ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

SEDIMENTOLOGY AND GEOCHEMISTRY OF COAL DEPOSIT IN GEBA BASIN, ILLUBABOR, WESTERN ETHIOPIA

**A THESIS
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(SEDIMENTOLOGY)

BY

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Praise be to the LORD, for He showed His wonderful love to me
when I was in a besieged city.

Psalm 31: 21

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Abstract

The sedimentary succession exposed in ≈386 sq. km Geba basin represents one of thick accumulations of continental sediments that are commonly known to associate the Ethiopian Tertiary volcanics. The succession is a coal and oilshale bearing, and comprises about 150m Conglomerate, sandstone, siltstone, mudstone, reworked tuff, oilshale and coal sediments. They are deposited in an east-west trending intracratonic rift basin, that may be evolved locally, from other regional contemporaneous tectonic episodes between Middle Oligocene and Early Miocene. The whole sedimentary sequence has been distinguished into five major sedimentological units correlable with depositional environments ranging from fluviatiles to lacustrine. Under fluvial conditions a number of coal seams are formed in flood plain. Under lacustrine condition, several thick coal seams have been formed in marshy areas, developed at the margin of the lakes.

Generally, the coal beds range in thickness from few tens of centimeters to about 4.0 meters. Chemically, they are high ash and medium sulfur coals. The maceral study reveals that huminite dominated the organic forms of Geba coals(>85%), with high proportion of humocollinite and minor humodetrinite sub groups. Humotelinite sub group is markedly rare. Low inertinite (<7%) and considerable liptinite, as high as 23%, are main features of the coals. The overall petrographic aspect of the coals suggests humic origin, possibly under shallow water condition. Reflectances measured on the huminite range from 0.32-0.39%R. This indicates an ASTM rank ranging from lignite to lower boundary of Sub bituminous.

INTRODUCTION

1.1 General

In Ethiopia, whose economy depends on large amounts of imported products, the assessment of mineral resources contribute much to the economic growth of the country. Although, extensive search has been undertaken, in this regard much of the potential of Ethiopia is either far from present knowledge or not amenable for immediate use. Therefore, more detailed and systematic studies are needed to understand the mineral resources of the country. One of these resources is its Hydrocarbon potential, which has been studied under an integrated geological surveys. This has shown the presence of some low - grade coal and oilshale deposits in the country.

With its lowest per capita energy consumption 300kg Oe, Ethiopia, spends a great share of its total currency for imported fuels. Still this imported fuel is so insignificant that more than 90% of the total energy consumption is covered by biomass fuels, (Omar,1994). Such utilization of biomass fuels, especially fuel-wood is steadily increasing from time to time and has led to mass deforestation and soil degradation. Hence, coal and oilshale deposits are important potential resources to build the energy sector together with other natural resources like geothermal, oil and gas, solar energy, wind energy and hydro power.

Although, the previous studies show that most of the Ethiopian coals have low calorific values and high ash contents, there had been no adequate studies helping to know their potential in the production of fertilizer, medicine or synthetic liquid fuels. This thesis deals with the geology, mode of deposition and evaluation of coal deposit of Geba basin, Illubabour Zone, Western Ethiopia. This coal deposit economically appeared to be promising and is currently studied for fertilizer production under Coal-Phosphate Fertilizer Complex Project (COFCOP), Ministry of Industry. In the thesis, attempts were made to distinguish the depositional environments of the coal beds, to determine the trend of the quality variation of the coals and to analyze the basin evolution. Conclusions and recommendations are given based on the geological and economical aspects of the deposit. Hence, the thesis work may provide a geological information on the nature and distribution of Geba coals and may help as a data source for further exploration work.

1.2 GEOGRAPHIC SETTING

The project area is located in Yayu and Kumbabe Woreda, Illubabor Zone, western Ethiopia (Fig 1). It is located 564 kms from Addis Ababa along the Jima - Bedele - Gambela, or 500 kms along Nekemt - Bedele- Gambela road (Fig.2). It covers about 1131 sq.kms, and is bounded between 8 ^{0}15’ - 8 ^{0}30’N and 35^{0} 42’ 47’’-36^{0} 05’E on the western plateau of Ethiopia (Fig.1). The surveyed area is penetrable on foot with limited access for vehicles. Physiographically, it is a part of the western plateau dissected by the Geba River. This major stream of the area drains to the west into the Baro River joining with Sese, Sor and Birbir Rivers on its way. In the studied area the river forms a large gorge in which sedimentary sequences outcrop. The Sese River Basin, containing another sedimentary sequence, is found north of the Geba and is separated from the latter by an east-west trending Elemo Block. The Elemo Block is gently dipping to north forming a south ward facing cliff that mark the northern boundary of Geba Basin. The Geba Basin is

