfur. The sulfur value presented for ultimate analysis may include, depending on the coal and any prior methods of coal cleaning, inorganic sulfur and organic sulfur (Speight, 1994). It is an important parameter for evaluating the fuel value of coal and its environmental impact since SO_2 emissions into the atmosphere are directly related to the sulfur content of the burned coal. For this, the sulfur content needs to be analyzed with high precision. The three most widely used test methods for sulfur determination are the

Eschka method, the bomb washing method and the high temperature combustion method. All these three methods are based on the combustion of the Sulphur containing coal to produce sulfate, which can be measured either gravimetrically or volumetrically (Zhu, 2014).

The sulfur is determined by ASTM methods D5373 - 08 or D4239 – 02, bomb washing method. In the test, a coal sample is ground to a set size and weighed, then placed in a sulfur analyzer. In the analyzer, the sample is combusted at a temperature of 1,370°C in an oxygen atmosphere. The oxygen reacts with sulfur to form sulfur dioxide gas. The gas passes through an infrared absorption detector in the analyzer, which measures the concentration of sulfur. Sulfur is precipitated as barium sulfate from the washings from the oxygen bomb calorimeter following the calorimetric determination. After titration with standard sodium carbonate solution to determine the acid correction for the heating value, the solution is heated and treated with ammonium hydroxide (NH_4OH) to precipitate iron ions as ferric oxide [$Fe(OH)_3$]. After filtering and heating, the sulfate is precipitated with barium chloride and determined gravimetrically. ASTM D2492 – 02 (2012) based on the principle that sulfate sulfur is soluble in dilute hydrochloric acid solution, whereas the pyritic and organic sulfur are not. Pyrite sulfur, however, is determined accurately by noting the quantity of iron extracted by dilute hydrochloric acid and subtracting this from the iron extracted by nitric acid, the difference being the iron present as pyrite iron (FeS_2), from which the equivalent quantity of pyrite sulfur can be calculated. Organic sulfur is then obtained by subtracting the combined percentages of sulfate sulfur and pyrite sulfur from the total sulfur determined (Speight, 2012; Carpenter, 2002).

3.2.2.3 Oxygen

Oxygen occurs in both the organic (phenol groups (– OH), carboxyl groups (CO_2H), methoxyl groups (– OCH_3), and carbonyl groups (= C = O)) and inorganic (in various forms of moisture, silicates, carbonates, oxides and sulfates) portions of coal. The silicates are primarily aluminum silicates found in clastic units. Most of the carbonate is calcium carbonate ($CaCO_3$), the oxides are mainly iron oxides (FeO and Fe_2O_3) and the sulfates are calcium and iron (Na_2SO_4, $CaSO_4$ and $FeSO_4$) (Speight, 1994, 2005; Zhu, 2014). The total oxygen content of a coal cannot be measured analytically, so it is determined through a calculation (ASTM D3176 - 09). During combustion some of the oxygen in coal is liberated in water vapor, carbon dioxide, nitrogen oxides and sulfur oxides while of some remains in solid minerals in the ash after combustion.

Essentially, total oxygen content is the remaining major element of the five major elements in coal – carbon, hydrogen, oxygen, nitrogen and sulfur, in addition to the noncombustible ash in coal. The total oxygen content is calculated from the measured (as-determined) values for the major elements and ash:

Total oxygen % = 100 – (total carbon % + total hydrogen % + total nitrogen % + total sulfur % + total ash %)

3.2.3 Calorific value (CV)

Calorific value (CV) is a direct indication of the heat content, energy value, of the coal. It is one of the most important parameters which commonly used as the benchmark of coal quality, hence its economic value (Mahapatra, 2016). The CV is usually expressed as the gross calorific value (the higher heating value) or the net calorific value (the lower heating value). The GCV assumes that all of the vapour produced from coal moisture during the combustion process is fully condensed. The NCV assumes that the water is removed with the combustion products without being fully condensed. The GCV is important for fuels like coal, which will usually contain some amount of water prior to burning. Most applications which burn fuel produce water vapor which is not used, and thus wasting its heat content. The Heating Value determines how much fuel is required in the power plant. Higher the CV lesser the amount of the coal required per unit of electricity, the cost of the coal is higher but is offset by the lower cost of logistics, storage and ash disposal. This is the most important parameter that determines the economics of the power plant operation, specifically for super power plant projects.

Standard methods for determining the CV of coal employ calorimeters and burning coal in oxygen under pressure in a closed system. The bomb calorimeter provides the most suitable and accurate reading for determination of the CVs of solid and liquid fuels, and is adopted in ASTM D5865 - 12 (Standard test method for gross calorific value of coal and coke). The procedures specified in the standards involve burning a weighed portion of the analysis sample of coal in high-pressure oxygen in a bomb calorimeter under specified conditions. The effective heat capacity of the calorimeter is determined in calibration tests by combustion the sample by known benzoic acid under similar conditions. The temperature measurements required for the evaluation of the corrected temperature rise are made during a for-period, a main period (reaction period) and an after-period. For the isoperibol (isothermal jacket) (ASTM, ISO) and the static-jacket-type calorimeters (ISO), the CV is computed from the corrected temperature rise observed during the fore-, main- and after-period. Water is added to the bomb initially to give a saturated vapour phase prior to combustion, thereby allowing all the water formed from the hydrogen and moisture in the sample to be regarded as liquid water (Zhu, 2014).

The quantity known as lower heating value (LHV) (or net calorific value) is determined by subtracting the heat of vaporization of the water vapor from the higher heating value. This treats any H_2O formed as a vapor. The energy required to vaporize the water therefore is not realized as heat. Gross heating value (GHV) accounts for water in the exhaust leaving as vapor, and includes liquid water in the fuel prior to combustion (Zhu, 2014). The result obtained is the GCV of the analysis sample at constant volume with all the water of the combustion products as liquid water, and is usually expressed in J/g (kJ/Kg,), Cal/g (kcal/kg), MJ/kg and Btu/lib (Mahapatra, 2016; Zhu, 2014).

3.2.4 Total Organic Carbon (TOC)

Total organic carbon (TOC) is the amount of organic carbon in which the result is expressed as the amount of carbon found in the sample. A TOC percentage comprises three carbon components: extractible organic matter carbon (EOM carbon), convertible carbon and a portion residual carbon (Jarvie, 1991). Although most coals (except anthracites) can be converted into liquid products, bituminous coals (seam 3, Table 5.4) are the most suitable feedstock for direct liquefaction since they produce the highest yields of desirable liquids. Medium rank coals are the most reactive under liquefaction conditions (Curley, 2012).

The method for this is a nonspecific method unable to distinguish between various organic species and indicates only that organic carbon compounds are present. The optimum choice of analyzer should always be made based on the intended application and required sensitivity levels. For lower detection levels, a method utilizing larger sample volumes (chemical oxidation) should be chosen. Total carbon consists of inorganic and organic carbon. Inorganic carbon, present as carbonate or bicarbonate ions, must be removed or quantified prior to the analysis of organic carbon. Once the inorganic carbon is removed, subsequent analysis of the sample aliquot assumes that all carbon remaining is organic. Methodology used to remove inorganic carbon relies on acidification that converts all bicarbonate and carbonate ions to carbon dioxide that is purged out of the sample using an inert gas. If quantification of inorganic carbon is desired, it is purged into a detector; otherwise it is vented to atmosphere. Once inorganic carbon is removed, the remaining organic carbon is oxidized to carbon dioxide that is purged by the inert gas into the detector.

The total organic carbon content of rocks is obtained by heating the rock in a furnace and combusting the organic matter to carbon dioxide. The amount of carbon dioxide liberated is proportional to the amount of carbon liberated in the furnace, which in turn is related to the carbon content of the rock. The carbon dioxide liberated can be measured several different ways. The most common methods use a thermal conductivity detector or infrared spectroscopy (Lipps, 2016). TOC analysis attempts to measure carbon contained in organic molecules and report results as a single value. The value obtained is dependent on the oxidation technique and no single oxidation technique is adequate for every purpose.

CHAPTER FOUR

4. LOCAL GEOLOGY

4.1 Lithologic Description

The geology of the study area consists of various lithological units; trachyte, basalt, pyroclastic material, brown coal, hard coal, mudstones and shale. But, it is mainly marked as underlain by trachyte. The sedimentary units are found intercalated with each other in between volcanic rocks. Different structures such as bedding, lamination, seam splitting and cleat are also observed.

Intercalated units are found in the south (S_3 stratigraphic section, Fig. 4.13), SWW (S_2 stratigraphic section, Fig. 4. 12), SW (S_1 stratigraphic section, Fig. 4.11) and NE (S_4 stratigraphic section, Fig. 4.14) parts of the study area. Different units in S_1, S_2 and S_3 sections are tilted at different strike and dip whereas; units in S_4 section are horizontally bedded. Along NW and SE parts, there is no any exposed sedimentary unit and the volcanic rock found is trachyte. The concern of this research is one of the sedimentary units, coal. This unit is found intercalated with other sedimentary units and without also. But from all these rocks only volcanic units are mapped in the prepared geological map. In order to show the surface distribution of the coal unit, it is marked by point and line. Around the center of the study area, there is normal fault which trends at a strike of N27^{0}E dipping to the NW general direction. Tilting of the exposed units might relate to this fault.

4.1.1 Volcanic Rocks

4.1.1.1 Trachyte

The main lithological unit which covers most part of the study area in terms of areal coverage relative to all other units exposed on the surface is trachyte. This unit show (brown and grey) weathered and (brown and light grey) fresh color. It has porphyritic texture and fine-grained groundmass. This unit is considered and correlated (based on physical descriptions and the place where the sample was taken) as analogous with the middle trachyte classified and named by Workineh Haro et al. (2012).

According to these authors the trachyte sample taken from east of Tercha show mainly glassy groundmass, iron-oxide (magnetite and hematite), microlites of sandine and sandine phenocrysts. East of Tercha, and west of Gojab town, the unit is mixed with ignimbrite. The ignimbrite is weathered and shows light grey color and medium grained texture. To the northwest of Chida, the unit is intercalated with coal beds.

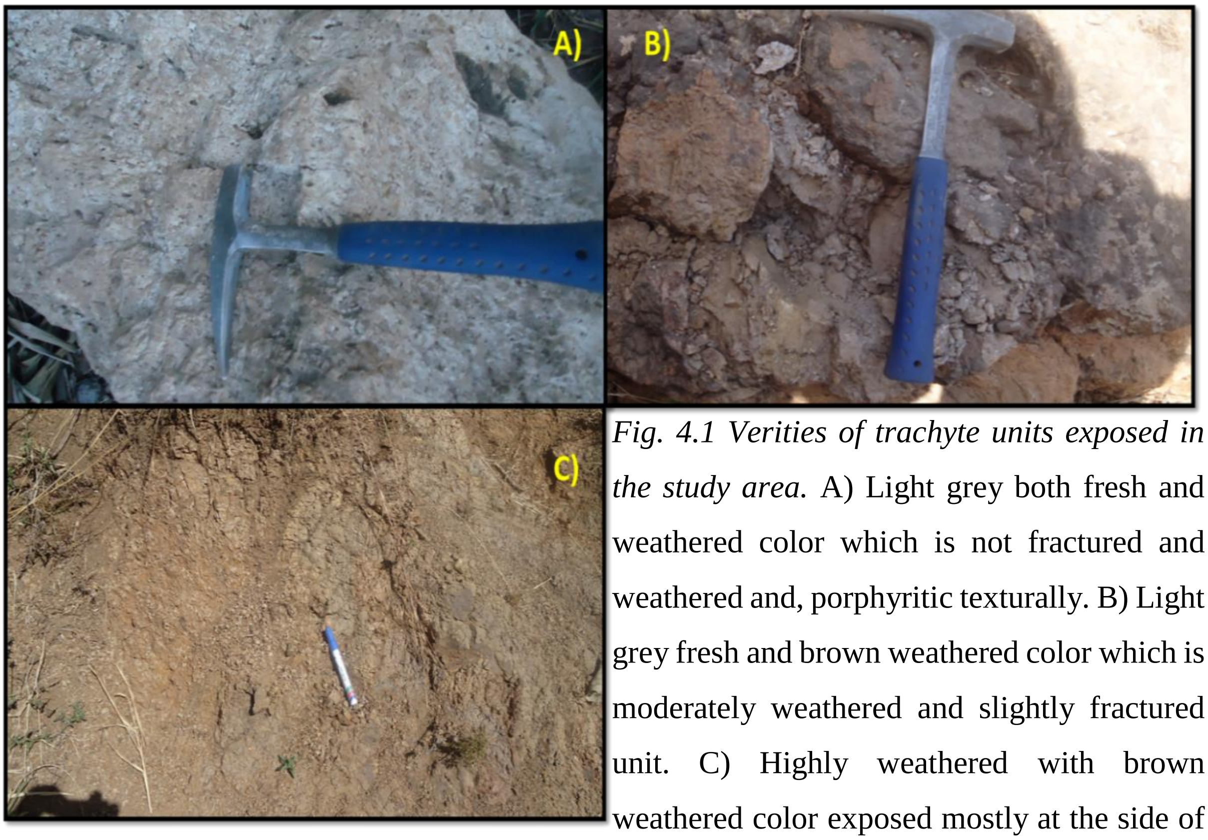


Fig. 4.1 Verities of trachyte units exposed in the study area. A) Light grey both fresh and weathered color which is not fractured and weathered and, porphyritic texturally. B) Light grey fresh and brown weathered color which is moderately weathered and slightly fractured unit. C) Highly weathered with brown weathered color exposed mostly at the side of ridges.

4.1.1.2 Basalt

This unit is exposed in the lower course of big rivers, Shata and Zoa. The basalt in the study area is slightly fractured and aphanitic texturally. It shows dark weathered and deep dark fresh color. This is not further observed in the study area other than river courses and nearby to the rivers. This unit is considered and correlated (based on physical descriptions and the place where the sample was taken) as analogous with the middle basalt classified and named by Workineh Haro et al. (2012). It is exposed in different area, regionally, like Bonga, Chida, NW of Dimitu (Geshe Mountain) and south of Tercha. Around Chida the basalt is fine grained and dark which forms rock boulders due to spheroidal weathering and in this unit pyroxene is observed (Workineh Haro et al., 2012).

According to these authors, microscopic study of the basalt sample taken around Bonga is termed as ferro basalt since iron-oxide is dominant in the groundmass while the sample on Geshe Mountain is aphyric with microlites of plagioclase. The basalt on slope to the south of Tarcha is pyroxene-plagioclase phyric basalt. This is coarse grained and dark grey. This basalt often show spheroidal weathering.

Fig. 4.2 Fractured basaltic unit found at the lower course and right side of Shata River.

4.1.1.3 Volcanic Glass

This volcanic flow (Fig 4.3) is characterized by brown weathered and black fresh color. The flow is exposed only in the southwestern part of the study area along Tabeno River. Most dominantly the rock is glassy with some quartz crystals that can be observed in naked eye and 10 x hand lens. It is not fractured but slightly weathered.

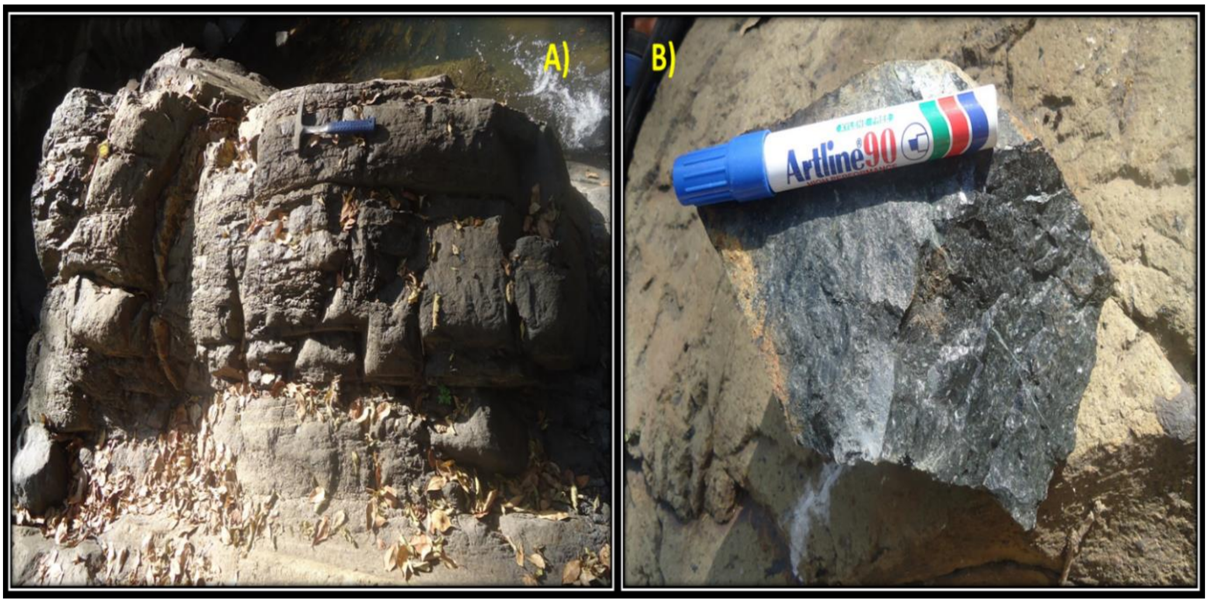


Fig. 4.3 Field photographs showing volcanic Glass. A) In situ volcanic flow where Tabeno flows. B) Sample that has been taken to show fresh color, it is shiny and has crystals.

4.1.1.4 Welded Tuff

This unit is characterized by light grey fresh and dark grey weathered color that exposed near the big river Zo-A along Tercha to Gena gravel road. It is highly compacted and not weathered. It has small crystals of quartz and medium grained clasts with highly welded ash matrix and foliation. This unit is, probably, analogues with upper pyroclastic unit which is classified and named by Workineh Haro et al., 2012.

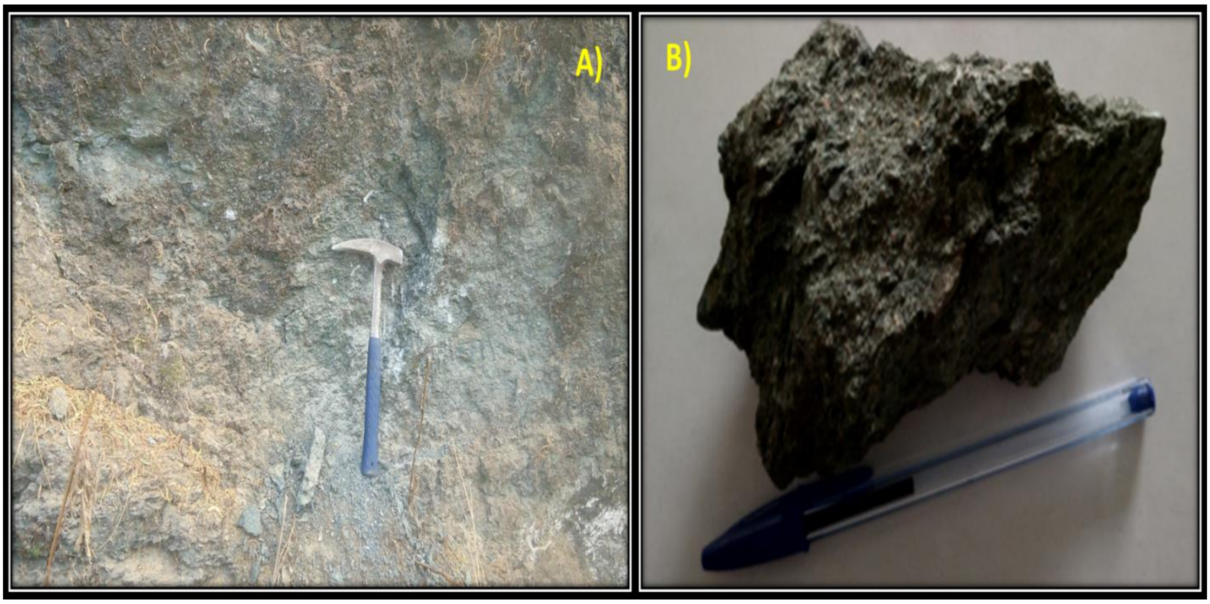


Fig. 4.4 Field photographs showing welded pyroclastic material. A) Highly compacted tuff. B) Sample taken from A) which shows crowded foliation and porphyritic clasts.

4.1.2 Sedimentary Rocks

4.1.2.1 Mudstone

This unit is exposed in different places of the study area as intercalated with other units (Fig. 4.11, Fig. 4.13). The intercalation is with shale and brown coal. It has red (fresh - the presence of iron) and grey (weathered – due to oxidation) color, very fine grained and highly friable. This clastic unit also found in between of two coal seams which results seam splitting (Fig. 4.10, Fig. 4. 11, Fig. 4.5 B, Fig. 4.5 D).

In S_1 stratigraphic section (Fig. 4.11), this unit is found intercalated with brown coal and variegated shale. The unit in this section, mainly exposed laterally to the Tabeno river side, is tilted at a strike of N72^0 E and dip of 52^0 NW (Fig. 4.5 D). It is wet, probably, that hence the river flows over the unit and, difficult to cut the deep extent. In S_3 stratigraphic section (Fig. 4.12, Fig. 4.5 A), the unit has the same characteristic but located at the bottom and between brown coal units at the top. It tilts at a strike of N46^0 E and dip of 70^0 NW. Bedding (Fig. 4.5 A, B) and lamination (Fig. 4.5 D) sedimentary structures are also observed.