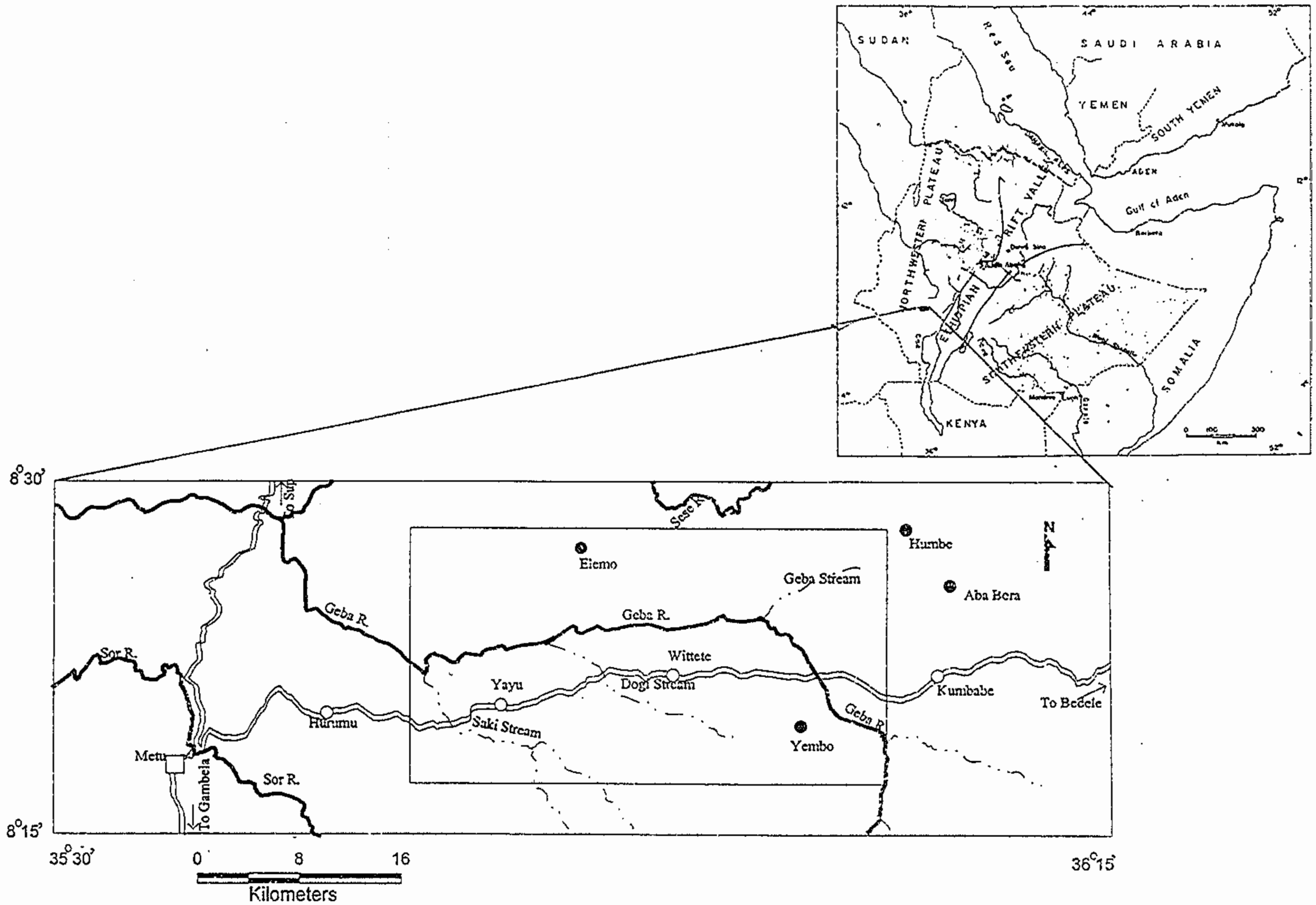


Fig. 1. Location map of the study area.

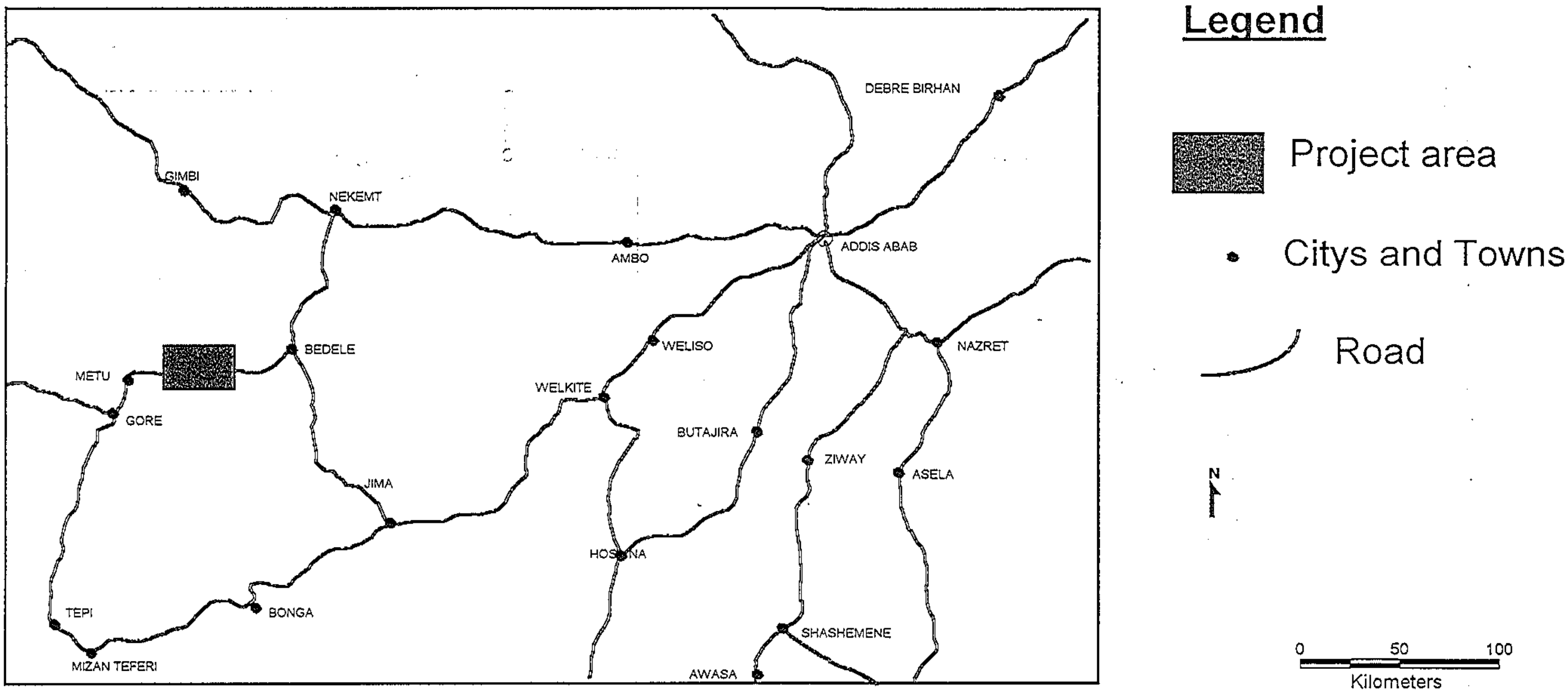


Figure 2 The accessebility map of the project area

bounded by a continuous cliff boundary in all directions which reach locally upto more than 100m. A number of streams flow towards the Geba from different directions across the cliffy boundaries forming water falls, which have potential for hydro electric power generation. Within the basin, topographic elevations range between 1300 and 1700m, where the lowest altitude is found in the highly dissected western extreme of the River Valley. Out side the basin, the surface of the plateau commonly varies between 1800 to 2000m above sea level. Generally, topographic highs are found in the eastern part of the project area.