This unit pictures taken from different parts of the study area are organized in Fig. 4.5 and described as follows; Fig. 4.5 A) Mudstone unit is intercalated with hard and brown coal. It has ~2m thickness and found at the bottom of S_3 stratigraphic section (Fig. 4.13). B) Mudstone intercalated and found in between brown coal. It is measured about 40cm thickness which is found at the top of S_3 stratigraphic section (Fig. 4.13). This clearly shows seam splitting. C) The unit is found below trachyte. It has red color, highly friable and highly weathered characteristic and it shows leaching effect from the upper unit, probably, with discontinuous white color at the top of this unit. D) Very thin mudstone and brown coal intercalation variably. It has, also, about 2m thickness intercalated with brown coal found in S_1 stratigraphic section (Fig. 4.11).

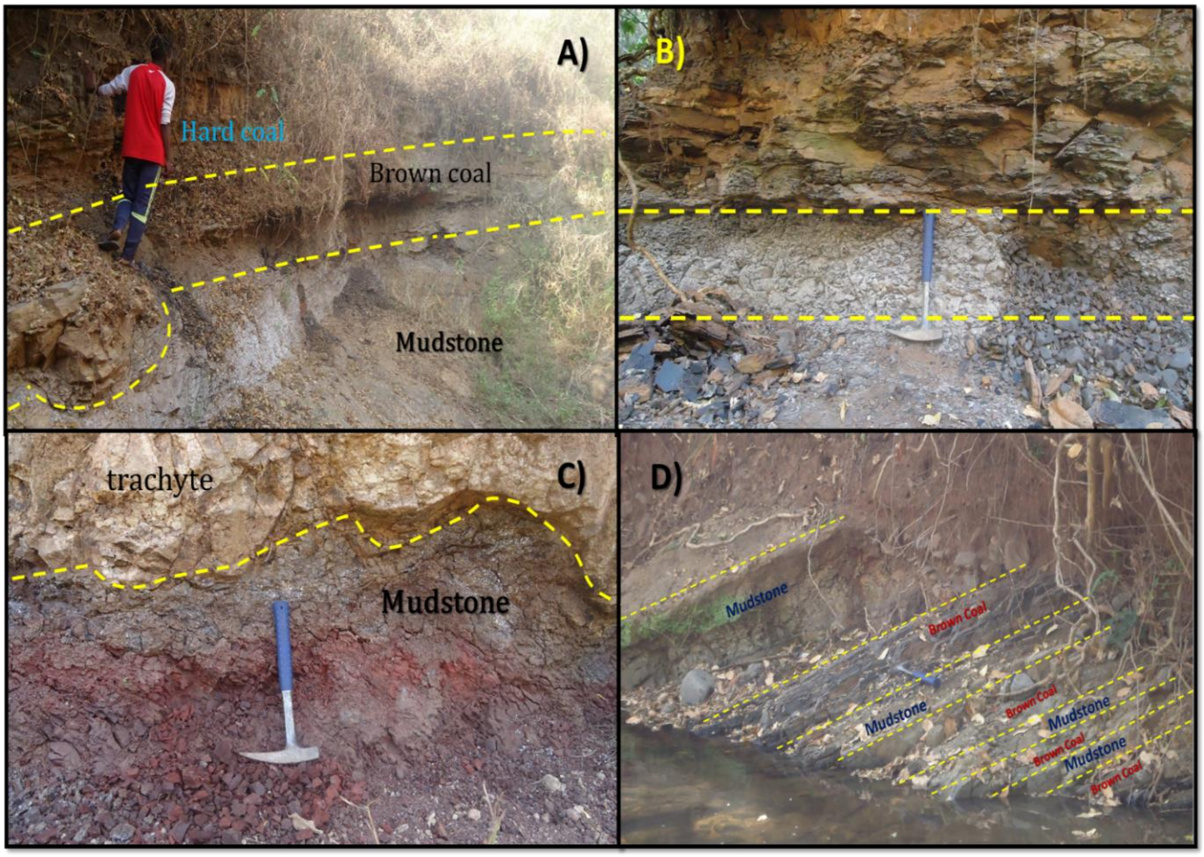


Fig. 4.5 Field photographs showing mudstone unit. A) Mudstone intercalated with brown coal. B) Mudstone found in between brown coal. C) Mudstone found below trachyte. D) Intercalation of thin lavered mudstone with brown coal.

4.1.2.2 Shale

This unit is found intercalated with brown coal and mudstone units at the top of S_1, S_3 and S_4 stratigraphic sections. In S_3 stratigraphic section the shale is found above the brown coal. It is characterized as grey in color, highly friable and fine grained texturally (Fig. 4.6 B). Whereas in S_1 stratigraphic section it shows variegated colors (red, brown, grey and black) with brown and grey color dominancy. The shale found in this section is highly weathered and clearly fissile found above the mudstone unit (Fig. 4. 6 A and C). There is also carbonaceous shale in S_2 stratigraphic section, hence it needs some chemical analysis to support, which do not discussed further.

The shale found at the top of S_4 stratigraphic section is different from those found in other sections in color, weathering degree and thickness. It is yellow color, highly compacted with a very low weathering degree and clear fissile nature (Fig. 4.6 D). It is found NE part of the study area at the top of hard coal.

Fig. 4.6 Field photographs showing variegated shale. A) It is variegated color (grey, brown, red and dark) shale found at the top of S_1 stratigraphic section (refer Fig. 4.11) on mudstone unit in S_1 stratigraphic section. B) Zoom in picture from (A) to show brown and grey dominant color and high fissility. C) This shale has been found at the top of S_3 stratigraphic section (Fig. 4. 13) and shows grey color only. It is also highly weathered and fissile. D) Yellow color shale found with very thin thickness at the top of hard coal at the side of Bodi Ara ridge.

4.1.2.3 Coal

Coal is exposed along NE, SWW, SW and Southern part of the study area in all stratigraphic sections. The unit, generally called as coal, is found intercalated with other units. The coal found in SWW part of the study area is the best exposure which shows as the unit is inter-trappean. The SW and SWW part coal, very small in thickness, is dominated by other units. The unit in NE part shows better physical property than others. The southern and NE part coal has good thickness and dominates other units. It is characterized as brown coal and hard coal according to different physical properties.

4.1.2.3.1 Brown Coal

This coal is found in SW, SWW and Southern part of the study area in S_1, S_2 and S_3 stratigraphic sections with different color and luster. The coal, found at the bottom of S_1 stratigraphic section, is weak in strength and dominated by clastic units. Lamination, bedding, seam splitting and cleats are also observed in this section units. It is light dark in both fresh and weathered color. The splitting is the result of inorganic clastic deposition replacing the organic accumulation which later causes lowering the coal quality since reaction takes place (Fig. 4. 5 D and Fig. 4.11). Cleats are systematically oriented orthogonal joints resulted due to tectonics.

In S_2 stratigraphic section the unit is trapped at the top and bottom by volcanic units (Fig. 4.12). The coal found in this section is brown in (fresh and weathered) color, wet and shows well preserved stem feature. It is moderately lustrous and show sub-conchoidal fracture when hammered (Fig. 4.7 C). It tilts at a strike of N60^0 E and dip of 65^0 NW (Fig. 4.7 A). Whereas; the brown coal found in S_3 stratigraphic section is good in thickness and characteristic relative to other brown coals in S_1 and S_2 stratigraphic section. It has about 6m thickness, high strength, slightly weathered, and shows dull luster (Fig. 4.7 E). Clear seam splitting is observed in this section also (Fig. 4.12 bed no. S3BD2 (coal), S3BD4 (mudstone) and S3BD5 (coal)) in between the two coal beds.

This coal, found in different stratigraphic sections as exposed in the study area, pictures are organized in Fig. 4.7 and described as follows; Fig. 4.7 A) Brown coal, which is measured about 90cm thickness, found below trachyte in S_2 stratigraphic section (Fig. 4.12). B) This has been exposed on the surface on the left side of Tercha to Gena road. It is highly fractured and weathered. C) A sample taken from the brown coal A) to show stem preservation clearly. It shows stem preservation clearly and luster moderately. D) Intercalation of brown and hard coal with mudstone found in S_3 stratigraphic section (Fig. 4.12). E) This is taken from S_3 section which is dull in luster, high strength, fractured and weathered with average thickness about 2m.

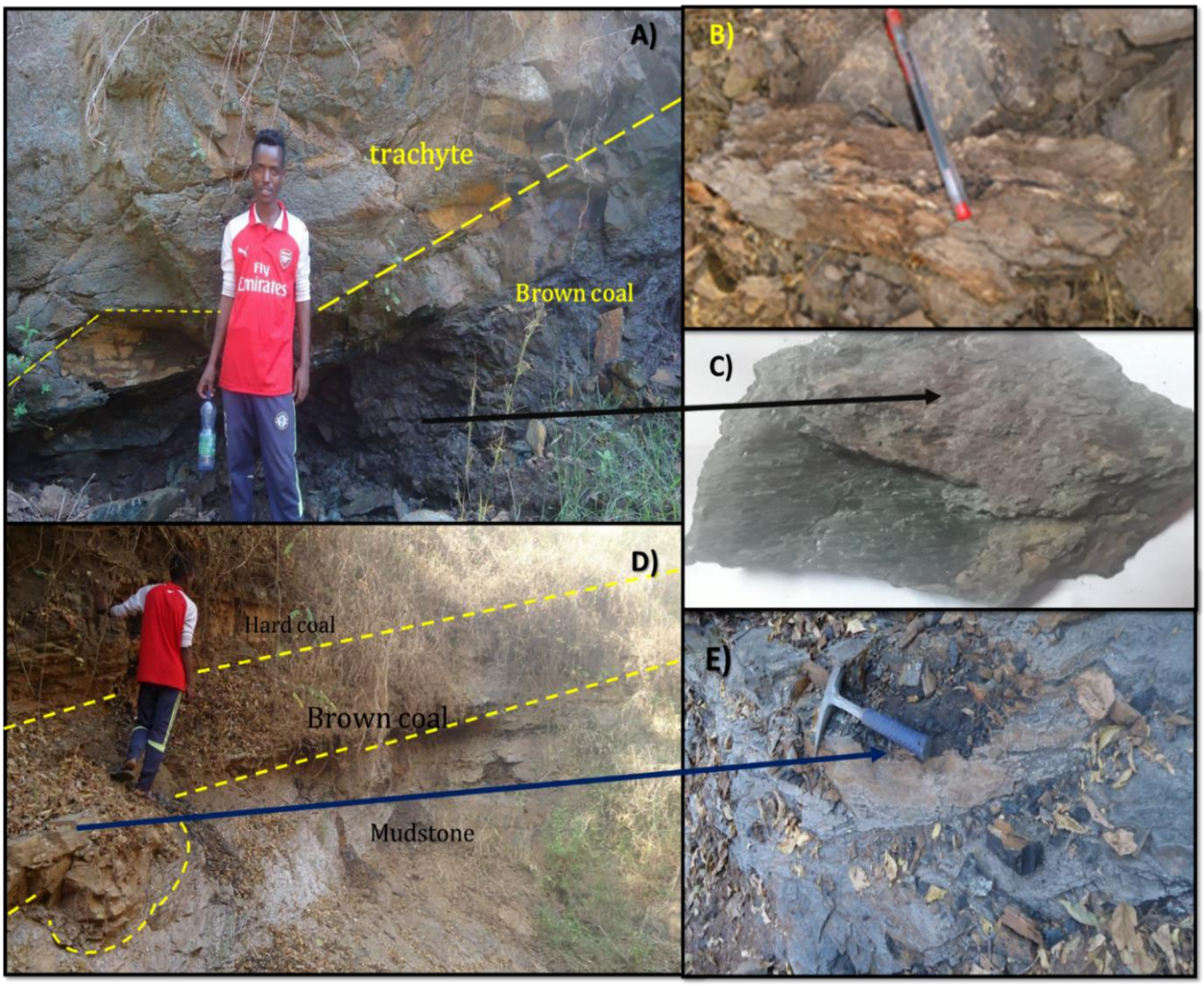


Fig. 4.7 Brown coal found as intercalated with sedimentary rocks and trapped by volcanic units.

4.1.2.3.2 Hard Coal

This unit is exposed on NE and Southern part of the Study area in S_4 and S_3 stratigraphic sections respectively. The maximum thickness ~10m hard coal is found in S_4 stratigraphic section (Fig. 4. 14). At its top the coal luster becomes less and banding nature increases. The hard coal in this section is highly lustrous, shows sub-conchoidal fracture and cleat structure. In between of the coal small banding is often observed. The bottom and middle part is very hard and non-fractured. The unit is bedded horizontally.

The hard coal in S_3 stratigraphic section is found between brown coal beds. It is deep dark fresh and brown weathered in color and lustrous in small scale (Fig. 4.8 A and B). It is slightly fractured, high in strength and weathered at small scale. It has good characteristic which makes it better than the other coal units found in the same. 4.7 B).

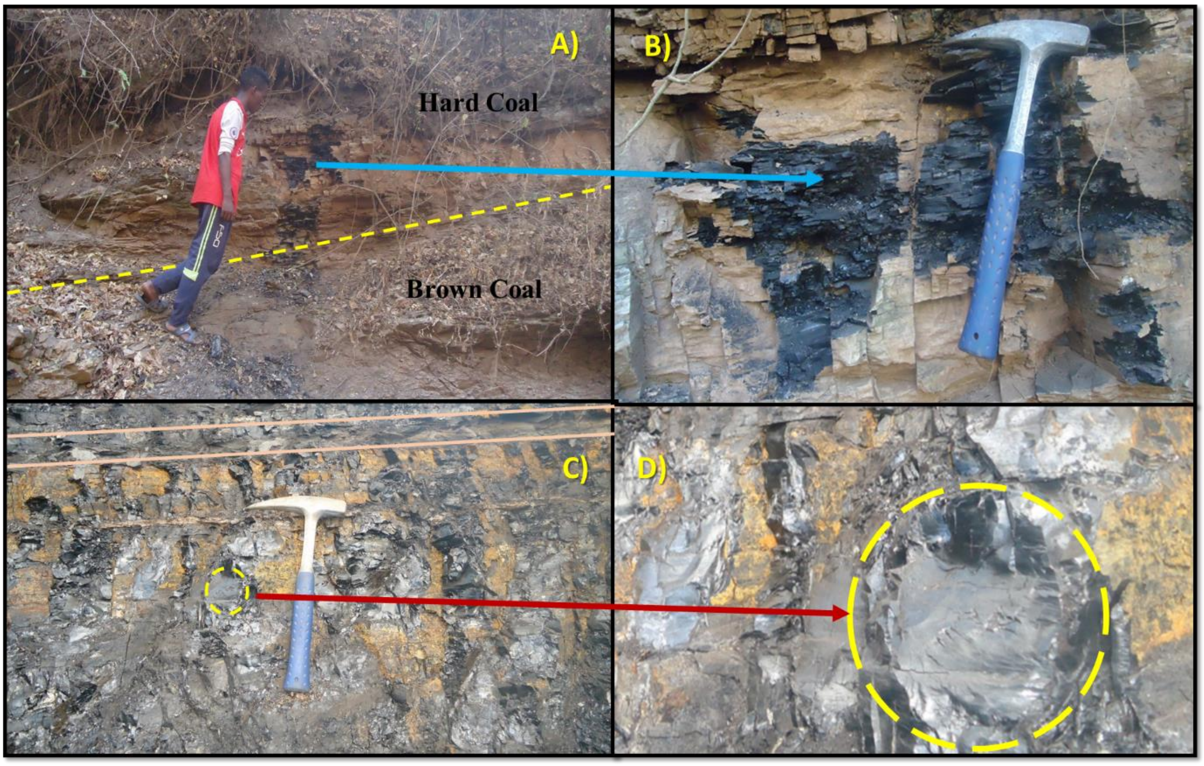


Fig. 4.8 Hard coal which is found intercalated with other units A) Intercalation of hard coal with brown coal found in S_3 stratigraphic section measured about 1m thickness. B) Zoom in hard coal from A) to show its small scale luster. It is moderately fractured, but has high strength, and weathered slightly. C) Very lustrous, highly compacted and high strength hard coal measured about 5m thickness. D) Zoom in hard coal image from C) to show clear sub - conchoidal fracture of typical high quality coal characteristic.

At top of S_4 stratigraphic section the hard coal shows clear cleat feature that has regular pattern of cracking in the coal that occur in two sets that are, in most cases, mutually perpendicular, and also perpendicular to bedding (Fig. 4.11 Bed No. S1BD4).

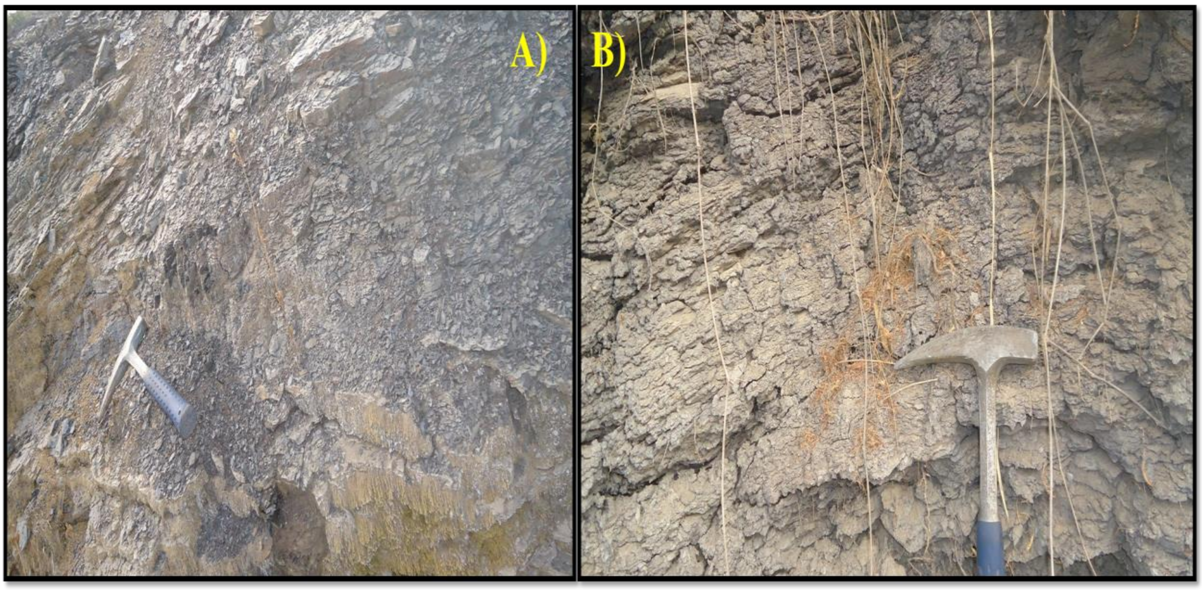
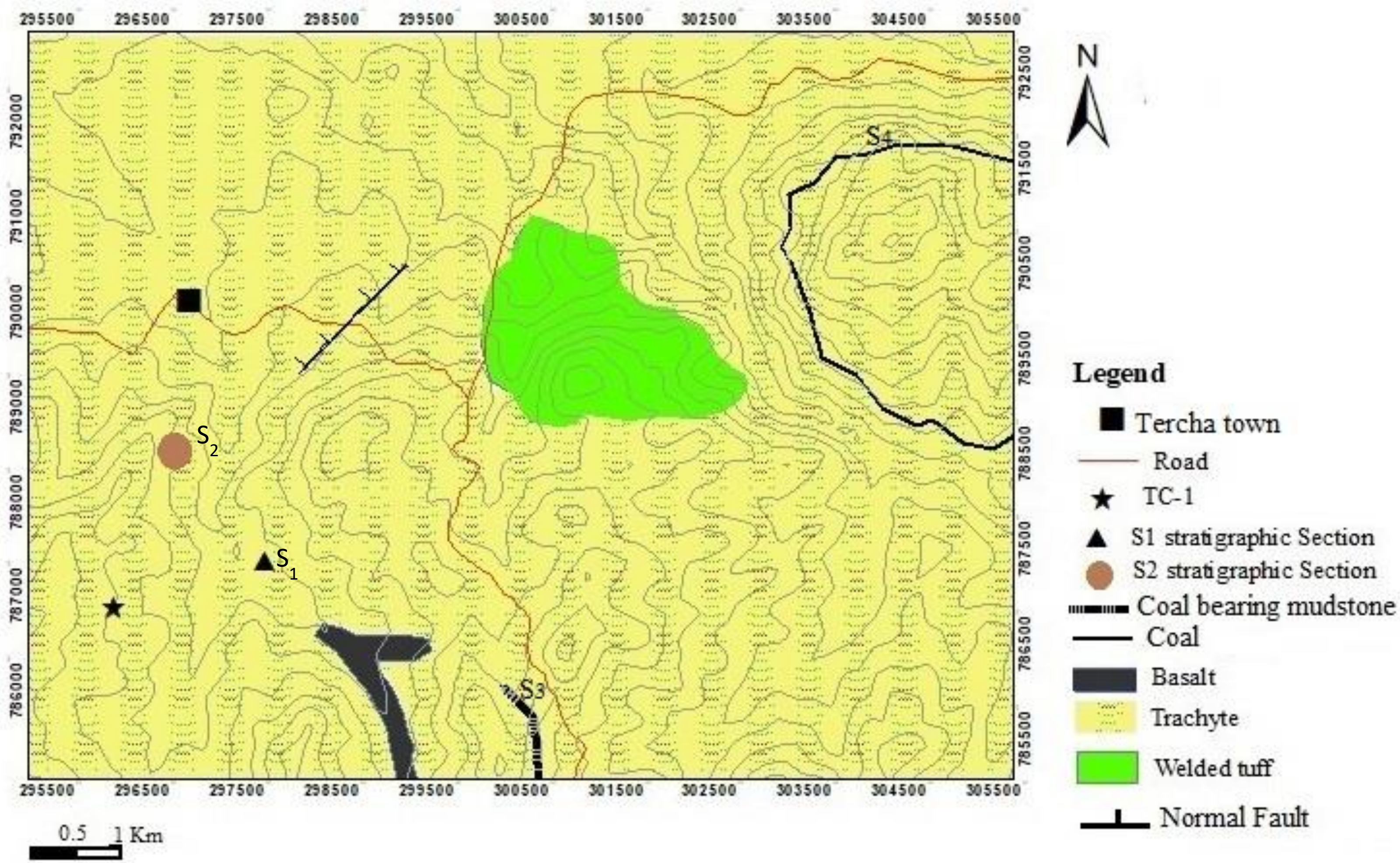


Fig. 4. 9 Cleats that are perpendicular to each other found on coal. A) Coal with cleats found around Bodi Ara ridge at the top of hard coal at the bottom of this. B) similar structure exposed near by to the road along Tercha to Gena street which shows clear cleats that are perpendicular to eachother.