According to the atlas of Woody Biomass Inventory And Strategic Planning Project (WBISPP) (1995), the highly dissected Geba basin is climatically «Kola» whilst the surrounding area is «Woyna dega». Mean annual rainfall in the Geba Basin ranges from 1600 - 1800 mm, whereas outside the Geba Basin ranges from 1800 - 2000 mm. Temperature range for the basin is between 20.1 and 22.5 ^{0}C, whilst the surrounding area is ranging from 17.6 to 20 ^{0}C. Along the major streams broad-leaved forest is common, whereas the large part of the area is intensively cultivated mainly for coffee.

1.3. OBJECTIVES

The purpose of the study is to evaluate the coal occurrence of Geba basin by -

1. undertaking facies analysis and defining the corresponding depositional environments of the coal-bearing sediments
2. constructing the geological history of the Geba basin.
3. determining the quality of the coal.

1.4 PREVIOUS WORK

Exploration and exploitation of coal and oilshale deposits , in Ethiopia, began in 1930s, when the Italian Army used up the Wuchale coal (Wollo), Nejo coal (Wollega), and Mush valley coal (Northern Shoa) (Jelence, 1966). Since then, different workers have studied different occurrences, but large deposits, that may be exploited beyond local consumption have not been discovered. Recent compilations of the Ethiopian coals, their occurrences, and geological classification were forwarded by Jelence, 1966; Getaneh and Saxena, 1981; Reinhardt and Sisay, 1981; Berhanu and Daniel, 1983; Heeman, 1985; Wolela, 1991 a&b. Many authors agreed that the Ethiopian coals are of high ash content and of low moisture, volatile matter and sulfur content (Heeman,1985; Omar, 1991; Tesfaye et al., 1992; Wollela, 1995).

Extensive exploration work on the coal and oilshale occurrences of the country has been carried out in the last two decades, by the Coal and Oilshale Division of EIGS (Ethiopian Institute of Geological Surveys). Several Ethiopian and foreign professionals have been participated on the exploration of the coal occurrences of the country. All the scholars participated in the coal and oilshale exploration activities have been well compiled in Wollela, 1991 a&b; Wollela, 1992 a&b, Wollela, 1995.

In the project area the existence of carbonaceous beds was originally reported by Jelence (1966). Latter on, Mengesha and Seife Michael (1982), have also briefly described the sediments, while mapping the Gore Sheet, as a thick fluvio lacustrine sediments with lignite beds (estimating the maximum thickness to be about 200m). Recently, Kibrie and Gashaw Beza (1997), mapped and delineate the Geba Sedimentary Basin. Since late 1997, the southeastern part of the basin is studied in detail for the occurrence of a coal deposit through drilling and geophysical logs. Zerihun et al. (1998) estimated the rserve of the coal in this part of the basin. The total reserve estimated in the southeastern part of the basin, at C1 reserve category is 64, 453, 113 tons of coal and at C2 reserve category is 57, 003, 920 tons of coal.

1. 5 METHODOLOGY

Surface Geological Mapping

Surface geological mapping was conducted in the study area at the scale of 1:50,000. In this work the Metu subsheet, the Yayu subsheet, and the Kumbabe subsheet, with a comparable scale of aerial photographs have been used. The air photos have mainly served to depict lineaments. The traverse lines are arranged primarily to pass along streams and rivers. Sedimentary Sections observed in the streams are logged and correlated. In outcrops, thickness measurements have normally been carried out by direct measurement of beds using a meter stick or meter tapes.

Outcrop Sampling

Representative samples were collected from outcrops in accordance with the purpose of the project. A total of 150 coal samples have been collected by two field seasons between December, 1995 and June, 1997. Samples were collected systematically. Commonly, thick coal beds are sampled at interval of 0.3m. The samples were taken from stream sections throughout the basin. Fig. 3 shows the major streams from which coal samples have been collected. But in this work, samples from western, southern, and eastern part of the basin have mainly been studied.

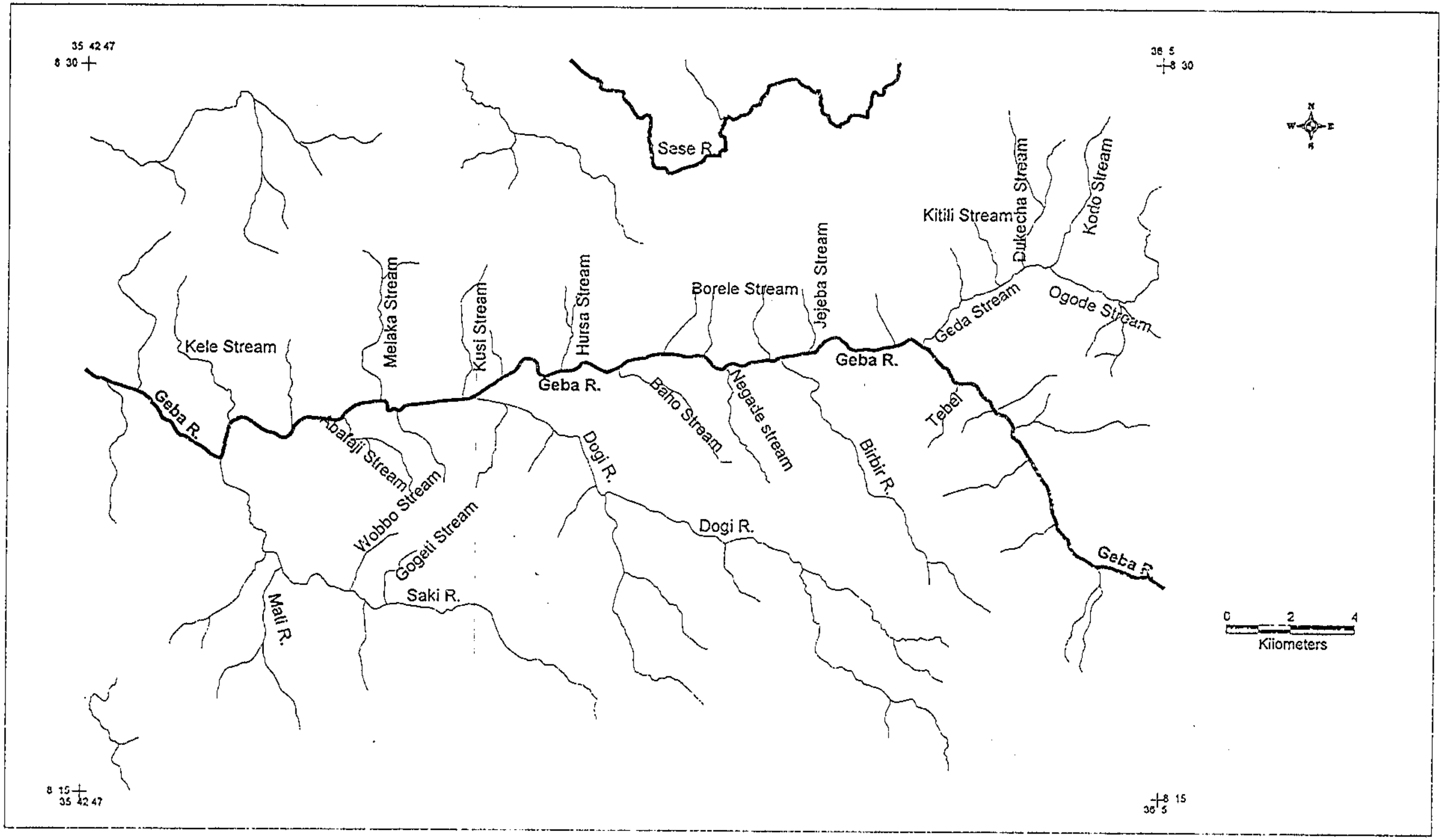


Figure 3. Location map of the investigated streams with a drainage pattern of the Geba Basin.

During sampling, the coal samples were emplaced in plastic sample bags immediately. Weathered surfaces and dirt bands are removed from them in the field. All samples were labeled using the number of the observation point together with the abbreviations of the subsheet, the name of the samplers, and the year of the field season in Ethiopian calendar. In the case of other lithologic units, sampling has been carried out when there is a lithologic change. The volcanics are sampled mainly across their contact.

Subsurface Investigation

A subsurface exploration has been carried out in the southeastern part of Geba Basin (eastern part of Wittete Block). The drilling work have been going on since late 1997. The data incorporated in this research includes that of 10 boreholes drilled during 1997-1998 by the Ethiopian Mineral Resource Development Enterprise (EMRDE). The Location of each borehole is given in Table 1 (UTM), and their relative position is shown in Figure 4. A total of 153 coal samples collected from such boreholes have been studieded in this work.

Laboratory Procedure

Both samples taken from outcrops and cores are submitted to the central laboratory of Ethiopian Institute of Geological Surveys (EIGS). Thin section and chemical analyses have been carried out. The chemical analyses of the fossil fuels has been accomplished by grinding the samples to the standard size of 200 mesh size and it includes: proximate analysis, determination of heat value, total sulfur and specific gravity. Such analytical data are implemented here to assess the quality of the coal and to classify them by rank following the specifications of the American Society for Testing and Materials (ASTM). All the data are cited and the rank is expressed in ASTM terms.

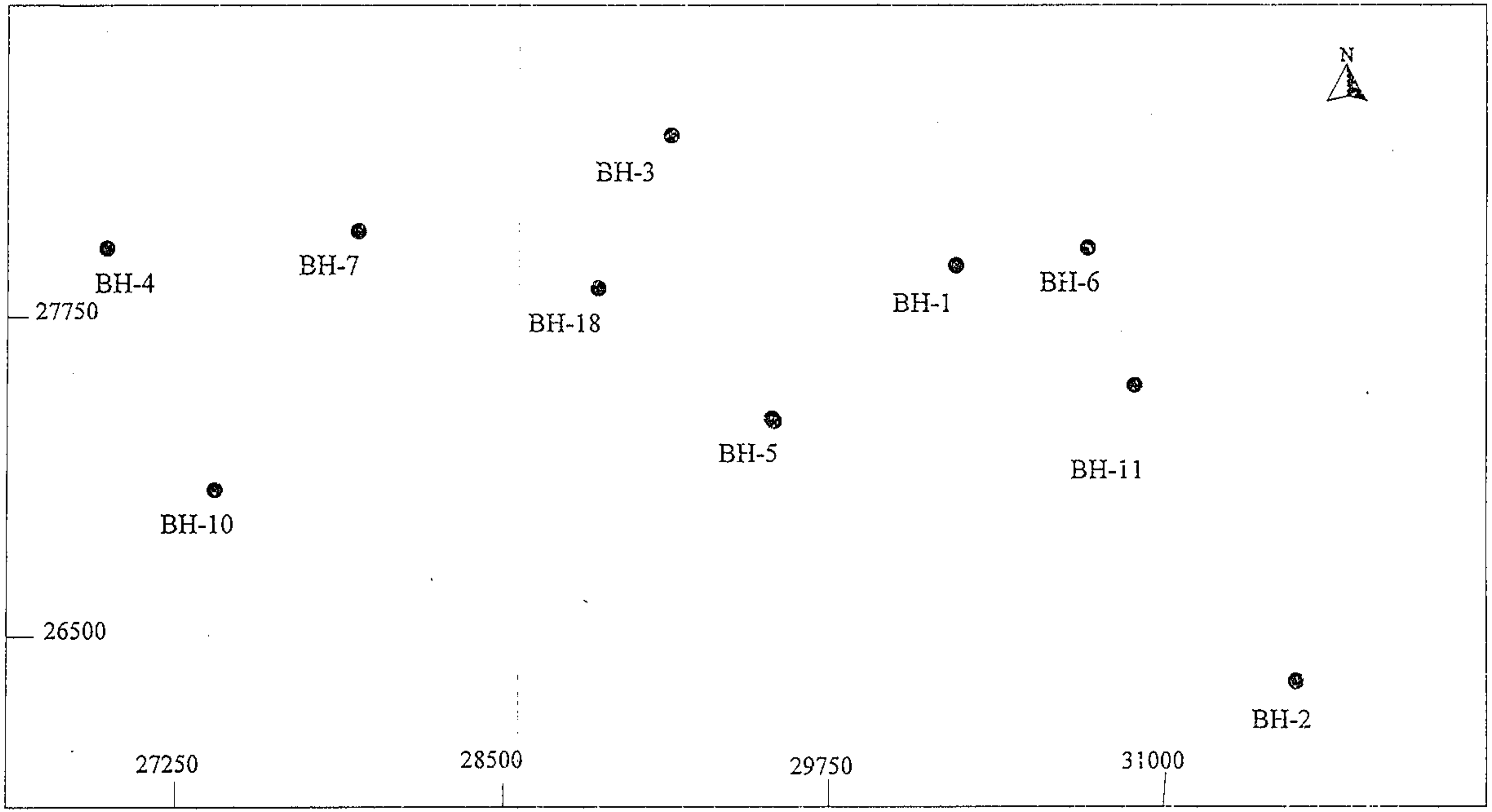


Fig **4** Location map of bore holes drilled by EMRDE (after Zerihun et al., 1998)