4.2 Geological Map of the Study area



4.10 Geological map of the study area modified after Workneh Haro et al., 2012. Where,★ is the coal sample location for TC-1 and S_1, S_2, S_3 and S_4 are locations where stratigraphic logs have been recorded.

4.3 Depositional Setting and Stratigraphic Sections

As it has been described in the introduction part of this chapter the study area consists of both volcanic and sedimentary rocks while the most areal coverage is dominated by trachyte. Sedimentary units (mudstone, shale and coal) are found, by forming intercalation, in between the upper trachyte at the top and lower trachyte and middle basalt at the bottom at regional and local scale. Since these volcanic rocks are part of the Trap Series the sedimentary units are inter-trappean. The intercalations of such sedimentary units are found as exposed on the surface along NE (S_4 stratigraphic section), South (one section; S_3 stratigraphic section), Southwest (S_1 stratigraphic sections) and South-West-West (S_2 stratigraphic section) part of the study area. These units are tilted towards NW direction. The section developed is depending on texture for horizontal scale and their actual measured thickness for vertical scale. Depending on their elevation, the relative sequence of the sections is S_3, S_4, S_2 and S_1 from top to bottom. Coal unit is better exposed on the surface at the South and NE part of the study area. The coal in each section S_1, S_2, S_3 and S_4 is taken as seam 4, seam 1, seam 2 and seam 3 respectively. The samples taken for analysis are TS_1-1, TC-1, TS_2-1, (TS_3-1 and TS_3-2) and (TC-2 and TC-3) from S_1, outcrop, S_3 and S_4 stratigraphic sections respectively. Three sections units (S_2, S_1 and S_3) are correlated whereas; S_4 is not correlated with this units.

The sedimentary units found in NE part of the study area are deposited in an isolated swamp with clear, possibly, anaerobic environment. This is indicated by good characteristic of the coal unit and absence of clastic flux in between the seam like other seams found in the study area. Whereas; lithostratigraphic correlation between S_2, S_1 and S_3 stratigraphic section units is developed to understand the depositional basin of these units (Fig. 3.15).

Field observation and correlation of sections units show that some of the units pinch out in the SWW direction, where S_2 is found. Towards this section (S_2) the thickness of variety of the sedimentary units decreases considerably. In contrast, the sedimentary unit thickness increases towards the southern part of the study area, where S_3 section is found. This can imply the depositional basin setting that S_3 is situated in the depo-center of the basin and S_2 is located in the margin of the basin. It is also noted that, as the thickness of the sedimentary units, the coal physical characteristics or quality also increases towards the depo-center. This can be due to the fact that deeper settings can facilitate anaerobic condition for organic accumulation. But the seams found in S_1 and S_2 sections can be influenced by aerobic circulation as they are situated at the margin of the basin and also affected by higher sediment dilution to the organic matter. Sedimentary units found in SW part of the study area are deposited in such way in the same basin. The sections are described in detail as follows.

S_1 section is present at the vertex of two main rivers, Shata and Tabeno, along SW part of the study area. It includes brown coal, mudstone, brown, mudstone and variegated shale from bottom to top (Fig. 4.11 below). This section mainly exposed laterally to the Tabeno river side (Fig. 4.5 D). The units in this section are tilted at a strike of N72^0 E and dip of 52^0 NW. In the brown coal, S1BD6, the seam is splitted by clastic material whereas the other brown coal, S1BD4, shows cleat. This section continuity is not further exposed in the study area due to, as it is tilted, burial of the lower part and erosion of the upper part.

S_2 section consists of thick trachyte, greenish brown coal, friable grey pyroclastic material, highly friable carbonaceous shale and basalt units from top to bottom (Fig. 4.12). The brown coal shows clear sub-conchoidal fracture and well preserved stem feature (Fig. 4.7 C). The section is found along SWW part of the study area and the coal seam in this section is very thin relative to other coal seams found in other stratigraphic sections. The coal unit is tilted at a strike of 60^0 NW and 65^0 NE. It is trapped at the top and bottom by volcanic units (Fig. 4.12). Hence of these, probably, this may be the end marker of the depositional setting or pinch out of the deposition. Like S_1 section it did not exposed on the surface further.

S_3 section has optimum thickness of brown and hard coal units along southern part of the study area. From top to the section includes shale, mudstone, brown and hard coal (Fig. 4.13 and Fig. 4.7). This section is exposed on the surface up to some extent around where it is found.

S_4 Stratigraphic section consists of lustrous hard coal and banded hard coal with cleats and trachyte from bottom to top (Fig. 4.14). Even it is not marked in the section because of its very thin thickness there is highly fissile yellow shale next to hard coal with cleats (Fig. 4. 6 D). This section main unit, coal, is exposed on the surface at different observation points that are extrapolated later to show its areal extent hence it is found by making planar bed.

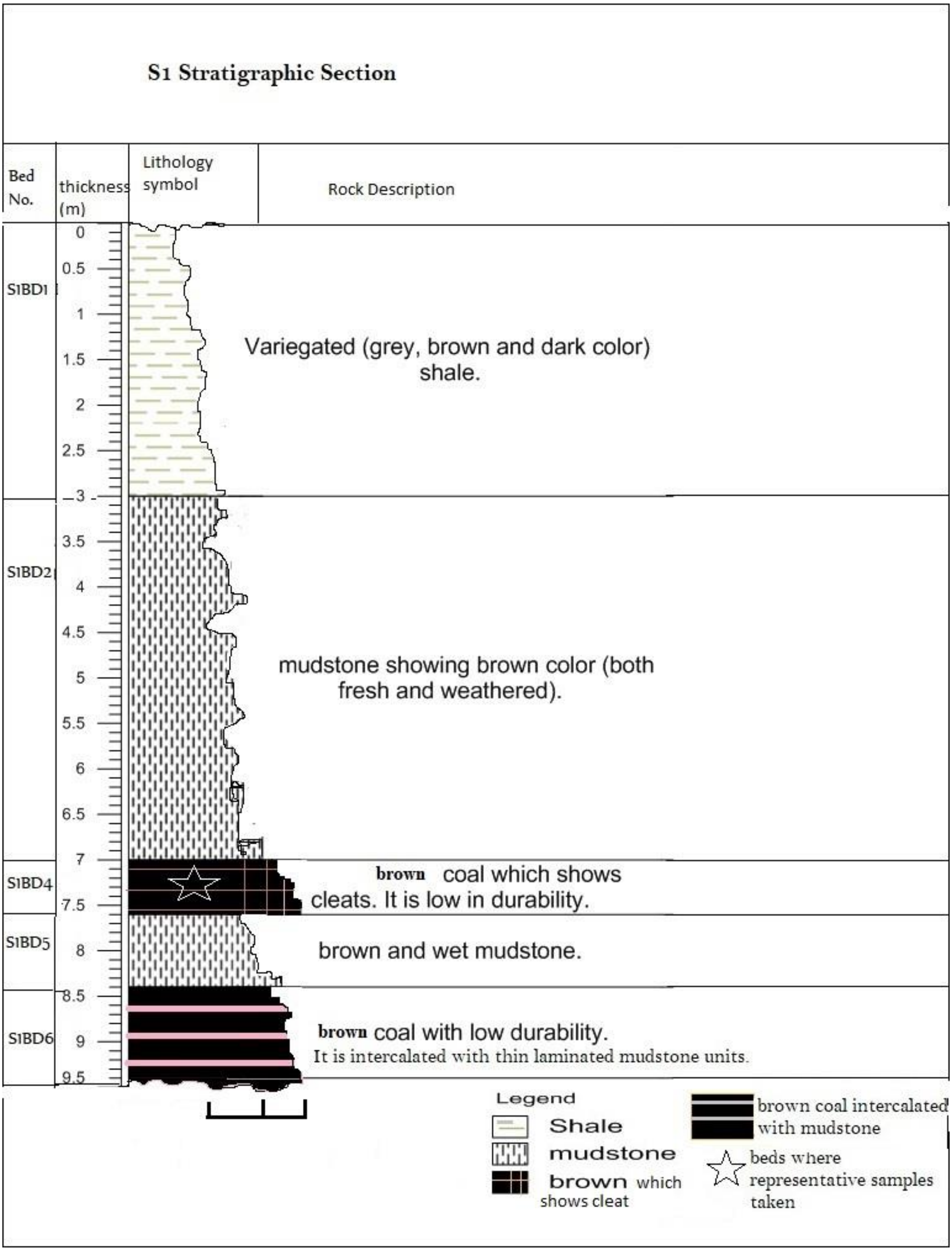


Fig. 4.11 S_1 Stratigraphic Section taken at the vertex of Tabeno and Shata River in SW part of the study area.

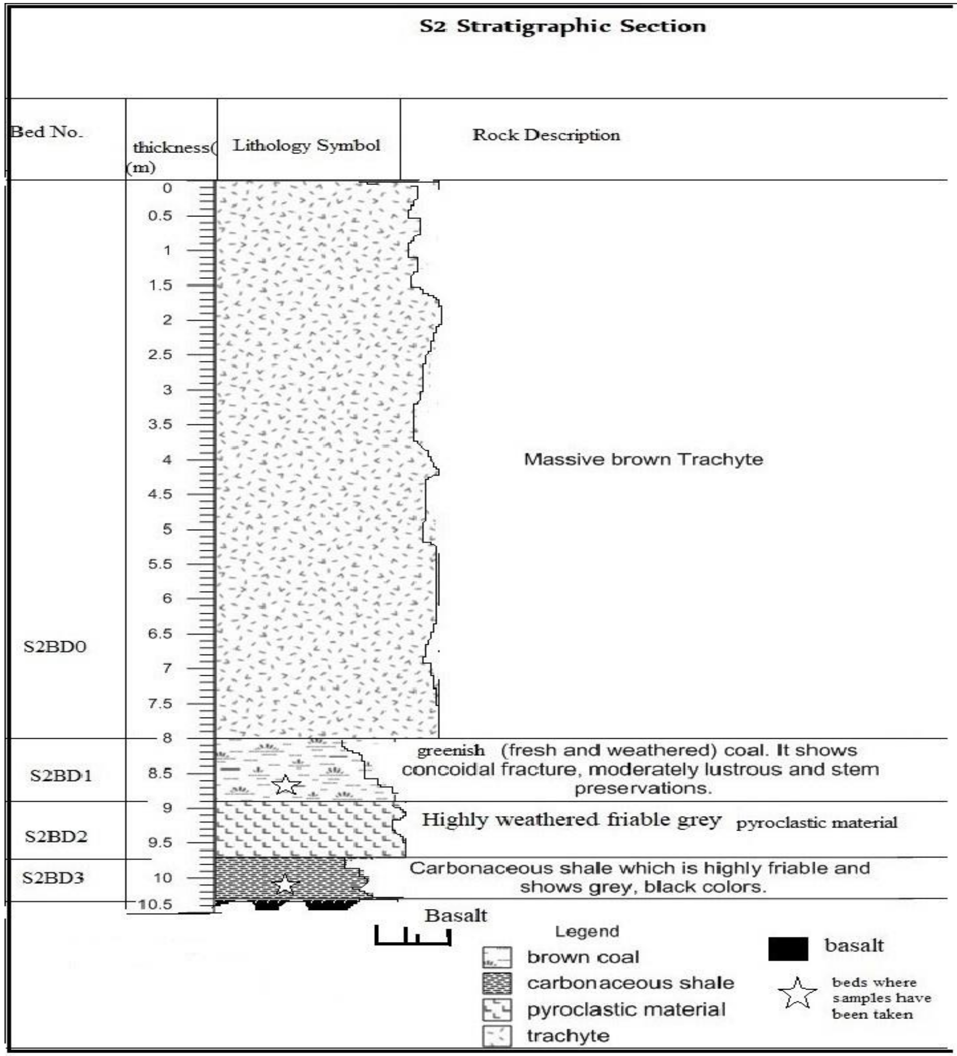


Fig 4.12 S_2 Stratigraphic Section along SWW part of the study aea.

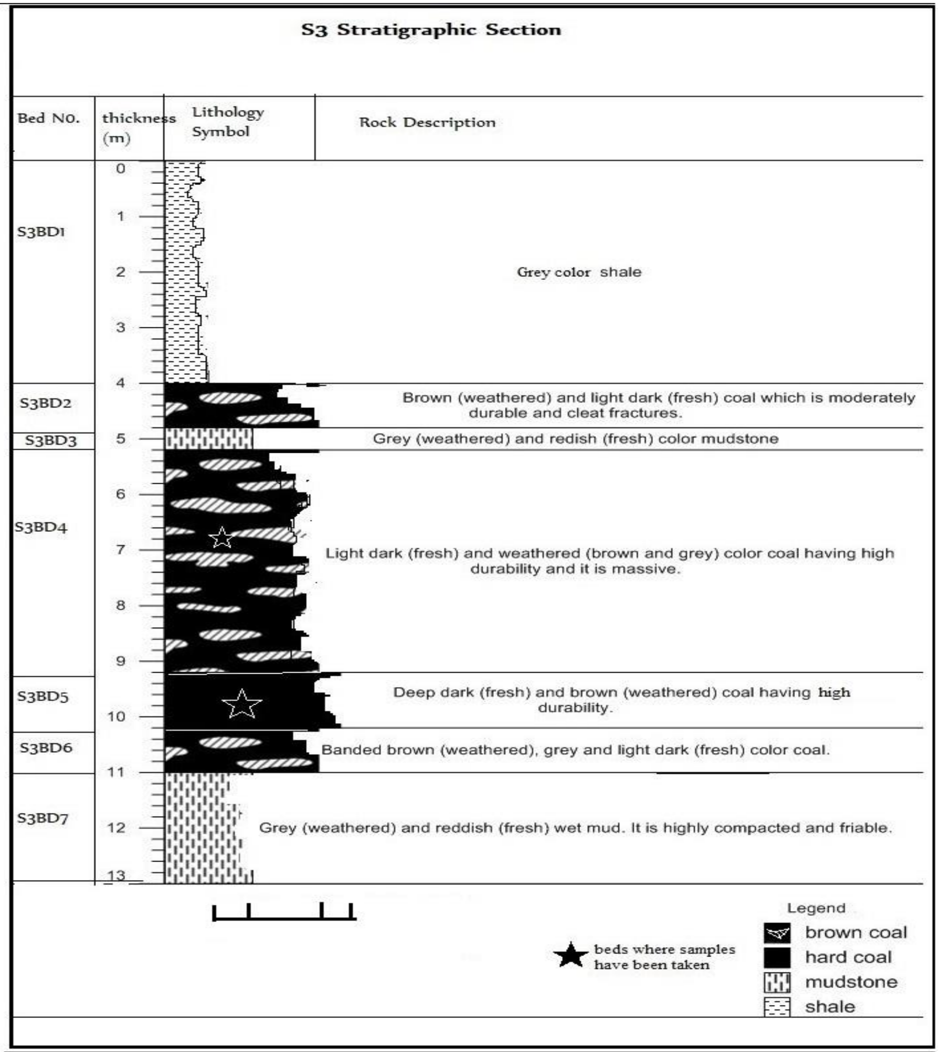


Fig. 4.13 S_3 stratigraphic section along the Southern part of the Study area.

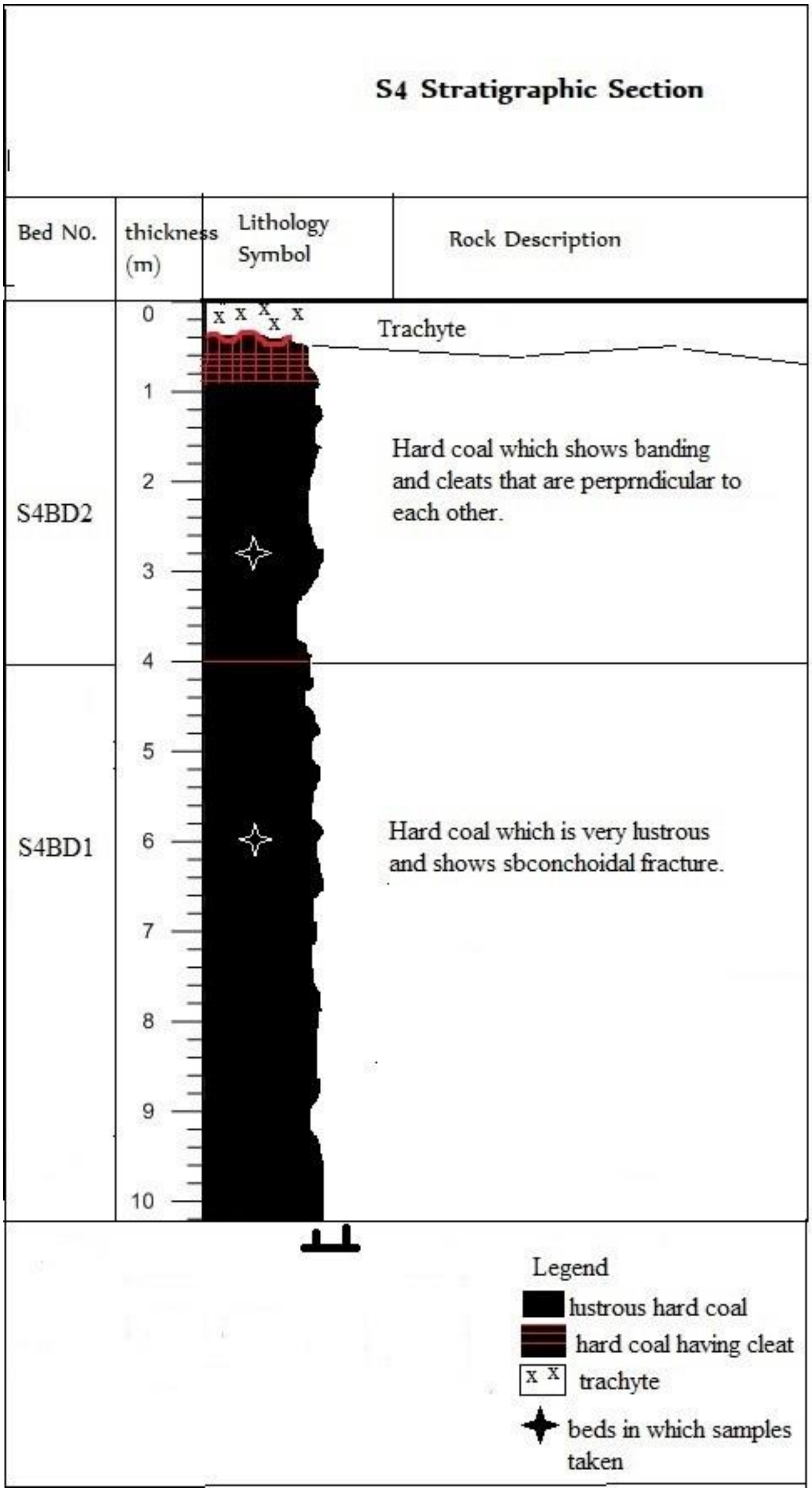


Fig. 3.14 S_4 stratigraphic section along NE part of the study area around Bodi Ara ridge.