Some borehole and outcrop samples of the coal beds have also been sent abroad and petrographically studied. The outcrop samples were taken from a 4m thick coal seam and studied in South Africa by C&N Coal Cunsultancy. The core samples, on the other hand, were analyzed in China by China Complete (China COMPLANT). The petrologic analyses comprehend determination of maceral type and vitrinite reflectance, which helped to infer the origin of the coals and their rank.

Table 1 The Easting, Westing and Collar Elevation Coordinates of Boreholes drilled by EMRDE in 1998

Borehole No.	Easting (m)	Westing (m)	Collar Elevation (m)
1	27938.152	30221.977	1607.3994
2	26368.462	31509.611	1633.5085
3	28462.682	29156.311	1588.4184
4	28024.787	26993.982	1543.5016
5	27349.146	29534.431	1683.0809
6	28002.711	30718.243	1581.5847
7	28074.846	27947.742	1600.5437
10	27089.647	27414.830	1624.2335
11	27467.944	30902.580	1595.8753
18	27843.199	28881.243	1620.3091

2. GEOLOGY

2.1 GEOLOGICAL SETTING

The general geological framework of western Ethiopia includes Precambrian crystalline basement, affected by the Pan African Orogeney, overlain by Tertiary volcanics. Figure 5 shows a simplified geological map of western Ethiopia with the project area located. A brief Geological summary of the region is presented as follows:

2.1.1 Lithology

Precambrian Rocks

Three major tectonic domains, namely- Geba, Birbir, and Baro Domains, are known in the Precambrian of western Ethiopia (Kazmin et al., 1979; TekleWold and Moore, 1989). Figure 5 shows the distribution of these Domains in relation to the study area. They have a north-south elongated geometry with such a pattern that Birbir Domain is wedging southward between the two. Geba Domain is found east of Birbir while that of Baro is in the west. Rocks of the Geba and Baro Domains, mainly gneisses metamorphosed at upper amphibolite facies, are part of the Mozambique Belt of northwest Kenya (Davidson, 1983; Teklewold and Moore, 1989). Genetically, they are believed to represent eastern and western older (Archean?) continental blocks, respectively (Mengesha et al., 1997). On the other hand, the Birbir Domain consists of different volcano-sedimentary schists, metamorphosed at low grade facies (green schist), together with ophiolitic sequences and several plutonic rocks. The lithologic assemblage of the Birbir Domain is believed to

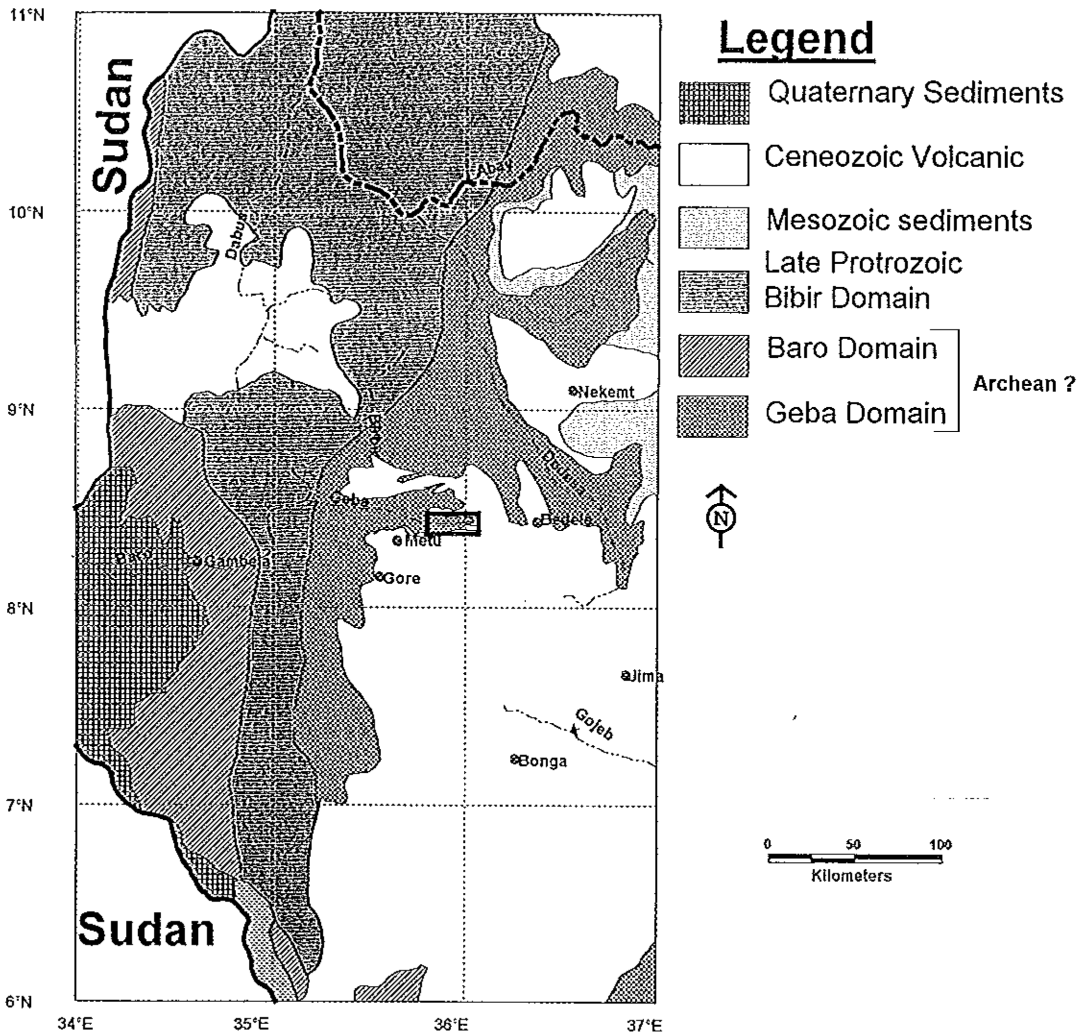


Fig 5. Simplified Regional Geological Map of Part of Western Ethiopia (Modified after Mengesha et.al., 1996 and Kazimin et.al., 1979). Rectangle box is location of the study area.