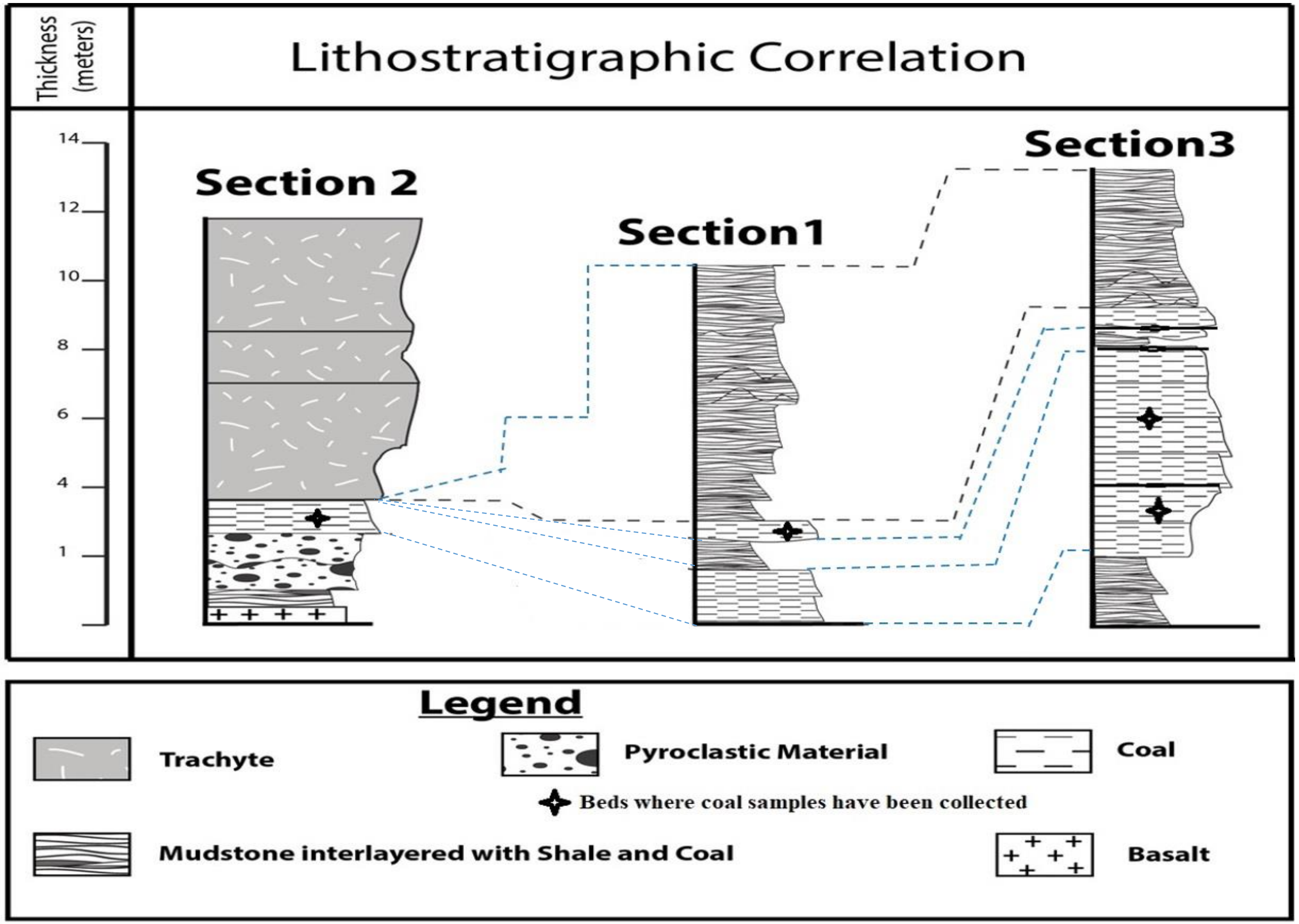


Fig. 4.15 Litho-stratigraphic Correlation of S_1, S_2 and S_3 Stratigraphic Sections.

CHAPTE FIVE

5. GEOCHEMICAL CHARACTERISTIC OF TERCHA COAL

Geochemical analysis of rocks reveals the general characteristics of the analyzed unit in accordance to the composition and concentration of varieties of chemicals in elemental or mineral level. The analysis result then interpreted which in turn helps to know the rock in accordance to different purposes. Different rocks have varieties of analysis results as their chemistry, behind their origin and the process going to form, set its influence. This becomes significantly observed in coals of even the same group since coal is very complex naturally. In order to state their rank, grade, type, trade value, utilization level, energy value and others the chemical analysis of coals has a great influential role either for an academic entity or commercial scope and/or then for utility. Organic geochemistry, inorganic geochemistry, Ash analysis (heavy metals and radioactive trace element analysis), palynology studies, TOC value quantification, fuel ratio and Free Swell Index analyses of the coal can be done for different purposes. Though these can be done, the three main analyses (proximate, ultimate and calorific value) are mostly used and this research also totally relies on these by including TOC. Proximate, ultimate and TOC results are present in as received basis (ar) in percent whereas CV is in dry, mineral matter free basis (dmmf) in Kcal/Kg, Btu/lib as needed.

Hence for proximate analysis results do not have a specific qualitative standard rather than quantitative range, a relative qualitative scale (as; very high, high – intermediate, low and very low) have been developed according to the result of these samples (TS_1-1, TC-1, TS_2-1, TS_3-1, TS_3-2, TC-2, TC-3). But for the ultimate analysis result quantitative standard is used to express according to Speight (1994) and Rasheed et al. (2015) (for hydrogen, nitrogen and oxygen) and Chou (2012) (for sulfur) as described in chapter two and four.

5.1 Proximate Analysis

The results of proximate analysis quantifies the moisture, volatile matter (consisting of gases and vapors driven off during pyrolysis), fixed carbon (non-volatile fraction of carbon) and ash (the inorganic residue remaining after combustion) value of the sample. The value of each analysis is different (Table 5.1, Fig. 5. 5 and Fig. 5. 6). This is used to characterize the quality of the coal in accordance with different approaches integrated with other analyses.

Moisture

This is an important property of coal as they, probably all, are mined wet since through all process it has moisture in different types. In this research the moisture content of samples taken in the study area ranges from very low, 5.01 (TS_1-1), to high, 11.22 % (TC-3) (Table 5.1). The samples in southern part of the study area, from S_3 stratigraphic section bed no. S3BD4 (TS_3-1) and S3BD5 (TS_3-2) have low and very low moisture content, 9.73 and 5.44 % respectively. And also in the SWW part, from S_2 stratigraphic section bed no. S2BD1 (TS_2-1) sample has low (9.54 %) moisture content. From all coal samples taken in the study area relatively high moisture contain sample is exposed along NE of the study area side of the Bodi Ara ridge with 10.99 (TC-2) and 11.22 % (TC-3).

The moisture content of coals around the world ranges from 5% to nearly 70% which is an undesirable constituent as it reduces the heating value and adds weight to the transportation cost. The increased and the decreased values of this parameter has its own influence on the quality of the coal (Stach et al., 1982), however, to characterize the coal generally it becomes better when integrated with other results. Generally, the moisture value of the collected samples is relatively low as compared with hence coals contain up to 70 %. However, it does not mean that the lower moisture coal is quietly, independently, the indication of all high rank coal.

Volatile matter (VM)

Volatile matter (VM) in coal refers to the thermal decomposition products liberated when coal is heated at high temperature in the absence of air. The VM value of the samples collected in the study area ranges from low, 5.72 (TS_2-1), to high, 38.40 % (TC-2) (Table 5.1). In the S3 stratigraphic section the VM value of samples from bed no. S3BD4 (TS_3-1) and S3BD5 (TS_3-2) is low (29.75 and 23.20 % respectively). The sample TS_1-1 from S1 stratigraphic section contains intermediate VM, 34.77 %. The samples from S_4 section contains relatively higher VM as compared with those in the Southern, SWW and SW part of the study area.

The amount of VM is used to establish the rank of coals, to provide the basis for purchasing and selling, or to establish burning characteristics such as combustibility (reactivity) of a coal, and ease of ignition and hence flame stability. The increased VM content is more characteristic of low-rank coals, while the decreased value is more typical of higher-rank coals (Stach et al., 1982). The high VM yield is also indicative for the enrichment in liptinite, hydrocarbons, CO,

CO_2, and chemically combined water, and for the depletion in inertinite (Berkowitz, 1979). In order to evaluate the coal integrated results could come up and individual results do not strictly taken to characterize the value.

Fixed Carbon (FC)

The FC content of the coal is the carbon found in the material which is left after volatile materials are driven off. The FC content of the samples taken in the study area ranges from very low, < 0.02 (TS_2-1), to intermediate, 45.22 % (TC-2). The highest FC content sample, TC-3, is exposed along the NE part of the study area side from Bodi Ara ridge. It is the higher FC next to TC-2. In the SW direction of the study area TC-1 sample contains low FC (34.20%) which is the third higher FC content relative to other samples. From S_3 stratigraphic section the upper bed (bed no. S3BD4, 28.18%) contains higher FC than the lower (bed no. S3BD5, 12.17%) while in the S_1 stratigraphic section TS_1-1 contains FC, 24.79% (Table 5.1). TS_2-1 and TS_3-2 coal samples contains very low FC.

The FC values are highly dependent on the values of C and OM in coals (Fig. 5.3). It is well known that the FC content increases with coal rank advance (TS_2-1, TS_3-2, TS_1-1, TS_3-1, TC-1, TC-3, TC-2 with respective of their FC). It is used as an estimate of the amount of coke that will be yielded from a sample of coal.

Ash

The ash in a coal, which is the non-combustible residue left after carbon, oxygen, sulfur and water are driven off during combustion, represents the bulk mineral matter. The ash value of the samples in the study area ranges from very low (TC-2, 5.39 %) to very high (TS_2-1, 84.81 %). The result (Table 5.1 and Fig. 4.10) shows that bed no. S1BD4 (TS_1-1) from S_1 stratigraphic section has very high ash, 59.18%. The analysis result confirms also that TC-2 and TC-3 sample have very low and low ash. The ash yield is commonly used as an indication of the grade or quality of a coal since it provides a measure of the incombustible material.

The high ash yield is normally marked by the relatively abundant supply of detrital materials in swamp (TS_2-1 and TS_1-1, refer Table 5.1), wherein; the authigenic minerals dominate mostly in low-ash (8-10%) coals (TC-2 and relatively TC-3). The proportion of detrital minerals increases and the concentration of organically bound elements decreases (Nicholls, 1968; Finkelman, 1988) with increased ash yield (FC vs Ash, Table 5.1).

According to Sahni et al. (2006) low-ash (<10%) coals also contain biogenic inorganic matter in addition to authigenic minerals, whereas those with higher ash yield (>10%) show simultaneous enrichment in detrital and authigenic inorganics. High ash value coal leads to requirement of more number of mills and also influences sizing of primary air fans, air pre-heaters, electro-static precipitators as well as coal and ash handling systems (Raaj et al., 2016).

Table 5.1 Proximate analysis result of samples. All values are in %.

Bed No.	Sample Code	Moisture	VM	FC	Ash
S1BD4	TS_1-1	5.01	34.77	24.79	59.18
	TC-1	7.78	31.00	34.20	27.02
S2BD1	TS_2-1	9.54	5.72	< 0.02	84.81
S3BD4	TS_3-1	9.73	29.75	28.18	32.34
S3BD5	TS_3-2	5.44	23.20	12.17	35.43
S4BD1	TC-2	10.99	38.40	45.22	5.39
S4BD2	TC-3	11.22	35.74	39.41	13.63

Mostly the increase in FC is related with the decrease in ash value which in turn increases in CV (Fig. 5.1, Fig. 6.3). But the increase or decrease in a single value is not quietly the only factor for the other one to be changed (Fig. 6.2, XVI-B and Fig. 6.4, sample 2). There is a decrease in ash value, yet, the FC is also decrease.

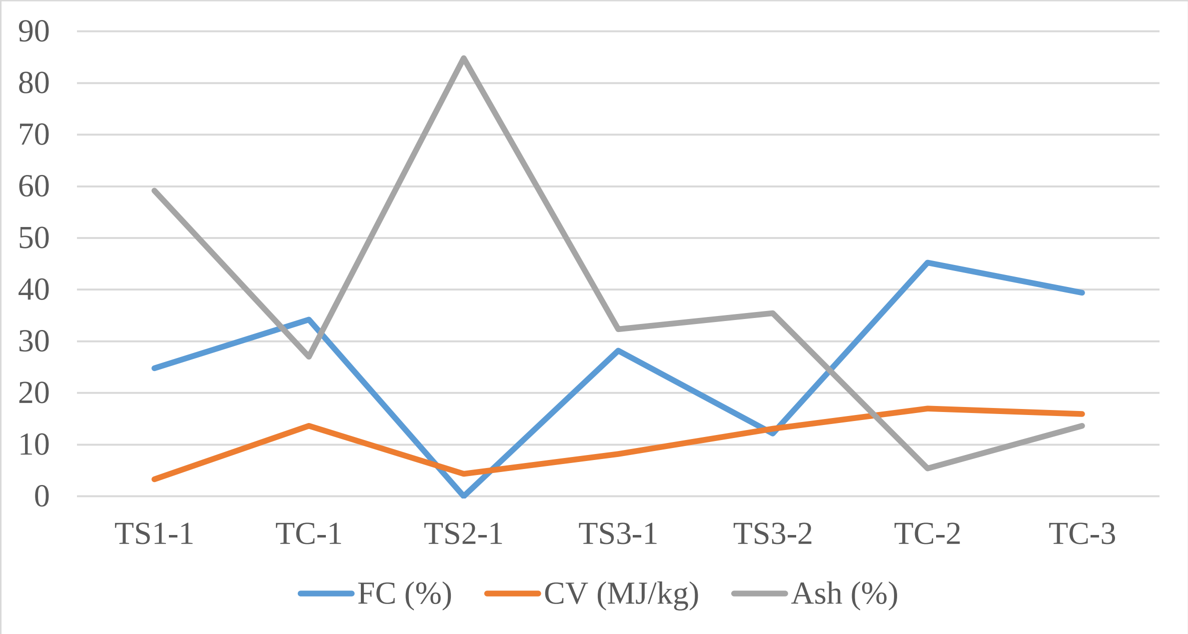


Fig. 5.1 FC, CV and ash value comparison trend of Tercha coal.

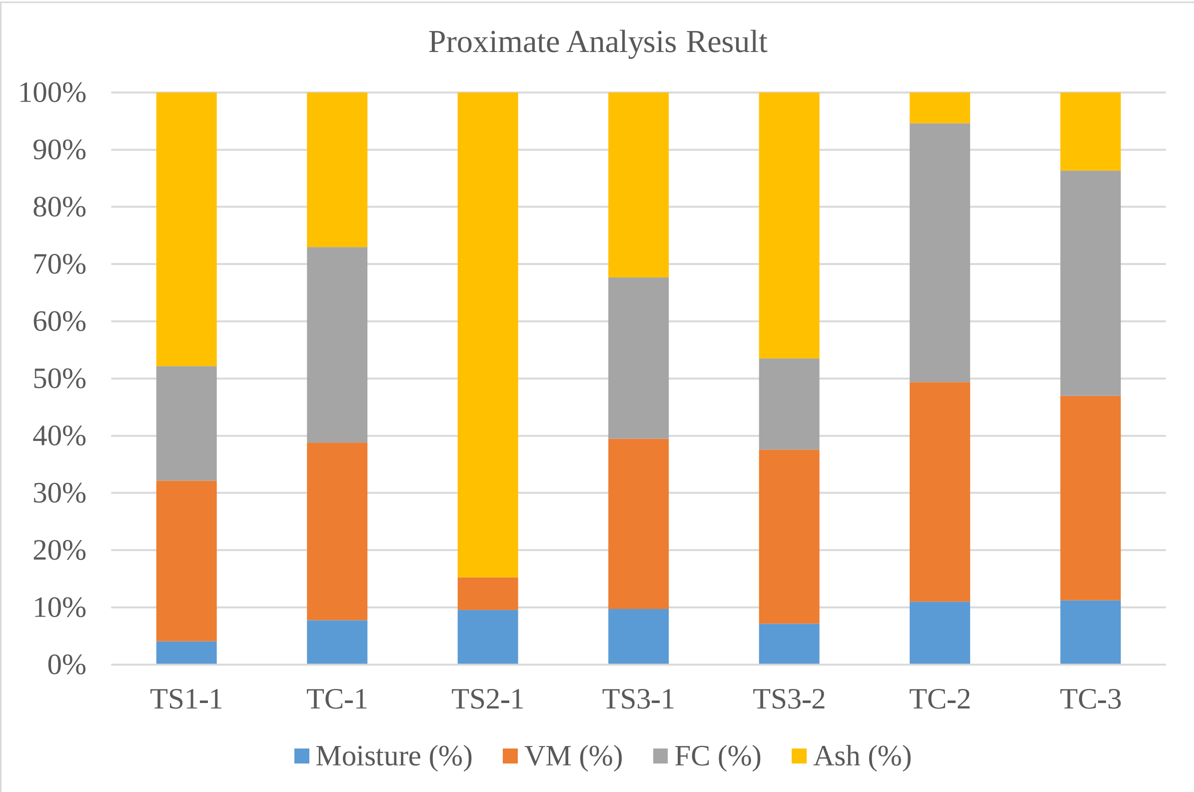


Fig. 5.2 Graphic representation of proximate analysis result by column chart.

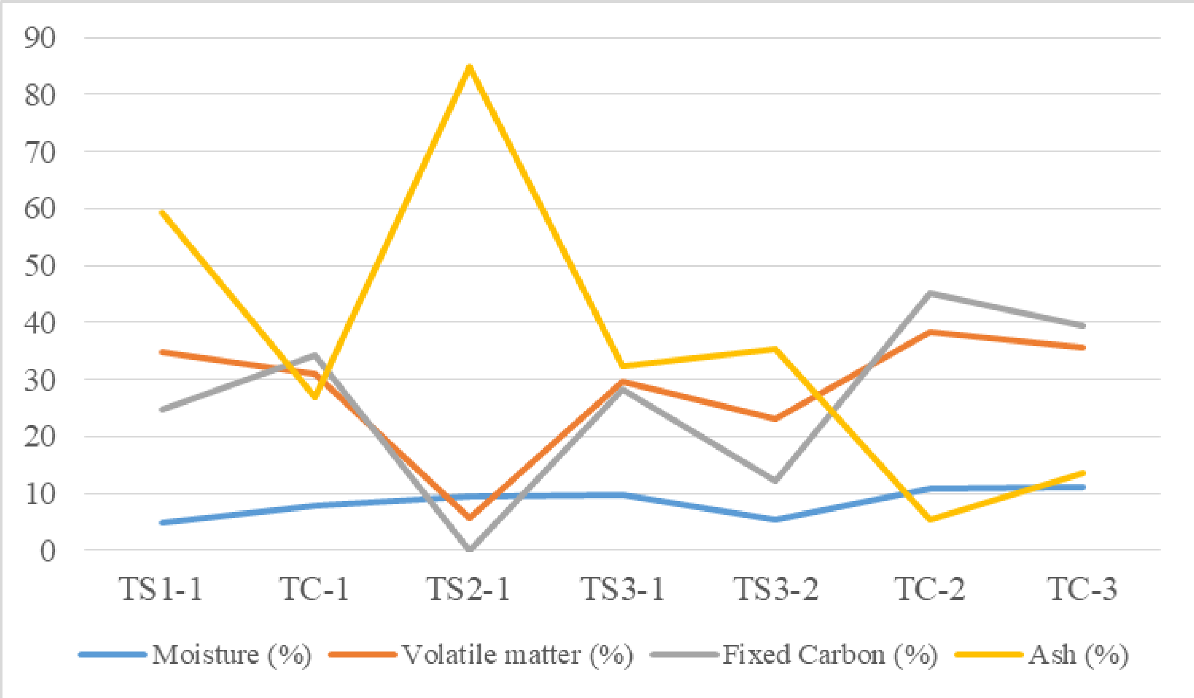


Fig. 5.3 Graphic representation of proximate analysis result by line chart.

5.2 Ultimate Analysis

The ultimate analysis of coal includes determination of the weight percent of carbon as well as sulfur, nitrogen, and oxygen in percent as received basis. Trace elements that occur in coal are often included as a part of the ultimate analysis (Speight, 1994). The carbon determination includes carbon present as organic carbon occurring in the coal substance and any carbon present as mineral carbonate. The hydrogen determination includes hydrogen present in the organic materials as well as hydrogen in all of the water associated with the coal whereas all of the nitrogen is assumed to occur within the organic matrix of coal.

However, sulfur occurs in three forms in coal: (1) as organic sulfur compounds; (2) as inorganic sulfides that are, for the most part, primarily the iron sulfides; pyrite and marcasite (FeS_2); and (3) as inorganic sulfates (e.g., Na_2SO_4, $CaSO_4$). The results of analyzed parameters Carbon, Hydrogen, Nitrogen, Sulphur and Oxygen are presented in Table 5.2. The results of selected samples of the study are discussed below in detail.

Carbon

Carbon, which accounts for 70 to 95% of the organic substance of coal, is the most important constituents of coal. The carbon content in the collected coal samples from the study area varies from low (TS_1-1, 51.78%) to high (TC-3, 81.14%). The intermediate carbon content from the analyzed samples are TS_3-1 and TS_3-2 with 62.47 and 67.3 % respectively.

The high concentration of carbon is normally characteristic of vitrinite macerals (relatively TC-2, TC-3 and TC-1) (Stach et al., 1982; Berkowitz, 1979) but inertinite group macerals also characterized by a high carbon content resulting from thermal or biological oxidation (Curley, 2012). It is also well known that the carbon content in coal increases steadily with increasing coal rank (Table 5.2) (Stach et al., 1982; Berkowitz, 1979; Li et al., 2010). The measurement of carbon concentration in coal is still the leading and most accurate parameter among other chemical characteristics for evaluation of coal rank (Stach et al., 1982; Vassilev et al., 1996; Berkowitz, 1979; Li et al., 2010; Ward, 1984; Kler et al., 1987; Taylor et al., 1998).