mark an oceanic basin with subduction tectonic regime (Kazmin et al., 1979; TekleWold and Moore, 1989; SeifeMicael, 1994). Based on the age and geochemistry of some plutonic rocks, TekleWold and Moore (1989), suggested that the formation of the sea was not older than 1Ga. Detailed consideration of Birbir Domain also indicates transcurrent movements of Geba and Baro Domains in a N-S direction (Amenti, 1989).

Paleozoic and Mesozoic Sediments

A few outcrops of the Karoo system have been identified at Gilo and Kari in southwestern Ethiopia (Davidson and McGregor,1976). The Mesozoic sediments which are widely distributed across a large part of the country, are absent in western Ethiopia indicating a synchronous regional up lift in this part. Getaneh (1991) realized a sharp westward decrease of formations in his formal lithostratigraphic classification and nomenclature of upper Mesozoic sequences in the northwestern plateau of Ethiopia. A thin Mesozoic sequence described by Giday et al. (1990), along the Guraghe western margin also confirms such a westward thinning of the sediments suggesting a regional pre-Cenozoic uplift of western Ethiopia. In the project area, there is no evidence that confirms the presence of such Paleozoic and Mesozoic sediments.

Cenozoic Rocks

During Cenozoic, Ethiopia has exercised extrusion of immense amounts of volcanics together with plateau uplift and rift development. Volcanism has started as early as Eocene (Davidson, 1983; Ebinger et al., 1993) with extensive development during Oligocene (Kazmin, 1979; Zanetine et al., 1974; Davidson, 1983). In western Ethiopia, pre-Oligocene volcanics are normally rare and the younger lavas constitute a relatively thinner sequence (Mohr, 1962).

Davidson (1983) explained such an absence of older flows by a regional uplift that started from Sidamo and GamoGofa, and extended to the north through Keffa and Illubabor. A wide development of acidic volcanics, known elsewhere, are also rare in western Ethiopia, which might be due to either erosion or non deposition of the rocks.

2.1.2 Structures

Many authors explain the Precambrian of Western Ethiopia to represent a part of closure of a north-south trending sea (Kazmin et al., 1979; de Wit and Senbeto, 1981; Mengist, 1986; TekleWold and Moore,1989; SeifeMichael,1990). The mafic-ultramafic belt in the Birbir Domain, is believed to represent an ophiolitic sequence: a disrupted oceanic floor (de Wit and Aberra, 1977; de Wit, 1977b; de Wit and Berg, 1981). This sequence extends from the Omo region through eastern Wollega (Yubdo, Daleti and Tulu Dimtu), and Blue Nile (Gojam), to the Sudan. Particularly, the Yubdo-Tulu Dimtu Ophiolite Complex (Wollega), is considered to be approximately in situ (SeifeMichael, 1990). Older northwest-southeast trending, strike slip faults, which may associate such plate collisions are widely occurred in the east and northeast Africa, including Marda, Najid and Aswan faults (SeifeMichael, 1990).

Since Paleozoic, uplifting seems prevailing in the western Ethiopia and expressed by peneplanation. During this time, older lithologic units were washed out and erosion has leveled the surface. Except thin and local continental sediments, there is no any other lithologic record during this time. The absence of Mesozoic sediments in this part of the country, also explains the persistency of uplifting through out the Mesozoic era. Even later, in the Cenozoic, the occurrence of thin remnants of older volcanics in the region witnessed the fact that the uplift was continued as long as early Oligocene. Davidson (1983), reported a regional uplift extending from Sidamo through Gamo Gofa and Keffa, to Illubabour, occurred during early Oligocene-Miocene.

2.2 GEBA BASIN

The Geba Basin has an extent of more than 386 sq. kms, with an outline of nearly rectangular in plan, lying along a north northeast-south southwest axis (60-70 E azimuth). In the west it bulges southward and in the east it gets narrow. In the wider part, it has a diameter of 13 or 14 km, in the narrower part it has a width of 7 kms. The present Geba River Gorge coincides with the sedimentary basin, bounded in all sides by vertical faults.

Figure 6 presents the geological map of Geba Basin and its surrounding area. The area is underlain by high-grade metamorphic rocks of Geba Domain (Mengesha and SeifeMichael, unpub. rep.; Kazmin et al., 1979; TekleWold and Moore, 1989), and Tertiary basalts. Mengesha et al. (1996) have catagorized the rocks of Geba Domain under Alghe Group (the oldest basement rock). The sedimentary succession exposed in the Geba Basin represents one of the thick accumulation of continental sediments that are commonly known to associate the Ethiopian Tertiary volcanics. Many workers have been reported several inter volcanic coal bearing sequences from different parts of Ethiopia (Jelence, 1966; Getaneh and Saxenna, 1984; Wolela, 1991; Minye, 1992; Getahun et al., 1993). In the Geba basin the sediments represent a graben filling, fluvio-lacustrine clastics with thicker beds of coal (4.0m), and oilshale (~35.0m). The sediments are lying on remnants of highly eroded older (late Eocene-early Oligocene), basalt and the Precambrian basement. The younger basalt, overlying the whole units, is regionally extensive and correlable to other early Miocene basalts. The term «upper» and «lower» has been utilized to distinguish the tow basaltic units in a reference to the sedimentary pile. A generalized stratigraphic succession for the Geba basin is shown in Fig 15.