Oxygen

The oxygen content is one of the most important characteristics for determining the chemical properties of coal (van Krevelen, 1992). The oxygen content in the samples is 11.14, 18.25 and 23. 36 % of TC-2, TC-1 and TS_3-2 respectively (Table 5.2).

The increased content of oxygen is characteristic of low rank coals, while the decreased concentration is typical of higher-rank coals (Stach et al., 1982; Li et al., 2010). The loss of oxygen occurs in the later stages of metamorphic development of coal due to the well-known decrease in oxy-containing functional groups as carboxylates and increase in aromaticity (Stach et al., 1982; Berkowitz, 1979).

Hydrogen

Hydrogen, which accounts 2 to 6% by weight of the organic substance of coal, present in the various forms of moisture found in coal in addition to its combined form with carbon in organic compounds (Speight, 1994). The hydrogen content of the samples is found very high (TC-3, 6.21 %) and high (TC-1 and TS_3-2, 5.54 and 5.43 % respectively) (Table 5.2).

The increased content of hydrogen is normally more characteristic of low rank coals, while the decreased values are commonly more typical of higher-rank coals. The hydrogen concentrations increase with increasing liptinite, alginite, resinite, sporinite, cutinite (Berkowitz, 1979; Kler et al., 1987). Wherein; liptinites have the highest hydrogen content among all macerals (Ting, 1978). The enhanced hydrogen concentration is also a characteristic feature of sapropelic coals (Berkowitz, 1979). Hydrogen is an important component of emissions in the way that water in the atmosphere combines with sulfur dioxide (SO_2) to form sulfuric acid (H_2SO_4), which is a regulated pollutant that contributes to acid rain.

Sulfur

Sulfur is an important consideration in coal utilization. The sulfur content of the samples range from very low (TS_3-1, 0.08) to very high (TS_1-1, 3.06%). According to Chou (2012), coals are generally termed as low sulfur (≤ 1% sulfur content) (TC-1, TS_3-1, TC-2 and TC-3), medium sulfur (≥1 to ≤ 3% sulfur content) (TS_2-1 and TS_3-2) and high sulfur coals (≥ 3 % sulfur content) (TS_1-1) based on their sulfur contents.

High sulfur coals are known to derive most of their sulfur from reduction of sulfate ions to H_2S in swamp water in the coal beds by microbial processes (Calkins, 1994). The decreased values of this element are very good for different utilities. The emission of sulfur oxides leads to the corrosion of equipment and slagging of combustion or boiler equipment, as well as contributing to atmospheric pollution and environmental damage. Sulfur data are therefore necessary for the evaluation of coals to be used for combustion purposes (Speight, 1994).

Nitrogen

Nitrogen occurs almost exclusively in the organic matter of coal. Very little information is available concerning the nitrogen-containing compounds present in coal, but they do appear to be stable and are thought to be primarily heterocyclic. The Nitrogen content in the coal samples of the study area is very high in which 2.14 (TC-1), 2.48 (TS_3-2) and 2.78 (TC-3) %.

The increased contents of nitrogen are normally more characteristic of higher-rank coals (Table 5.2) (Williams and Keith, 1963). Oxides of nitrogen are an environmental concern because they produce nitric acid (HNO_3), which contributes to acid rain. They also contribute to the formation of ground-level ozone, an ingredient of smog, another human health concern (Energy Information Administration, 2003).

Table 5.2 Ultimate analysis result of samples. All values are in %.

Bed No.	Sample Code	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
S1BD4	TS_1-1	51.78	-	-	-	3.06
	TC-1	73.45	6.21	18.25	2.14	0.43
S2BD1	TS_2-1	56.15	-	-	-	1.36
S3BD4	TS_3-1	62.47	-	-	-	0.08
S3BD5	TS_3-2	67.3	5.54	23. 36	1.78	2.13
S4BD1	TC-2	79.8	-	-	-	0.82
S4BD2	TC-3	81.14	5.43	11.14	2.48	0.46

The pie-chart representation of the studied area coal ultimate analysis results show that the relative proportion of each four elements out of 100% hence the sum up of all elements is 100.

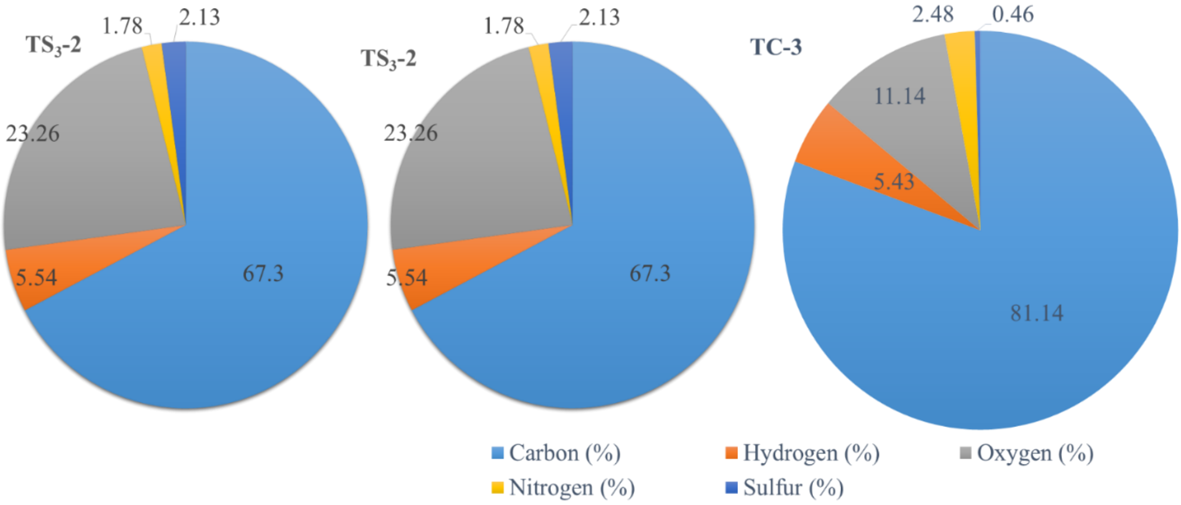


Fig. 5.4 Pie-chart representation of ultimate analysis result.

5.3 Total Organic Carbon (TOC)

Total organic carbon (TOC) is a measurement of the organic richness in a given sedimentary rock reported in weight percent of organic carbon. The organic carbon content of the studied area coal ranges from very low (TS_2-1, 0.01%), which did not expect to convert to other liquids or gases, to high (TC-3, 67.1%) (Table 5.3). Seam 2 (TS_3-1, TS_3-2) and TC-1 coal has an intermediate TOC values; 38.3%, 44.5% and 41.4% respectively. Seam 1also has moderately intermediate value 37.5%. The highest TOC content coal relative to other seams is Seam 3 which found NE of the study area.

Derived from organic matter, organic carbon is the component of the rock sample that can potentially convert to hydrocarbons (Jarvie, 1991). TOC analysis is usually the first screening process done to assess potential for hydrocarbon generation, through liquefaction and gasification from coal. A TOC value of 1 wt. % implies that in 100 grams of sediment, only 1 gram organic carbon exists (Jarvie, 1991). However, coal generally contains greater than 50% by weight and 70% by volume of TOC (Rice, 1993).

Table 5.3 Calorific value and TOC values of samples. (1Kcal/Kg = 0.002326 MJ/Kg, 1Kcal/Kg = 1.8 Btu/lib)

Bed No.	Sample Code	Carbon content in (%Wt.)		Gross Calorific Value in moist, mineral matter free basis		
		Total Carbon	Organic Carbon (TOC)	(Kcal/Kg)	MJ/kg	Btu/lib
S1BD4	TS_1-1	>50	37.5	1416	3.29	2549
	TC-1	48.3	41.4	5850	13.61	10530
S2BD1	TS_2-1	0.09	0.01	1870	4.35	3366
S3BD4	TS_3-1	>50	38.3	3512	8.17	6322
S3BD5	TS_3-2	>50	44.5	5615	13.1	10107
S4BD1	TC-2	>50	62.3	7300	16.97	13140
S4BD2	TC-3	>50	67.1	6846	15.93	12323

5.4 Calorific Value (CV)

The energy value of coal, the amount of potential energy, has a great importance to use it in another fuel forms or directly. Directly by converting the chemical energy in it to actual heating ability and then at a power plant into electric energy with determined efficiency. The CV of the samples collected in the study area from the stratigraphic sections (Fig. 3.9, 3.10, 3.11) as well on the outcrop ranges from 1416 (TS_1-1 sample code and in S1 stratigraphic section Fig. 3.9 S2BD4 bed No.) to 7300 (TC-2 sample) Kcal/Kg (Table 5.3 below).

Samples collected in SW of the study area have the CV ranges from 1416 to 5900 (TS_3-2 sample) Kcal/Kg. From S_2 (Fig. 3.10) stratigraphic section in the S2BD1 bed no. TS_2-1 sample has 1870 Kcal/Kg CV. In S_3 stratigraphic section (Fig. 3.11) two samples, from S3BD4 bed no. (TS_3-1) and from S3BD5 bed no. (TS_3-2), have 3512 and 5615 Kcal/Kg CV respectively. The samples TC-1, TC-2 and TC-3 are taken from the SW and NE part of the study area at different ridge side respectively (Fig. 3.). In the NE, TC-2 and TC3 had 7300 and 68460 Kcal/Kg CV respectively while the TC-1 sample has 5850 Kcal/Kg CV (Table 5.3).

5.5 Classification

Coals have usually been classified according to the coal's chemical properties in relation to their industrial usage. Several classifications are in common usage, which classify both hard and brown coals, and refer to particular parameters; the percentage of fixed carbon and volatile matter (on a dry mineral matter free basis), calorific value (on a moist mineral matter free basis) and the caking properties of coal (Free Swell Index and Roga index). Coals have been classified either for 'academic' purposes or for different uses, commercially.

5.5.1 Rank

Coal exists, or is classified, as various types and ranks that each has distinctly different properties from the other. The ASTM classification (D 388-99), used on a worldwide basis, is based on two coal properties, the fixed carbon values and the calorific values (in dmmf basis). The higher rank coals are classified according to fixed carbon, the lower rank coals are classified according to gross calorific value, which is here used to classify the coal of the study area (Table 5.4). A correlation of the ranks property and volatile matter with the mean maximum reflectance group of macerals ASTM D2798-09 is used as supplemental. Further classification is given for those coals with agglomerating or coking properties. The coal in the study area, hence as the analysis results confirm there is no coal which has higher CV greater than 15000 Btu/lib that leads to classify based on their VM and FC values, the rank as well agglomerating character, depends only on CV. Based on this scheme the rank of the studied area coal ranges from lowest energy value, which is not even capable to be in the lowest range

Of rank (2549 and 3366 Btu/lib), to high volatile B bituminous (13140 Btu/lib) of TS_1-1 and TS_2-1 and, TC-2 coal samples.

Table 5.4 Classification of Tercha coal based on ASTM standard.

Bed No.	Sample code	Calorific Value (Btu/lib, moist, mineral matter free basis)	Rank	Agglomerating Character
S1BD4	TS_1-1	2549	-	-
	TC-1	10530	Sub bituminous A	agglomerating
S2BD1	TS_2-1	3366	-	-
S3BD4	TS_3-1	6322	Lignite A	Non agglomerating
S3BD5	TS_3-2	10107	Sub bituminous B	Non agglomerating
S4BD1	TC-2	13140	High volatile B bituminous	Commonly agglomerating
S4BD2	TC-3	12323	High volatile C bituminous	Commonly agglomerating

The coal samples taken from S_1 and S_2 stratigraphic sections have lowest rank while S_3 has both Lignite to sub bituminous of the upper and lower beds, S3BD4 and S3BD5 respectively. The highest rank coal sample is found NE of the study area, TC-2. S_3 section also has the lower rank while the lowest found in S_1 and S_2 stratigraphic sections of the area. The agglomerating characteristic of coal also varies as agglomerating (TC-1), commonly agglomerating (TC-2 and TC-3) and non-agglomerating (TS_3-1 and TS_3-2). Generally, the rank of each coal is different while their agglomerating characteristic is shared by some coals of different rank.

5.5.2 Type

As discussed in chapter two section 2.1.1, coal is composed of the sum of all the organic matter preserved and buried as peat. Changes in the chemical and physical properties of whole coal are the summation of, eventually, changes to the coal constituents. There are three main groups of macerals, that constitute coals, used to define coal type identified under an optical microscope in reflected white light microscope (refer section 2.1.2). They are characterized by materials that belong together because of their similar origin or mode of preservation as well as by their gross chemical composition (in this case the research implies the material based on the proportion of elements according to Curley (2012)).

Vitrinite group macerals contains relatively more oxygen (relatively TS_3-2) than the other macerals at any given rank level but they are also usually the most abundant maceral group occurring in higher rank coals. Liptinite group macerals are characterized by having higher hydrogen content than the other macerals (TC-1, TS_3-2 and TC-3). However, at the boundary between subbituminous and bituminous coal there is a marked decrease in their volatile content and increase in carbon. The inertinite group macerals are characterized by a high carbon content resulting from thermal or biological oxidation (relatively TC-2 and TC-3) (Teichmüller and Teichmüller, 1966).

5.5.3 Grade

Coal grade is a term used to indicate the value of coal material as determined by the amount and nature of range of impurities (ash yield and the sulfur content) following the complete oxidation of the organic fraction. The calorific value of coal is taken as one of the principal measures of a coal's value as a fuel because of it is directly influenced by mineral impurities.

Formal classification systems have not been developed with regard to the grading of coal; however, grade is important to the coal user. But, according to the Government of India, Ministry of coal, since 2014, the grading of non-coking coal is based on Heat Value (HV), the grading of coking coal is based on ash content and for semi coking / weakly coking coal it is based on ash value plus moisture content (https://coal.nic.in/content/coal-grades).

The chemical analysis of the studied area coal, so that, have different grading scale from coking to semi-coking grade. The coking grade coal which has not exceeding 15% ash content that is

TC-2 and TC-3 scale as steel Grade-I where as S3 stratigraphic section, TS_3-1 and TS_3-2, is Washery Grade –IV in which their ash content ranges from 28 – 35%. TC-1 is graded as Washery Grade –III (ash ranges from 24 – 28%). TC-2 also characterized as Semi coking grade – I because of that the sum up result of ash and moisture is not exceeding 19%. Generally, the studied area coal is graded as Steel Grade- I, Washery Grade –III, Washery Grade –IV and Semi coking grade – I. The coal in S1 and S2 stratigraphic sections is not in the range used to grade of coal as their value is lower.

Table 5.5 Grading of Tercha coal.

General specification for Grades of Coking Coal		Samples which are found in the range
Grade	Ash	
Steel Grade - I	Not exceeding 15%	TC-2, TC-3
Steel Grade -II	Exceeding 15% but not exceeding 18%	-
Washery Grade -I	Exceeding 18% but not exceeding 21%	-
Washery Grade -II	Exceeding 21% but not exceeding 24%	-
Washery Grade -III	Exceeding 24% but not exceeding 28%	TC-1
Washery Grade -IV	Exceeding 28% but not exceeding 35%	TS_3-1, TS_3-2
General Specification for Grades of Semi-coking and Weakly Coking Coal		
Grade	Ash + Moisture Content	Sum up results sample
Semi coking grade - I	Not exceeding 19%	TC-2
Semi coking grade - II	Exceeding 19% but not exceeding 24%	

5.6 Resource Estimation

The estimation of any coal resource is carried out to make sure that it can be mined economically and marketable. For this purpose, a number of countries and organizations have cooperated in developing sets of definitions and methods to be used to calculate coal resources and reserves. These include the principal coal-producing countries (Thomas, 1992). In this research for the evaluation of the resource in the study area the world class coal producer countries standard is used. Although other variations of resource and reserve classification codes are currently used and/or are proposed for international use, the JORC Code is widely used and stock exchanges and financial institutions are now fully familiar with its principles and definitions. And also this standard is virtually similar with the South African Code for Reporting of Mineral Resources and Mineral Reserves, the SAMREC, Code (2009). This is the reason that JORC standard is selected.

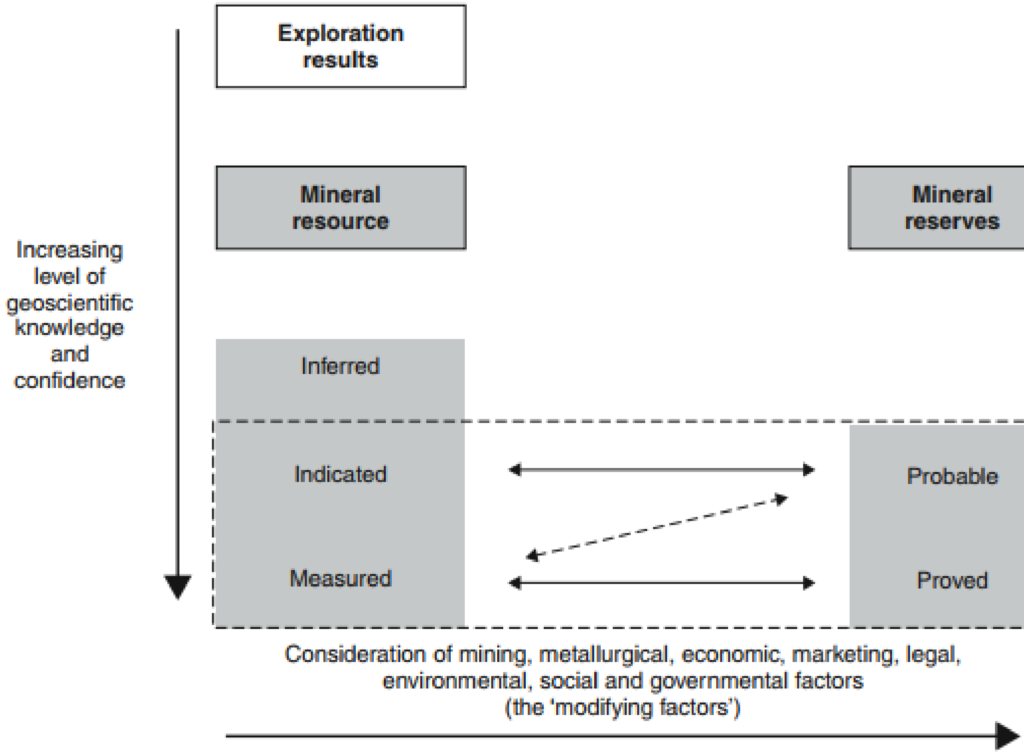


Fig. 5.5 Relationship between mineral resources and mineral reserves (Thomas, 1992).

The coal found in the study area exposed separately with different orientations (Fig. 4.10) having different rank and grade. In order to estimate the resource in the study area detail further analyses are needed. However, these data are not known the resource estimation of the coal is inferred. The calculation is based on the average thickness of the coal and the area exposed on the surface with estimating the sub-surface extension to some extent.

Both SWW and SW coal occurrence is not exposed widely on the surface in more than one observation point because of burial. In addition to this, they are very thin in thickness and dominated by non-coal materials. Samples taken from different part of the study area, also, shows values less than the standard (TOC, CV, proximate and ultimate analysis results) for any utilization.

Alternatively, to the southern and NE part coal possess high quality coal and considerable thickness. However, resource calculation for these was done separately as they are found in different swamps with a considerable distance. To make clear the seams occurrence plane view map (Fig. 5.6 - for southern by extending of estimating the sub surface and Fig. 5.7 - for NE) is produced by removing the overburden. Since there is no any previous drilling conducted in the study area the resource potential calculated in this research is inferred. The area is calculated using ArcGIS. The relative density used for the calculation is specific gravity which varies between different coal ranks.

NE coal displays high thickness variation across the exposed area. For that reason, the coal mapped area is subdivided into two, Area 1 and Area 2 (Fig. 5.6), to consider the thickness variation in the resource estimation. The coal rank is bituminous and the specific gravity of these group of coals ranges from 1.1-1.4 g/cm^3. Considering the range, average value is used for the calculation for both areas. For Area 1 the resource amount is;

Coal thickness (m) × area 1 × RD = total ton,

6m × 1.95Km^2 × 1.25 t/m^3 = 14.62 Mt.

For Area 2 the inferred resource potential is;

Coal thickness (m) × area 2 × RD = total ton,

1m × 1.43Km^2 × 1.25 t/m^3 = 1.78 Mt.

Total inferred potential of Seam 3 = Area 1 + Area 2 = (14.62 + 1.78) Mt

= 16.4 Mt.