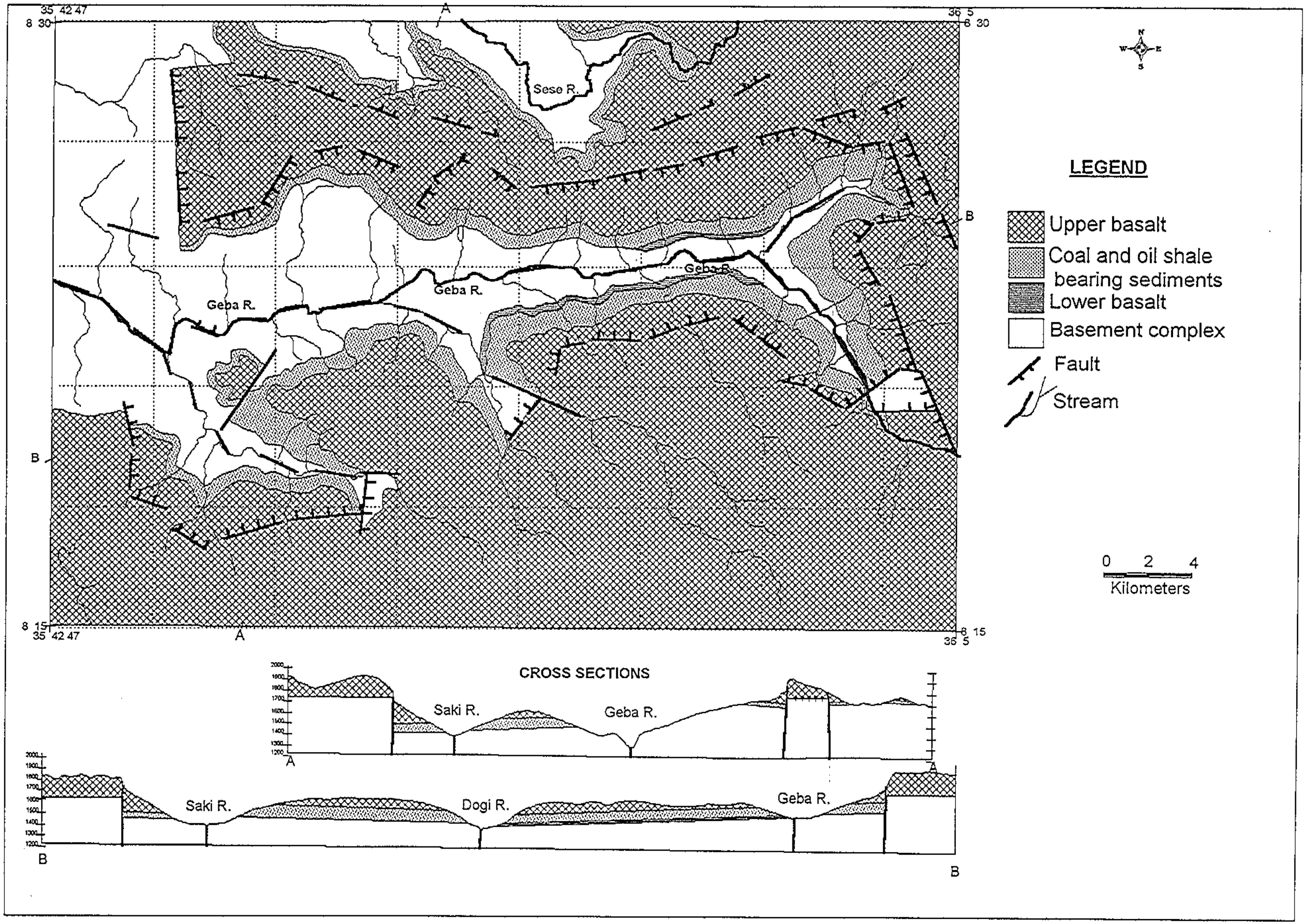


Figure 6. Geological map of Geba Basin and a part of Sese Basin.

2.2.1. Lithology

A brief overview of each rock unit is given below in accordance with their stratigraphic sequence, from the oldest to youngest rock unit.

1. Crystalline Basement: The basement rocks are exposed commonly in the deeply dissected Geba valley and its tributaries. Along the basin floor, mainly in the northwest, metamorphic rocks are generally observed at higher altitudes (about 2000m). To the east it continues below Tertiary sequences at elevations of less than 1400m. This implies an eastward inclination of the basin floor. The basement rocks are also found along the escarpments of the boundary faults, exposed by local windows. The unit includes biotite gneiss, amphibole-biotite gneiss, banded gneiss, granitic gneiss and various minor schists. Few pegmatites and quartz veins are observed having a common association with the schist lenses.

2. Lower Basalt: This unit represents a remnant of older basaltic flow. The rock has been encountered in the courses of deeply cut streams, in southwestern, southeastern and northeastern part of the Geba Basin, beneath the sedimentary sequence. It is very thin (< 20.0m), and patchy, but mapped with exaggeration (Fig. 6). Commonly, it is altered but in

fresh it appears dark gray and has microporphiritic texture. Well developed columnar joints are present. Where its bottom part is exposed, there is a thin (<3.0m), weathered surface of the basement.

The lower basalt is observed only in the Geba basin and its distribution outside the basin is not well known. There is no any outcrop evidence that confirms its extension outside the basin. Mengesha et al. (1997), described these basalts as Jima Basalt (correlable to Omo basalt and Ashangei-Aiba Basalt), whose age range from 40 to 25Ma (Davidson, 1983; Zanettine and Justine Visentine, 1974).

3. The Coal and Oilshale Bearing Sediments: A sequence of coal and oilshale-bearing clastics is exposed around Yayu area, in the eastern part of Geba River gorge. Within the Geba basin the sediments are lying on a metamorphic basement floor with remnants of older Tertiary basalts. Block faulting affected the basin floor giving rise to four major fault blocks: Yayu, Wittete, Geda and Didu Blocks (Kibrie and GashawBeza, 1997). The sediments vary in type and thickness from block to block. In a broad sense, the thickness of the sedimentary sequence increases eastwards, however, syndepositional adjustment of such blocks has caused complication in the lateral thickness variation of sediments. The lithology of the succession comprises: conglomerate, sandstone, siltstone, mudstone, oilshale, coal and tuff. Generally, finer sediments are dominant in the central part than in the margins. Thick succession of coarser sandstone occur at the bottom part in the east and northwest (lower sandstone), and at the top in the west, in the south and northeastern part of the basin (upper sandstone). Abundant coal beds occur in the eastern part. Two oilshale sequences are separated by thin coal rich mudstone unit. The oilshale sequences are distinguished as lower and upper oilshale, with respect to this mudstone unit. The upper oilshale hosted abundant and relatively thick coal seams. The thickest coal seam measured to be 4m is situated in this oilshale. The lower oilshale is generally, poor in coal seams. Chemically, the coals appear to be of high ash, with medium to high sulfur content. Their level of maturity is subbituminous C. The sediments display a simple low lying attitude (horizontal to sub-horizontal) and have no visible fossil except rare fishes.