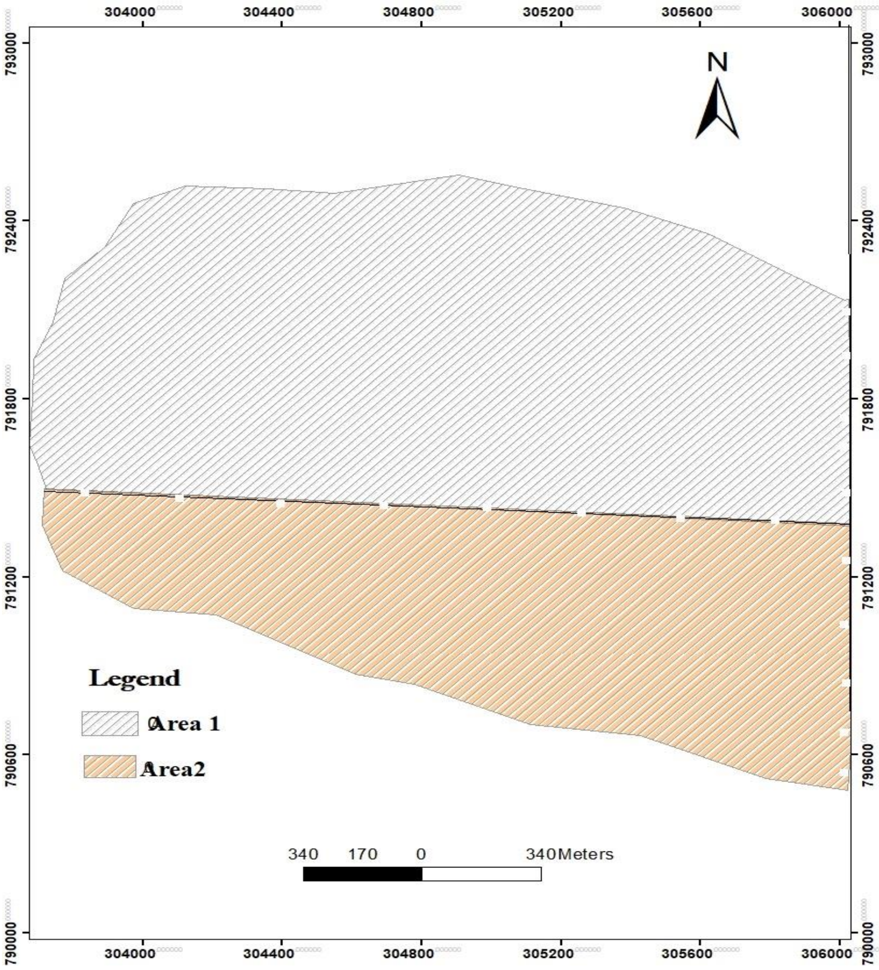


Fig. 5.6 Plane view of seam 3 which is found NE of the study area.

For the SW cal (Fig. 5.7), hence its rank is lignite and subbituminous, the relative density is 1.3. The northern end of this seam is pinch out. This is because of that the seam exposed as tilted bed in which the northern extension is uplifted (ridge top) which eroded later. The lateral extension of this coal is taken by estimating the lateral extension of the correlated coal.

Therefore; the resource amount of this coal is;

Coal thickness (m) × area (seam 2) × RD = total ton.

1m × 7.38Km^2 × 1.3 t/m^3 = 9.59 Mt.

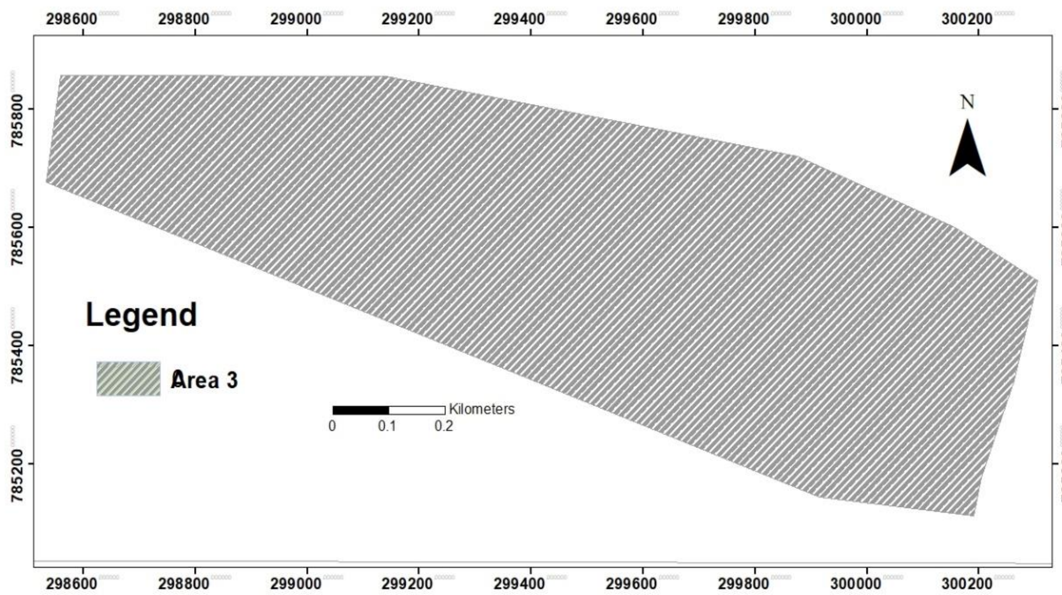


Fig. 5.7 Plane view of seam 2 which is found Southern of the study area.

One ton of coal equivalent equals 1 metric ton (2,205 pounds) of coal with a heating value of 29.3 mega joules per kg (12,600 British thermal units per pound) (Curley, 2012) so that the NE and SW coal have 480.52 and 280.98 million MJ/Kg heating values respectively.

CHAPTER SIX

6. DISCUSSION

6.1 Characteristics of the Deposit

The coal resource found around Tercha is exposed along NE (S_4 stratigraphic section), South (S_3 stratigraphic section), SWW (S_2 stratigraphic section) and SW (S_1 stratigraphic section) part of the study area with different physical and chemical characteristics having different thickness intercalated with other sedimentary units (Fig. 4.10, 4.11, 4.12, 4.13). The coal have different color, luster, strength, rank, grade and type. Different sedimentary structures like bedding, lamination, cleat and seam splitting are also found. The presence of these structures, mainly cleat and seam splitting, have their own influence in the quality of the resource. The seam splitting cause is mainly due to the leaching of mobile elements from the clastic materials down depending on the depositional condition that are deposited. The presence of cleats in the coal has their own role in environmental friend making with the people live around. Hence through openings gaseous molecules (moisture, VM and sulfates) are already escaping so that if exploration proceeds enhanced environmental effect might not face.

The coal present along NE part is found by making horizontal bed and it has relatively better quality than the other seams. It has high thickness relative to other coal beds with best shinning characteristic and sub-conchoidal fracture when hammered. These characteristics are the indication of increasing rank coals. The chemical analysis and CV of the samples from this stratigraphic section confirms that it is high bituminous C to high bituminous B in rank and steal grade I.

The coal bearing sediments found SW part are found as inclined bed with different strike and dip orientation. In S_3 stratigraphic section characteristically different beds are found (Fig. 4. 12). The coal found in this section has good thickness relatively than S_1 and S_2 sections coal (Fig. 3. 10). S3BD5 coal bed, in this section, is sub-bituminous B in rank and washery grade IV in which relatively higher than S3BD4 (Lignite A) bed of the same section. Whereas TC-1 sample is better in rank (sub-bituminous A) and grade (washery grade III) than the coal found in S_3 stratigraphic section. The coal, in S_1 and S_2 section, are the lowest in rank and grade and even below to the classification standard used. The NE part coal is the highest rank and grade coal in the study area (Table 5.4 and Table 5.5). Generally, the studied coal ranks from Lignite A – High bituminous B in Steel grade I, semi-coke grade I and washery III and IV grade.

6.2 Energy Value

The energy value of coal, or the fuel content, is the amount of potential energy in coal that can be converted into actual heating ability. This value is affected by a range of impurities which are mineral matters, authigenetic or detrital minerals, found in the coal. These decreases the value of the coal, rank and utility scope and also causes environmental health problems. Because the physical properties and chemical quality vary widely, coal-fired power plants must be engineered to accommodate the specific properties of available feedstock and to reduce emissions of pollutants such as sulfur, mercury, and dioxins as it contains a variety of minerals in varying proportions that, when the coal is burned, are transformed into ash. The stored potential energy within coal is described as CV which is directly related to rank.

The energy of the studied area coal varies with respect with the CV, rank and grade values of the resource. NE part of the study area coal has high energy value in terms of rank (high-volatile bituminous B) and grade of steel grade-I. Its CV is the highest relative to coal beds and even with Ethiopian best known coal deposits which are in this rank and energy. Southern part of the study area coal is relatively better than SW and SWW part coal beds, however its energy value is optimum in the way that it can be blended with each other, because of the coal has different ranks, or other coals to improve the energy. The energy of coal beds in S_1 and S_2 stratigraphic section is very low and its rank and grade is below the need for other uses.

Sulfur content, ash fusion temperatures (i.e., measurement of the behavior of ash at high temperatures) and the quantity of trace elements in coal are also used to grade coal. Hence mineral matter may occur as finely dispersed or in discrete partings in the coal, the mineralogy challenges during coal preparation/cleaning, the coal combustion and conversion (i.e., production of liquid fuels or chemicals) characteristics, and metallurgical coke properties (Miller, 2005).

6.3 Utilization of Coal

Coal is a bounteous resource that has been used for long period to produce energy. This is in the form of both heat and electricity in combustion or by conversion into useful solid, gaseous and liquid products. The most common and important use of coal is in combustion (in which heat is generated to produce steam, which in turn powers the turbines that produce electricity) even metallurgical coke also be the major product of coal conversion. Though, coal has verities of utilities, sulfur and ash values are always under consideration in great deal in any coal usage. High sulfur coals are unsuitable for efficient use, such as combustion, gasification, carbonization, liquefaction, etc. Direct combustion of high sulfur coals produces SO_2 which leads to acid rain and corrosion of boilers, pipelines and other machineries (Mukherjee and Borthakur, 2003). In the steel industry, low-sulfur coals are used for coking. In general, total sulfur contents less than 0.8 % are used to make coke for steel (TC-2, TC-3, TC-1 and TS_3-2) (Table 5.2) (Stach et al., 1982; Thomas, 1992; Suárez-Ruiz and Crelling, 2008).

Coal has two kinds in broad term accordingly to its use: steam coal, which is used to generate electricity, and metallurgical coal, which is used in the production process for certain metals, especially steel. Virtually all steel utilizes coal. Metallurgical coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace. The result is pig iron, and is too rich in dissolved carbon, so it must be treated further to make steel. The amount and nature of the ash and its behavior at high temperatures affect the design and type of ash-handling system employed in coal-utilization plants too (Stach et al., 1982; Thomas, 1992; Curley, 2012). Though it is known as described above the utilization of coal is different, the discussion here below is based on the quality of the coal found in the study area.

6.3.1 Caking and Steam Coal

Coke is the purified, hot, liquefied carbon that solidifies into lumps. This can be fed into a blast furnace along with iron ore and limestone to produce steel. In terms of coal properties, coke quality is largely influenced by coal rank, composition (reactive and inert macerals and minerals), and an inherent ability when heated to soften, become plastic, and resolidify into a coherent mass. Several properties of coals are measured to identify appropriate coking coals, including swelling, fluidity, composition, maceral analyses, and vitrinite reflectance (Van Krevelen, 1993; Ward, 1984; CIBO, 2002). The mineral matter, or ash, content of the coal is of interest in coke production because the ash dilutes the coal and affects its caking properties. The composition of the ash is also important, as the quality of iron and steel is affected by the sulfur and phosphorus content.

Although, some analysis (like CV and organic geochemistry) alone cannot be used to predict whether a coal is suitable for coking or not. Coals that are low in rank (TS_3-1), such as lignites, or high in rank, such as anthracites, do not cake and therefore are not capable of forming coke.

In the steel industry, low-sulfur coals are used for coking. In general, total sulfur contents less than 0.8 % are used to make coke for steel (TC-2, TC-3, TC-1 and TS_3-2) (Stach et al., 1982; Thomas, 1992; Suárez-Ruiz and Crelling, 2008). It is necessary for the formation of coke that some of the coal's organic constituents or macerals melt when the coal is heated. The relative proportions of reactive and inert materials in a coking coal affect the strength of the final carbonized product. It is common practice to blend high-volatile coals with low-volatile and/or medium-volatile coals to improve the strength of the coke (TC-2, TC-3, TC-1, TS_3-2, and TS3-1) (Miller, 2005).

Steam coal, also known as thermal coal, is suitable for electric power production. Steam coal is ground into a fine powder that burns quickly at high heats and is used in power plants to heat water in boilers that run steam turbines. It may also be used to provide space heating for homes and businesses. According to Speight (2012) bituminous, sub- bituminous, and lignite (TC-2, TC-3, TC-1, TS_3-2, and TS3-1), exclusively, rank coals are used primarily as fuel in steam-electric power generation. However, bituminous coal with substantial quantities also used for heat and power applications in manufacturing and to make coke.

Total sulfur is an important criteria in steam coal. This is because of that sulfur combines with oxygen in boilers and form sulfur dioxide (SO_2), which is emitted in the gas stream. Then SO_2 reacts with water vapor to form sulfurous acid (H_2SO_3), which oxidizes to sulfuric acid (H_2SO_4), a major component of acid rain. Coals with high sulfur are also causes corrosion of boilers, pipelines and other machineries (Mukherjee and Borthakur, 2003). Generally, high sulfur coals (TS_1-1, TS_2-1 and TS_2-2) are not suitable for efficient use, such as combustion, gasification, carbonization, liquefaction, etc.

6.3.2 Cement

Though limestone is the major source of CaO a wide variety of secondary materials such as coal combustion products can be used as partial substitutes for primary rock-based raw materials. Selection criteria of fuel include composition, energy and other cost savings and the potential to reduce carbon dioxide emissions. The coal residue left after burning was utilized in the cement raw material, for which a new raw mix was designed (Ursula et al., 2002). When coal is burnt with the raw mix, it produces heat which is utilized to convert the raw mix in to clinker. The residue/ash, lift after burning of the coal disturb the composition of raw mix and clinker obtained from it.

The net result of the coal used as a fuel is that, the composition of raw mix does not remains in the limits which may give clinker having all parameters not in accordance to the standard specifications. In order to bring, all the parameters of the resulting kiln feed and clinker to the normal range, new raw mix designing was performed, in which the required amount of coal ash has been incorporated in such a way that the composition of the final raw mix containing coal ash, remains within the specification (Amin and Ali, 2010).

6.3.3 Fertilizer Production

Most of the available farmland lacks, however, enough nitrogen, the building block of chlorophyll and the catalyst of the photosynthesis process, nutrients to be commercially productive. Without nitrogen increasing soil productivity, the world would be utilizing twice more farmland to produce the same quantities of food of today. Nitrogenous fertilizers can be only produced through burning and reforming natural gas or by gasifying coal. However, most countries have not been producing more fertilizers because they do not have low-cost natural gas and have not had the access to the technology to cleanly transform its coal reserves into urea. Actually there is no clear specification of coals specifically for fertilizer production yet, however, coals which has lower sulfur and high nitrogen content are expected to be used. The studied area coal better for this scope hence it fits the requirement accordingly to nitrogen and sulfur content.

6.4 Comparison with other Coal Deposits

Different coal deposits found throughout the world has different physical, chemical, depositional and value characteristics. This difference has its role in the use and commercial track. To make relative value of Tercha coal with other deposits this resource is compared with the Indian Talchar (Appendix IV) and Jharia coals (Appendix V), Waterberg South Africa coal (Appendix III) and other Ethiopian coals (Delbi-Moye, Yayu, Gojeb-Chida, Mush, Nejo, Wuchale, Chilga and Lalo-Sapo) (Table 6.1, Table 6.2, Fig. 6.1, Appendix I and II) which are described in the same unit of measurement. For this comparison CV, FC, ash, nitrogen and sulfur are selected because they have vital roles to characterize the coal for utilization and impact on the coal. The selected results of deposits are the best results to mainly focus on their application and higher status.

Tercha coal has higher FC than Talcher Coal and lower than Jharia Coal but relatively equivalent with other Ethiopian coals. The ash value of Tercha coal is higher than that of Jhaira coal and relatively lower than the Talchar coal. Seam 3 Tercha coal is very lower than other Ethiopian coals. Yayu, Mush Valley and Godeb-Chida coals are relatively lower and others are higher than Tercha coal. The CV of Tercha coal is higher than Talchar and other Ethiopian coals but lower than Waterberg coal. The Talchar and Waterbeg coals are used for power plant project (Kumar et al., 2015; Makgato and Chirwa, 2017).

The sulfur content of the Indian Talchar coal is equivalent with Tercha coal. But TS_3-1 sample has very low sulfur content than the Indian Talchar coal and other Ethiopian coals whereas Seam 3 and TC-1 samples contain equivalent sulfur with Talchar, Nejo, Gojeb-Chida, Wuchale, Moye and Delbi coals. TS_1-1 and TS_3-2 samples have the highest sulfur content relative to Talchar and other Erhiopian coals. The sulfur content of Yayu coal is equivalent with TS_2-1 Tercha coal sample. The Nitrogen content of Tercha coal is higher than the Indian Talchar, low value - intermediate, and other Ethiopian coals.

The CV of Ethiopian coals is low - high in which the Tercha coal, the concern of this paper, has the highest CV of Ethiopian Coal (Table 6.1, Table 6.2 and Fig. 6.1). The next higher value CV content is Delbi – Moye. The best coking coal deposit, Moye area is lower than other Delbi, Nejo, and Tercha so that coal with only high calorific value can't be used as parameter for caking ability characteristic. It has an equivalent of oxygen with Tercha coal value which implies this also be used and be best caking coal. The great issue in deal comes as the value of sulfur increases, the quality of the coal is decrease and increases the hazard. Tercha coal has higher in sulfur content than those of Gojeb-Chida and Moye coals, however, the difference is not that much.

According to Wolela (2007) Yayu coal can be gasified to produce chemical fertilizers as its VM and nitrogen amount is very good with high CV. The general increases and decrease of one parameter does not verify the other in parallel way hence coal is a very complex rock.

Table 6.1 Local coal resource ultimate analysis (%) and CV (Kcal/Kg) results comparison.

Location	CV	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur
Mush Valley	4390	5.72	68.93	1.23	24.12	1.5
Nejo	4990	5.17	72.2	0.82	21.81	0.6
Gojeb - Chida	4080	6.44	73.54	1.28	18.74	0.4
Wuchale	3710	5.41	74.84	1.53	18.22	1.6
Moye	4920	5.34	80.22	2.27	12.17	0.4
Delbi	6580	5.5	66.1	1.11	27.29	0.6
Yayu	5788.9	4.2	69.4	1.2	25.2	1.65
Tercha	7300	5.43	81.14	2.48	11.14	0.46

Tercha result (present study); other results (Wolela Ahmed, 2008).

Table 6.2 Local coal resource proximate analysis results (%) comparison. CV in Kcal/Kg.

Location	Specific Locality	Moisture	VM	Ash	FC	CV	sulfur
Delbi - Moye	BH-21 (142m)	1.2	21.5	18.3	60.2	6900	0.3
Yayu	BH3-1 (62.25m)	11.06	43.99	18.65	54.07	5099	1.52
	BH10-1(78.35m)	10.98	46.53	11.32	42.15	5930.8	1.45
Mush Valley	In valley outcrop	1.6	27.4	33.1	37.9	4390	1.2
Nejo	Aleltu outcrop	8.1	44.7	5.3	41.9	4990	0.9
Wuchale	Outcrop	12.32	29.71	22.64	48.72	5761	1.25
Chilga	BH-27 (65.35m)	6.6	31.8	16.6	45.2	4599.5	0.4
Gojeb - Chida	Outcrop (1.2m)	7.7	29	31	32.3	5480	0.3
	Outcrop (1m)	13	31	20	38.7	4800	0.6
Lalo-Sapo	Bokai Outcrop	13.4	32.4	20.9	33.1	4120	0.4
Tercha	Outcrop	10.99	38.40	5.39	45.22	7300	0.46

Tercha result (present study); other results (Wolela Ahmed, 2008).

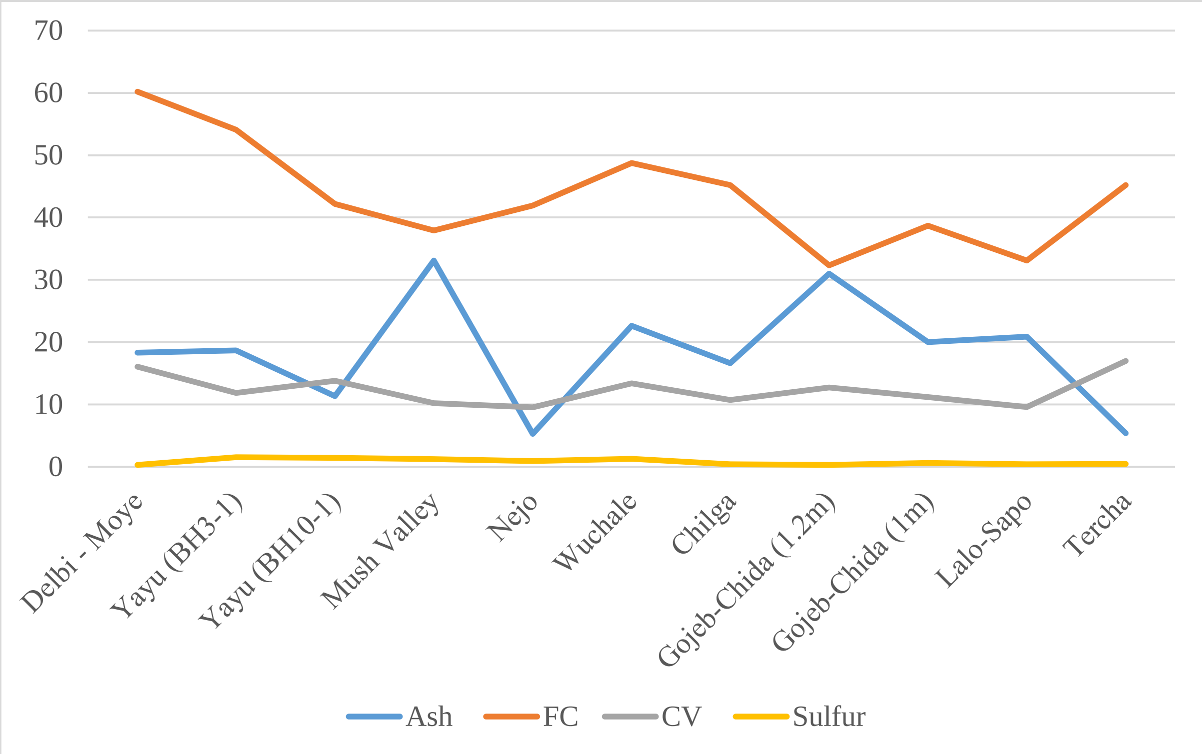


Fig. 6.1 Ash, FC, CV and sulfur value comparison trend of Ethiopian coals.

Ash, sulfur and FC values are in % and CV in MJ/Kg.

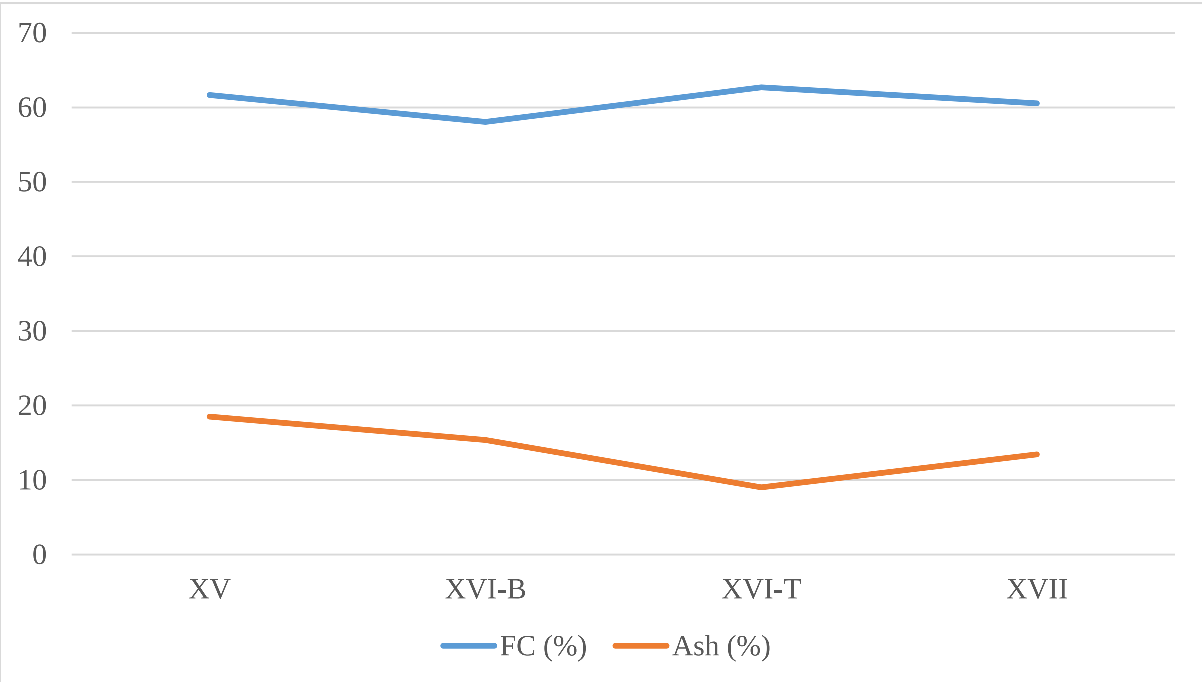


Fig. 6.2 FC and ash value comparison trend of Jharia coal (Cheepurupalli et al., 2015).

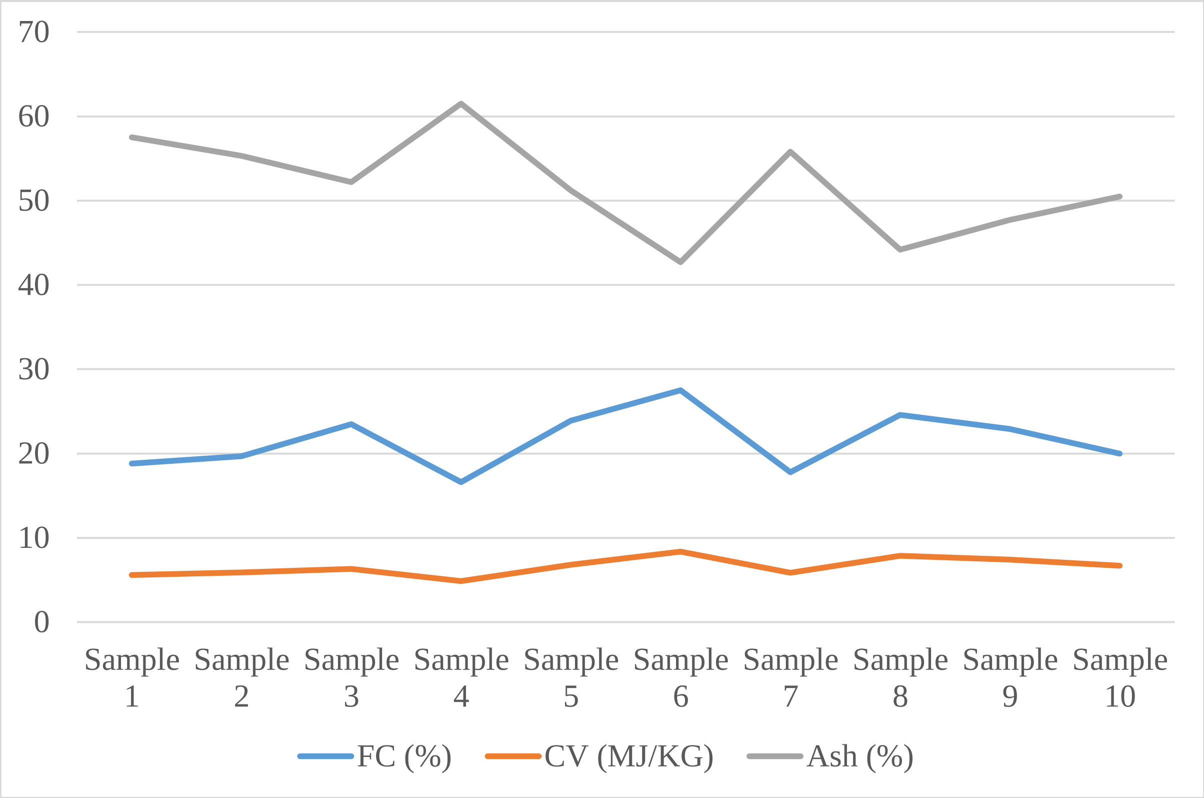


Fig. 6.3 FC, CV and Ash value comparison trend of Talchar Coal (Kumar et al., 2015).

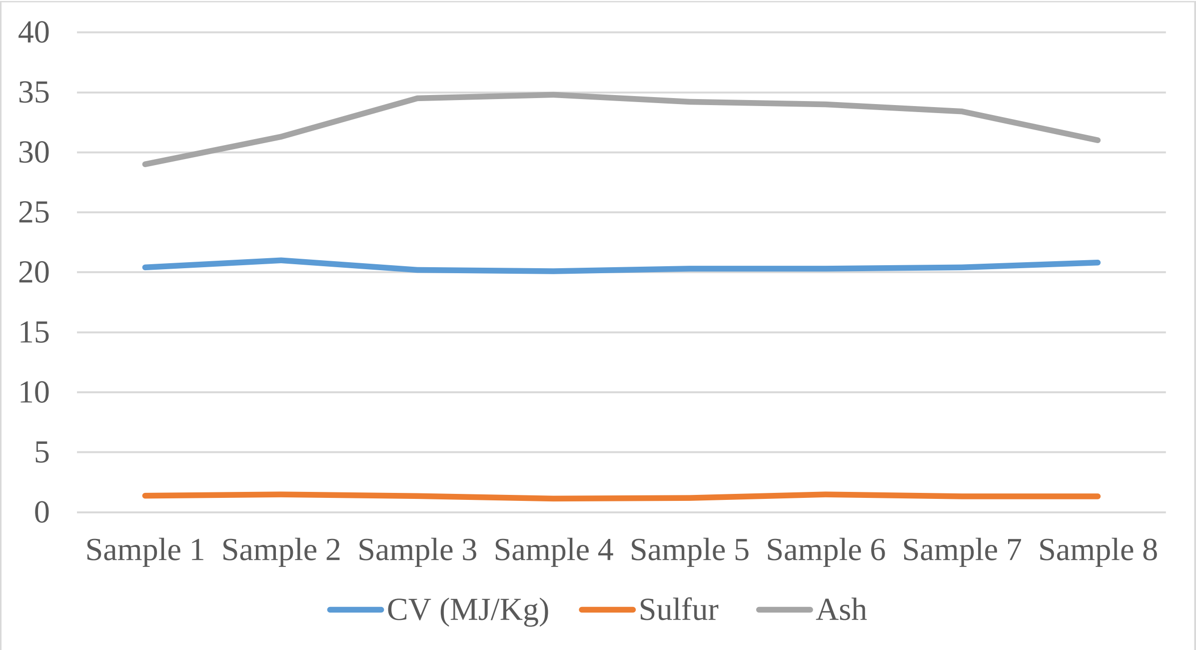


Fig. 6.4 CV, sulfur and ash value comparison trend of Waterberg coal, South Africa (Makgato and Chirwa, 2017). Ash and sulfur values are in dry basis.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The Ethiopian coal deposits are distributed in central and southwestern part of the country as inter-trappean and pre-trapean geological settings with sandstone–coal–shale and siltstone/mudstone–coal–shale facies. The studied area coal is also in these remarks; found in southwestern Ethiopia as inter-trappean setting Oligocene period with the mudstone-coal-shale facies formation.

The proximate analysis, ultimate analysis, TOC and CV of the coal reveals different characteristics. The proximate analysis result ranges from low to high ash (5.39 – 84.81%), and moisture content (5.01 – 11.22%), fixed carbon from 0.02 - 45.22% and volatile matter (5.72 - 38.40%). The calorific value analysis (ranges from 2549-13140 Btu/lib) results revealed that the coal range from lignite (seam 2) to bituminous coal (seam 3) in rank and different agglomerating character.

The organic carbon, TOC, values of analyzed coals ranges from 0.01% - 67.1%. The ultimate analysis also provides the proportional content of carbon (51.78 - 81.14%), hydrogen (5.43 - 6.21%), oxygen (11.14 - 23.36%), nitrogen (1.78 - 2.48%) and sulfur (0.08 - 1.36%) that supports the clear change in rank and type, mainly depends, of the coal.

The general geochemical characteristic of coal samples taken in S_2 and S_4 stratigraphic sections is very poor that does not allow any economic utilization. But samples taken from S_3 and S_4 sections, having considerable thickness, have good quality which can be used for space heating in home, production of oil and gas through liquefaction and gasification (as Jhaira, Delbi-Moye and Yayu coal), chemical fertilizers production (as Delbi-Moye and Yayu), cement industries (as raw material and energy source), power generation and metallurgical coke (like Yayu and Delbi-Moye) from high volatile bituminous coal.

7.2 Recommendation

Even the geochemical characteristic analysis of the resource that had been completed are the core and first hand measures in order to use it for different industrial applications, as economic and social importance, and full academic entity the following recommendations should be done further.

- It is known that coal contains varieties of elements in different concentration. The proximate and ultimate analysis results of the exposed coal are known in this research. But advance geochemical analysis of trace element and Rare Earth Elements (REE) studies, which are known as mineral matter in coal, should have to be done.
- The estimated resource potential is based on the average thickness of the coal and the area only exposed on the surface. In order to be sure that the seam is continuous in the subsurface and the change in chemistry, hence complex, detail exploration is recommended specially to NE and south part of the study area.
- The maceral types described in this research is based on the chemical concentration of the coal samples. To make sure this, individual petrography and palynology studies should be done to know the maceral sub-group and litho-type of the coal.
- It should also need further studies for the depositional environment of the inter-trappean sedimentary unit at micro-basin level.
- Ash Fusion temperature, a set of temperature that characterize the behavior of ash as it is heated, and grind ability index, the easy of pulverizing a coal in comparison to a reference coal, should further study for a specific use of resource.
- Free Swell index (FSI), gives a measure of the extent of a coal and its tendency to agglomerate when heated rapidly, also be examined independently.
- Contracting and thermoplastic properties also needs further and detail analysis.

REFERENCES

Abatte, E. and Sagari, M. (1979). The volcanites: in: Merla, G., Abatte, E., Azzaroli, A., Buni, P., Fazzoul, M., Sagri, M., Tacconi, - Edts. Comments and geological map of Ethiopian and Somalia, scale 1:2,000,000, Firenze, Italy, p49.

Amin, N. and Ali, K. (2010). Raw Mix Designing for Coal as a Fuel in Cement Kiln as a Major Fuel and its Impact on Clinker Parameters**.** J. Chem. Soc. Pak., Vol. 33, No. 2, 2011

Bae, G.Y., Minye Beteru, Getahun Belay, Wolela Ahmed, Yirga Tura, Asmamaw Temesgen. (1989). Report on geology and sub-surface exploration for coal and oil shale occurrence of Delbi and surrounding areas, Kaffa Administrative Region. Unpublished report, Ministry of Mines and Energy, Addis Ababa, Ethiopia, 80p.

Bechtel, A., Karayiğit, A.I., Sachsenhofer, R.F., İnaner, H., Christanis, K., Gratzer, R. (2014). Spatial and temporal variability in vegetation and coal facies as reflected by organic petrological and geochemical data in the Middle Miocene Çayirhan coal field (Turkey). Int. J. Coal Geol. 134-135, 46–60

Bechtel, A., Sachsenhofer, R.F., Markic, M., Gratzer, R., Lücke, A., Püttmann, W. (2003). Paleoenvironmental implications from biomarker and stable isotope investigations on the Pliocene Velenje lignite seam (Slovenia). Org. Geochem. 34, 1277–1298.

Berkowitz, N. (1979). An Introduction to Coal Technology. Academic Press Inc., London. 345 pp.

Calder, J.H., Gibling, M.R. and Mukhopadhyay, P.K. (1991). Peat formation in a Westphalian Bpiedmont setting, Cumberland basin, Nova Scotia: implications for the maceralbased interpretation of rheotrophic and raised paleomires. Bull. Soc. Géol. Fr. 162, 283–298.

Calkins, W. (1994). The chemical forms of sulfur in coal: a review. Fuel 73, 475–484.

Carpenter, A.M. (2002)**.** Coal quality assessment – the validity of empirical tests. CCC/63, the IEA Clean Coal Centre, UK, London.

Cheepurupalli, N.R., Radha, A.B., Singh, C.S., Sharma, G.V.S., Rao, D.E.N. (2015). Chemical Characteristics and Trace Element Concentration of Non Coking Coals from Talcher Coal Fields, Orissa, India. Star Journal.

Chou C.L. (2012). Sulphur in coals: A review of geochemistry and origins, Int. J. Coal. Geol., 12, 1–13. p11.

Conko, K.M., Landa, E.R., Kolker, A., Kozlov, K., Gibb, H.J., Centeno, J.A., Panov, B.S., Panov, Y.B. (2013). Arsenic and mercury in the soils of an industrial city in the Donets Basin, Ukraine. Soil Sediment Contam. Int. J. 22, p 574–593.

Curley, R. (2012). Energy: past, present, and future fossil fuels. Britannica Educational Publishing, Britannia.

Dai, S., Ren, D., Chou, C.L., Finkelman, R.B., Seredin, V.V., Zhou, Y. (2012). Geochemistry of trace elements in Chinese coals: a review of abundances, genetic types, impacts on human health, and industrial utilization. Int. J. Coal Geol. 94, 3–21.

Davidson, A. (1983). Reconnaissance Geology and Geochemistry of Parts of Ilubabor Kefa, Gemu Gofa and Sidamo, Ethiopia. Bull. No2. Ottawa.

Diessel, C. F. K. (1986). On the correlation between coal facies and depositional environments. 20th Newcastle Symposium on “Advances in the Study of the Sydney Basin”: Publ., 246, Proc. Department of Geology, University of Newcastle, Australia, pp. 19–22.

Engedasew Andarge, Abraham Shonga, Mathewos Agize and Asfaw Tora. (2014). Utilization and conservation of medicinal plants and their associated Indigenous Knowledge (IK) in Dawuro Zone: An ethnobotanical approach, International Journal of Medicinal Plant Research.

Fettweis, G. B. (1979). World Coal Resources: Methods of Assessment and Result. Elsevier, Amsterdam, Netherland.

Finkelman, R. (1988). The inorganic geochemistry of coal: a scanning electron microscopy view. Scanning Microscopy 2, 97–105.

Francis, W., 1961. Coal: Its Formation and Composition. Edward Arnols, London.

Getahune Belay, Yirga Tura and Minye Betru. (1993). Detail geological mapping, subsurface exploration, geochemical studies and reserve evaluation of coal and oil shale resources at Delbi-Moye Basin. Ethiopian Institute of Geological Surveys Technical Report, Addis Ababa, Ethiopia, 119p.

Getaneh Assefa and G. N. Saxena. (1984). A review of Ethiopian lignite occurrences, prospects and possibilities: Energy Exploration and Exploitation, Vol. 3, p. 35–42

Gluskoter, H. J. (1975). Advances in Chemistry Series 141: in: S. P. Babu – Editor. Trace Elements in Fuel**.** American Chemical Society, Washington, DC, pp. 1–22.

Jarvie, D. M. (1991). Total Organic Carbon (TOC) Analysis. In R. K. Merrill (Ed.), Treatise of Petroleum Geology: Handbook of Petroleum Geology: Source and Migration Processes and Evaluation. Tulsa: American Association of Petroleum Geologists.

Jelenc, D. (1966). Mineral Occurrences of Ethiopia. Ministry of Mines, Addis Ababa, Ethiopia, 552p.

Kalkreuth, W., Kotis, T., Papanicolaou, C., Kokkinakis, P. (1991). The geology and coal petrology of a Miocene lignite profile at Meliadi Mine Katerini, Greece. Int. J. Coal Geol. 17, 51–67.

Karayiğit, A.I., Oskay, R.G., Christanis, K., Tunoğlu, C., Tuncer, A., Bulut, Y. (2015). Palaeoenvironmental reconstruction of the Çardak coal seam, SW Turkey. Int. J. Coal Geol. 139, 3–16.

Karr, C.Jr. (1978). Analytical Methods for Coal and Coal Products, Vol. I. Academic Press, UK.

Kazmin, V. (1972). The Geology of Ethiopia. Ethiopian Institute of Geological Survey. Addis Ababa, Etrhiopia

Kazmin, V. (1975). Explanatory note to the Geology of Ethiopia. Ethiopian Institute of Geological Survey. Bull. Number 2, Addis Ababa, Ethiopia.

Kibre, T. and Gashaw Beza, M. (1997). Preliminary geological report of Geba Basin (Yayu area), Western Ethiopia. Unpublished report, Ethiopian Institute of Geological Surveys, Addis Ababa, 55 pp.

Kler, V., Volkova, G., Gurvich, E., Dvornikov, A., Jarov, Y., Kler, D., Nenahova, V., Saprikin, F., Shpirt, M. (1987). Metallogeny and Geochemistry of Coal and Shale Bearing Stratum in USSR: Geochemistry of Elements. Nauka, Moscow, 240 pp.

Kumar, H., Mishra, S., Mishra, M.K., Parida, A. (2015). Petrographical Characteristics of Bituminous Coal from Jharia Coalfield India: It's Implication on Coal Bed Methane Potentiality. Elsevier.

Li, Z., Ward, C.R., Gurba, L.W. (2010). Occurrence of non-mineral inorganic elements in macerals of low-rank coals. International Journal of Coal Geology 81, 242–250.

Lipps, W. (2016). Measuring Organic Carbon: A Brief History and Discussion of Methodologies. American Laboratory Module, USA.

Mahapatra, D. (2016). A review on Steam Coal Analysis - Calorific Value. AIJRSTEM, USA.

Maitlis, P. and Rourke, J. (1993). Rich seams for chemicals. New Scientist 1857, 37–41

Makgato S. and Chirwa E.M.N. (2017). Characteristics of thermal coal used by power plants in waterberg region of South Africa, Chemical Engineering Transactions.

Markic, M. and Sachsenhofer, R.F. (1997). Petrographic composition and depositional environments of the Pliocene Velenje lignite seam (Slovenia). Int. J. Coal Geol. 33, 229–254.

Mathewos A., Sebsebe D. and Zemede A. (2013a). Ethno botany of Medicinal Plants in Loma and Gena Bosa Districts (Woredas) of Dawro Zone, Southern Ethiopia. Top class Journal of Herbal Medicine. Vol.2 (9): 194–212.

Mengesha Tefera and B. Seife Michael, (1982), Geology map of sheet NC 36-16 (Gore sheet): Ethiopian Institute of Geological Surveys, Addis Ababa, Ethiopia, scale 1:250,000

Mengesha Tefera, Tadious Cherenet and Workneh Haro. (1996). Explanation of the Geologiacal Map of Ethiopia. Scale 1: 2000,000. Ethiopian Institute of Geological Surveys Bulletin, No. 3, pp. 1–79.

Merla, G., Abatte, E., Azzaroli, A., Buni, P., Fazzoul, M., Sagri, M., Tacconi, P. (1979). Comments and geological map of Ethiopian and Somalia, scale 1:2,000,000, Firenze, Italy, Consiglio Nationale delle Ricerche, pp. 1–59.

Miller, B. G. (2005). Coal Energy Systems. Elsevier. UK.

Miniye Betru (1992). Sedimentology, Petrology and Geochemistry of Coal and Oil Shale Deposits in Delbi-Moye Basin, southwestern Ethiopia. Msc thesis.

Mitchell, G. (1997). Basics of Coal and Coal Characteristics (Selecting Coals for Quality Coke Short Course, Iron and Steel Society, Warrendale, PA.

Mohr, P.A. (1962). The Geology of Ethiopia. Addis Ababa University Press, 268p.

Moore, E.S. (1922). Coal: Its Properties, Analysis, Classification, Geology, Extraction, Uses, and Distribution. John Wiley & Sons. New York. pp 124.

Mukherjee S. and Borthakur P.C. (2003). Effect of leaching high sulfur subbituminous coal by potassium hydroxide and acid on removal of mineral matter and sulfur. Fuel; 82:783.

Panov, B.S., Dudik, A.M., Shevchenko, O.A., Matlak, E.S. (1999). On pollution of the biosphere in industrial areas: the example of the Donets coal basin. Int. J. Coal Geol. 40, 199–210.

Petersen, H.I. and Ratanasthien, B. (2011). Coal facies in a Cenozoic paralic lignite bed, Krabi Basin, southern Thailand: changing peat-forming conditions related to relative sea-level controlled watertable variations. Int. J. Coal Geol. 87, 2–12.

Raaj, S.S., Arumugam, S., Muthukrishnan, M., Krishnamoorthy, S., Anantharaman, N. (2016). Characterization of coal blends for effective utilization in thermal power plants, Appl. Therm. Eng., 102, p9–16.

Rasheed, M.A., Srinivasa Rao, P.L., Boruah, A., Hasan, S.Z., Patel, A., Patel, V.V.K. (2015). Geochemical Characterization of Coals Using Proximate and Ultimate Analysis of Tadkeshwar Coals, Gujarat.

Rice, D.D. (1993). Composition and origins of coalbed gas, in: Law, B.E., Rice, D. D. –Edts. Hydrocarbons from Coal. AAPG Studies in Geology. a38: 159- 184.

Sahni, A., Saraswati, P.K., Rana, R.S., Kumar, K., Singh, H., Alimohammadian, H., Sahni, N., Rose, Kd, Singh, L. And Smith, T. (2006). Temporal constraints and depositional palaeoenvironments of the Vastan lignite sequence, Gujarat: Analogy for the Cambay Shale hydrocarbon source rock. Indian Jour. Petrol. Geol., v.15, pp.1-20.

Saurez-Ruiz, I. and Crelling, J. (2008). Applied Coal Petrology: The role of Petrology in Coal Utilization. Academic Press, UK.

Schobert, H.H. (1987) Coal: The Energy Source of the Past and Future (American Chemical Society, Washington, D.C.

Scott, A. C. (2002). Coal petrology and the origin of coal macerals: a way ahead? International Journal of Coal Geology. Elsevier. P 119– 134.

Serendin, V.V. and Dai, S. (2012). Coal deposits as potential alternative sources for lanthanides and yttrium. Int. J. Coal Geol. 94, 67–93.

Serendin, V.V. and Finkelman, R.B. (2008). Metalliferous coals: a review of the main genetic and geochemical types. Int. J. Coal Geol. 76, 253–289

Speight, J.G. (1994). The Chemistry and Technology of Coal**,** 2nd ed. Marcel Dekker, New York.

Speight, J.G. (2005). Handbook of Coal Analysis. Wiley and Sons, Canada.

Speight, J.G. (2012). Coal analysis. In: The Chemistry and Technology of Coal. 3rd ed. Boca Raton, FL, USA, CRC Press, pp 215–250.

Stach, E., Mackowsky, M., Teichmuller, M., Taylor, G., Chandra, D., Teichmuller, R. (1982). Stach's Textbook of Coal Petrology. Gebruder Borntraeger, Berlin, 535 pp.

Stock, A.T., Littke, R., Lücke, A., Zieger, L., Thielemann, T. (2016). Miocene depositional environment and climate in Western Europe: The lignite deposits of the Lower Rhine Basin, Germany. Int. J. Coal Geol. 157, 2–18.

Swaine, D.J. (1990). Trace Elements in Coal. London, Butterworths, 278 pp.

Tamirat Solomon, Gebreslassie Welu and Lemlem Tajebe. (2014). Resource Potential of Non Timber Forest Products in Dawro Zone, South Ethiopia. Journal of Biology, Agriculture and Healthcare, p171.

Taylor, G. H., Teichmuller, M., Davis, A., Diessel, C. F. K., Littke, R., Robert, P. (1998). Organic Petrology, Gebruder Borntraeger, Berlin – Stuttgart, 704 pp.

Teichmüller, M., and Teichmüller, R. (1966). "Coal Science," Adv. Chem. Ser. 55, p. 133. American Chemical Society, New York.

Tessfaye Lemma, Wolela Ahmed and Cheru, G. (1992). Chemical analyses and characterisation of some Ethiopian coals. Bulletin of the Chemical Society of Ethiopia 6, 59–73

Thomas, L. (2013). Coal Geology, 2nd ed., Wiley, United Kingdom.

Ting, F. (1978). Petrographic techniques in coal analysis. In: Karr, C. (Ed.), Analytical Methods for Coal and Coal Products. Academic Press, New York, vol. I, 3–26.

Tissot, B.P. and Welte, D.H. (1984). Petroleum formation and occurrence, Second Revised and Enlarged Edition, Springer-Verlag, Berlin.

Ursula, K., Ron, Z., Rainer, B. and Hupa, M. (2002). “Alternative fuels / the impact of alternative fuels on the cement manufacturing process.” Nordic Concrete Research Symposium, Helsingör, Denmark, pp 3.

Van Krevelen, D.W. (1993). Coal: Typology–Physics–Chemistry–Constitution, 3rd ed. Elsevier Science, Amsterdam.

Van Krevelen, D.W. 1961. Coal. Elsevier, Amsterdam.

Vassilev, S. and Vassileva, C. (2009). A new approach for the combined chemical and mineral classification of the inorganic in coal. 1. Chemical and mineral classification systems. Fuel 88, 235–245

Vassilev, S., Kitano, K. and Vassileva, C. (1996). Some relationships between coal rank and chemical and mineral composition. Fuel 75, 1537–1542.

Ward, C.R. (1984). Coal Geology and Coal Technology. Blackwell Scientific Publications, Melbourne, 345 pp.

Williams, E. and Keith, L. (1963). Relationship between sulfur in coals and the occurrence of marine roof beds. Economic Geology 58, 720–723.

Woldegabriel G., Aronson J. L and Walter R.C. (1990) Geology, geochronology, and rift basin development in the central sector of the Main Ethiopia Rift. Geol. Soc. Am Bull 102:439–458.

Wolela Ahmed. (1991). Coal and oil shale occurrences and their geological setting in Ethiopia, Unpublished Report, Ministry of Mines and Energy, Addis Ababa, Ethiopia, p205.

Wolela Ahmed. (1991a). Coal and oil shale occurrences and their geological setting in Ethiopia. Unpublished report, volume I and II, Ministry of Mines and Energy, Ethiopia, 205 pp.

Wolela Ahmed. (1991b). Highlights on coal and oil shale occurrences of Ethiopia (catalogue). Unpublished Report, Ethiopian Institute of Geological Surveys, Addis Ababa, Ethiopia, Note No. 363.

Wolela Ahmed. (1992a). An overview on the geographical distribution, geological setting and chemical characteristics of Ethiopian coal and oil shale. Unpublished report, Ethiopian Institute of Geological Surveys, Addis Ababa, Ethiopia, Note No 364.

Wolela Ahmed. (1992b). Significant coal deposits and their economic and mining possibilities in Ethiopia. Unpublished Report, Ethiopian Institute of Geological Surveys, Addis Ababa, Ethiopia, Note No 365.

Wolela Ahmed. (2004). Sedimentology, depositional environments and basin evolution of coal and oil shale-bearing sediments in the Delbi-Moye Basin, Southwestern Ethiopia. Sinet. An Ethiopian Journal of Science 27, 45–60.

Wolela Ahmed. (2006). Fossil fuel energy resources of Ethiopia: Oil shale deposits, Petroleum Operations Department, Ministry of Mines and Energy, Addis Ababa, Ethiopia.

Wolela Ahmed. (2007). Fossil fuel energy resources of Ethiopia: Coal deposits, Petroleum Operations Department, Ministry of Mines and Energy, Addis Ababa, Ethiopia.

Wolela Ahmed. (2008). Fossil Fuel Energy Resources of Ethiopia, Petroleum Operations Department, Ministry Of Mines and Energy, Addis Ababa, Ethiopia.

Workneh Haro, Asamnew B., Daba Bulto, Fikadu, B., Mohamed E. (2012). Geology, Geochemistry and gravity survey of Jima area, unpublished report, Ministry of mines, Geological survey of Ethiopia, Addis Ababa, Ethiopia, 28p.

Zeng, F. (2009). Organic and Inorganic Geochemistry of Coal: in: G. Jinsheng - Editor. Coal, Oil Shale, Natural Bitumen, Heavy Oil and Peat. V II. Encyclopedia of Life Support Systems, Oxford, United Kingdom, p72.

Zhu, Q. (2014). Coal sampling and analysis standards. CCC/235, London, UK, the IEA Clean Coal Centre.

https://coal.nic.in/content/coal-grades - last updated June 26/2018.

Appendix I (Proximate Analysis result of Ethiopian Coals)

Basin	Locality	Depth (m)	Thickness (m)	Moisture %	VM %	Ash %	FC %	CV cal/g	Sulfur %	VR (%)
Delbi-Moye	BH-18	40.75	0.65	2.3	18.9	52.6	29.1	3689	1.4	0.34-0.64
		70.2	1.8	1.5	26.2	16.9	56.9	6900	2.1	
		117.4	0.65	1.5	22.2	28.5	49.3	5730	1.3	
	BH-19	30	0.6	2.7	28.5	27.4	49.9	5741	1.6	
		40	1.8	2.7	26.3	35.6	38.2	5040	0.4	
		81	1.05	3	24.9	42	33.2	4393	0.3	
		102	1.1	0.3	25.6	27.1	47	5780	0.3	
	BH-21	6	1	2.5	21.3	21.3	36.4	5080	1.7	
		79.85	2	0.3	17.9	39.9	42.2	4880	0.3	
		142	1.2	1.2	21.5	18.3	60.2	6900	0.3	
		147	1.3	1.5	21.4	24.9	54.2	6276	0.3	
		162.3	0.55	1.3	20.7	20.5	58.8	6743	0.3	
	BH-10	132	1.1	1.8	25.9	36.9	37.5	5030	1.3	
	BH-11	133.8	1	3.9	30.9	27.9	38.3	5622	0.6	
	BH-2	50.55	1.35	5.4	28.6	38.6	27.6	4300	0.4	
		59.7	2	5.6	32	15	47.4	6165	0.4	

	BH-1	93.85	2.2	2.3	36.5	13.9	47.3	6100	0.6	
Yayu	BH2-1	90.8	1.54	8.09	44.98	16.85	30.17	5788.9	1.65	0.3–0.4
		95.15	1.41	6.45	43.44	14.46	42.1	5604.9	1.83	
	BH3-1	53.5	1.55	21.1	45.15	15.46	39.39	5623.3	1.41	
		58.4	1.35	15.88	41.57	15.94	42.49	5444.6	1.82	
		62.25	1.6	11.06	43.99	18.65	54.07	5099	1.52	
	BH4-1	102.35	0.6	18.53	42.46	18.34	39.2	5423.1	1.41	
		108.35	1.33	18.81	42	16.18	41.82	5418.3	1.86	
		111.64	2.8	8.9	40.27	18.57	41.16	5199	1.56	
	BH6-1	77.85	0.94	8.17	43.96	14.96	41.12	5618.6	1.12	
		82.7	1.91	12.41	48.7	15.61	35.69	5263.3	1.92	
		87.85	2.4	13.18	46.51	15.75	37.74	5649	1.99	
	BH7-2	112.5	0.72	26.31	44.51	14.66	40.83	5649	1.21	
		119.1	1.95	20.65	42.02	16.02	41.96	5430.2	2.07	
		123.6	2.79	16.72	40.89	24.3	34.8	4724	1.93	
	BH8-1	140.65	0.82	16.79	45.54	12.97	41.49	5806.7	1.48	
		146	1.52	6.98	43.03	17.79	39.18	4350.4	1.83	
		149.85	2.19	16.41	40.12	19.07	40.81	5280.1	1.29	
	BH10-1	78.35	2.1	10.98	46.53	11.32	42.15	5930.8	1.45	

		83	1.87	23.96	44.4	11.68	43.92	5811.7	2.33	
		86.9	1.27	12.14	37.97	25.01	37.02	4822.4	2.39	
Mush	Mush	Outcrop	1.75	1.6	27.4	33.1	37.9 23.9	4390	1.2 1.2	0.34-0.46
Valley	Valley			22.4	34.1	19.6		3658.6		
				18.7	39.2	16.3	25.8	3656.2	1	
			1	20.3	35.1	18.8	25.8	3764.4	0.8	
Nejo	Mechakani	Outcrop		6.1	38.7	16.7	38.5	4470	0.8	0.36-0.47
	Aleltu			8.1	44.7	5.3	41.9	4990	0.9	
	Achacha			5.4	36.2	30.2	28.2	3530	1.2	
Wuchale	Totito	Outcrop	0.5	1.4	18	45.4	35.2	3710	2.6	0.3–0.48
				11.33	21.37	44	46.7	4516	1.8	
			0.4	12.32	29.71	22.64	48.72	5761	1.25	
Chilga	BH-31	34.75	0.7	7	19.2	46.5	27	2430	0.6	0.34-0.54
		45.95	0.95	8.6	17	36.2	38.2	3465	0.8	
		53.2	0.7	9.3	21.1	39.4	37.2	2649	1	
		54.8	0.65	10.7	22.6	26.6	40.1	4007.2	0.8	
	BH-30	22.5	0.35	10	22.8	24	43.2	4188.7	1.2	
		54.5	0.8	8.2	20	43.7	28.1	2925	0.6	
		59.45	0.45	8.6	22.3	38	33.1	3548	0.6	

	BH-34	23.2	0.8	6.9	11.5	54	20.6	2840.2	0.8	
		28.3	0.4	7.1	21.2	31.3	30.4	3740	0.5	
	BH-27	65.35	0.65	6.6	31.8	16.6	45.2	4599.5	0.4	
		70.4	0.85	13.2	15.8	49.8	21.2	2531.5	0.5	
Gojeb-	3 km south of Gojeb	Outcrop	1	13	31	20	38.7	4800	0.6	0.3–0.54
Chida	River Bridge	Outcrop	1.2	11	15.2	51.8	22.8	2490	0.2	
		Outcrop	0.4	10.7	32.2	18.9	38.2	4740	0.5	
		Outcrop	0.7	18.5	27.9	13.6	39	4740	0.4	
	Bokai Stream	Outcrop	1.2	7.7	29	31	32.3	5480	0.3	
Lalo-	Waro Stream	Outcrop	2	13.4	32.4	20.9	33.1	4120	0.4	0.3–0.64
Sapo	Geta Stream	Outcrop	1	12	18.2	58.3	11.5	4015	0.6	
			0.7	9.1	20.5	52.4	18.1	2626	0.5	

Appendix II (Ultimate analysis result of Ethiopian Coals)

Basin	Locality	Depth in meter	Thickness in meter	Calorific value in cal/g	Hydrogen in %	Carbon in %	Nitrogen in %	Oxygen in %	Sulfur in %	Coking property
Mush Valley	Mush Valley	Outcrop	1.75	4390	5.72	68.93	1.23	24.12	1.5	Weak
Nejo	Mechakani	Outcrop	0.5	4470	4.6	69.6	0.8	25	0.8	Strong
	Aleltu	Outcrop	1.7	4990	5.17	72.2	0.82	21.81	0.6	
	Achacha	Outcrop	1.2	3530	5.4	76.5	2.12	15.98	0.8	
Gojeb-Chida	Gojeb	Outcrop	1	4080	6.44	73.54	1.28	18.74	0.4	Weak
Wuchale	Totito	Outcrop	0.6	3710	5.41	74.84	1.53	18.22	1.6	Weak
Moye	BH-19	40	1.8	4920	5.34	80.22	2.27	12.17	0.4	strong
	BH-21	81	1.05	4138	5.21	76.24	2.16	16.39	0.5	
Delbi	BH-1	93.85	2.2	5390	6.57	68.36	1.22	23.85	0.6	Weak
				6270	6.44	73.54	1.27	18.75	0.4	
	BH-2	59.7	2	6580	5.5	66.1	1.11	27.29	0.6	
				6160	5.7	60.3	1.31	32.69	0.5	
Yayu	BH2-1	90.8	1.54	5788.9	4.2	69.4	1.2	25.2	1.65	Weak

BH3-1	53.5	1.55	5623.3	4.7	66.6	1.68	27.02	1.41
BH4-1	108.35	1.33	5418.3	5.6	71.2	1.5	21.7	1.86
	111.64	2.8	5199	5.4	76.42	1.4	15.78	1.56
BH6-1	77.85	0.94	5618.6	4.7	68.8	1.7	24.8	1.12
	82.7	1.91	5263.3	5.2	69.2	2.1	23.5	1.92
	87.85	2.4	5649	5.6	70.1	2	22.3	1.99
BH7-2	119.1	1.95	5430.2	5.3	71.2	1.76	21.74	2.07
	123.6	1.9	4724	5.4	70.4	1.8	22.4	1.93
BH8-1	140.65	0.82	5806.7	5.2	67.4	1.2	26.2	1.48
	146	1.52	4350.4	5.8	68.4	1.4	24.4	1.83

Appendix III (Proximate Analysis and Ultimate Analysis Waterberg Coal, South Africa) (Makgato and Chirwa, 2017). All values are in % except CV (MJ/Kg).

Sample	Carbon	Hydrogen	Nitrogen	Oxygen	Sulphur	Ash	CV	Moisture	VM
Sample 1	50.7	3.20	1.10	5.63	1.37	29.0	20.4	2.7	21.4
Sample 2	49.2	2.75	1.22	9.04	1.49	31.3	21.0	2.5	24.0
Sample 3	48.7	2.98	1.12	6.65	1.35	34.5	20.2	2.2	24.9
Sample 4	53.8	3.18	1.14	5.66	1.15	34.8	20.1	2.5	24.8
Sample 5	52.5	3.13	1.14	7.15	1.20	34.2	20.3	2.5	25.7
Sample 6	51.5	2.79	1.58	4.27	1.48	34.0	20.3	1.8	25.6
Sample 7	51.2	3.07	1.18	5.15	1.34	33.4	20.4	2.1	24.6
Sample 8	53.2	3.07	1.11	5.41	1.32	31.0	20.8	2.2	26.2

Appendix IV (Proximate and Ultimate analysis (%) of Talchar Coal, India) (Kumar et al., 2015). CV is Cal/g.

Sample No	Moisture	Ash	VM	FC	C	H	N	S	O	CV
Sample 1	4.4	57.5	19.3	18.8	25.45	1.98	0.70	0.46	13.90	2370
Sample 2	4.5	55.3	20.5	19.7	28.79	2.30	0.84	0.43	12.30	2540
Sample 3	4.0	52.2	20.3	23.5	29.9	2.57	0.86	0.54	13.90	2710
Sample 4	2.9	61.5	19.0	16.6	23.9	2.34	0.78	0.52	11.00	2100
Sample 5	3.7	51.2	21.2	23.9	31.13	2.82	1.09	0.47	13.29	2930
Sample 6	5.7	42.7	24.1	27.5	38.44	3.50	0.94	0.46	14.00	3600
Sample 7	5.3	55.8	21.1	17.8	27.63	2.25	0.89	0.41	13.00	2520
Sample 8	7.2	44.2	24.0	24.6	35.48	3.60	1.14	0.40	15.20	3390
Sample 9	5.1	47.7	24.3	22.9	34.33	3.26	1.04	0.31	13.40	3190
Sample 10	7.6	50.5	21.9	20	29.91	3.48	0.99	0.38	14.70	2880

Appendix V (Results of Proximate Analysis (%) of Iharia coal, India) (Cheepurupalli et al., 2015).

Sample	Depth (m)	M	A	VM	FC
XV	500	0.93	18.49	18.92	61.64
XVI-B	475	1.26	15.38	25.28	58.06
XVI-T	450	1.4	9.01	26.88	62.7
XVII	450	1.19	13.46	24.81	60.53