The occurrence of the sediments outside the basin seems more unlikely. Instead, they appear to be bounded by vertical faults in all sides. These faults coincide with the present Geba Gorge boundaries near Yayu. Data from different exposures along these fault boundaries explain poor extension of the sediments outside the faults. In the southwest corner, of the basin, the upper basalt is observed lying directly on the basement (in Meti stream). A thin (<3.0m), coarser sandstone is observed in the south between the basement and upper basalt. In the southeastern and northwestern part of the basin, the whole sedimentary sequence is observed to decrease continuously and die out between the basement and upper basalt. In the east (east of Geda village), a north-south trending gniessic block is observed to bound a coarser sandstone. Along Yayu-Elemo road, in the north, the upper basalt is observed in an east-west cliffy section lying directly on the basement. In the Geba north, the whole sediments decrease in thickness towards the north fault boundary. In the west, (west of Saki Bridge) the upper basalt and the metamorphic basement are exposed by Metu-Addis Ababa main road along a steep section, in a few tense of meters of separation

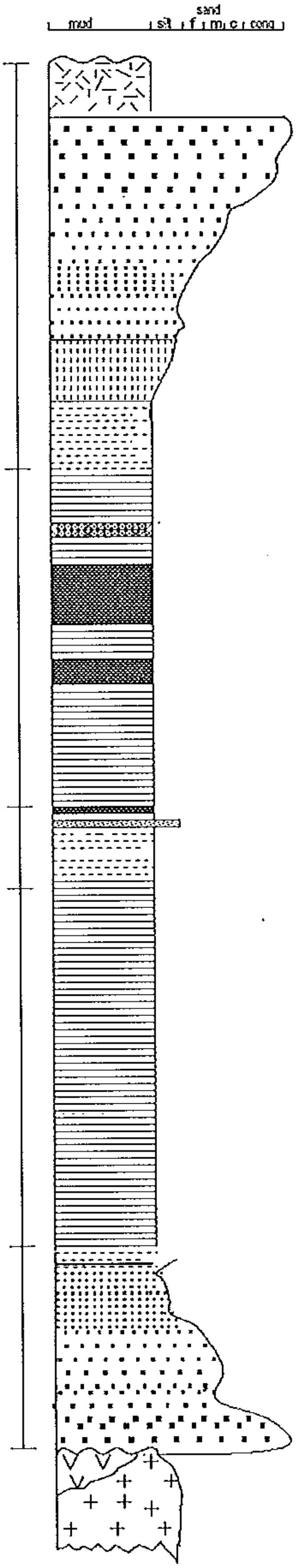
4. Upper Basalt: Upper basalt is a part of Makonnen basalt whose absolute age ranges between 34.8 and 23.1 Ma (Davidson, 1983; Mengesha et al., 1996). In the study area it capes the whole stratigraphy forming terraces within the Geba basin, and occupies topographic highs outside the basin. Generally, it is dark gray and aphanitic with relatively thick development of soils. Columnar jointing is common in its bottom part. It comprehends a number of flows separated by different succession of reworked tuffs, mudstone, sandstone and conglomerate. In borehole 2 and 7 such flows, separated by tuff beds are clearly observed. Outside the basin a thick succession of such reworked tuff covers the whole area between Kumbabe and Bedele town (east of the study area). The tuff sequence is measured to have a thickness of upto 60m in a section found south of Kumbabe.

2.2.2 STRUCTURE

In the study area, the metamorphic basement rocks are commonly foliated having a dip amount of 15^0-30^0, with a distinction of deformational pattern in the area north and south of

The north-south trending faults are not common like that of the east-west ones. But, they are prominently observed in the east and west extremes of the basin acting as a boundary. Commonly, they have a westerly component and have a north-northwest trend. The north-south faults, generally, are well expressed in the east than in the west. The throw of the two major faults (E-W and N-S), is estimated to reach up to 100m. Though, it is difficult to understand their relationship from this study, the eastern boundary fault (NNW-SSE) appears to be regional and may probably be older (see section 4.1). However, the southwestern and northeastern curved corners of the basin suggest reactivation of the two faults together at least once after the emplacement of upper basalt. Perhaps reactivation of the faults was an important process even earlier, during and after deposition. Recent reactivation of the faults is clearly seen in the aerial photographs from shattered grounds near the northern and the southern boundary faults.

The nortwest-southeast trending faults are recognized mainly from dranage pattern and are observed in the southern part of the basin. These faults are not seen in the area north of Geba River (Didu Block). They separate Yayu and Wittete Blocks, and Wittete and Geda Blocks. The Geba River follow such lineaments when enter to and going out of the mapped area. Major tributaries of Geba River: Saki, Dogi, Baho, Negade and Birbir Streams (in the south) are controlled by northwest-southest trending faults (Fig.3). The Shallow dip angle of the Precambrian structures (foliation), do not encourage the idea that they may give way to such high angle faults.



UNIT V(Upper Sandstone): Includes conglomerate, cross bedded coarser sandstone, fine sandstone, laminated and massive siltstone, reworked tuff and mudstone beds. It exhibits upward coarsening and basinward fining. Coarser sediments are ristricted to the west, northeast ,and southern part of the basin.

Unit IV (Upper Oilshale): Comprhends beds of oilshale, carbonaceous shale, coal, organic rich mudstone, with intercalation of sandstone and mudstone. Thick succession of the sandstone and mudstone intercalation is frequent in the eastern part (Geda Block). Coal beds are found in the upper part of the unit. The thickest coal seam (4m) is hosted by this unit in the south-southeastern part of the basin (Wittete Block). The maximum thickness of the unit is 37m.

Unit III (Coal Rich Mudstone Unit): Consists of principally, mudstone and coal beds. However, a succession of sandstone and mudstone locally, found in the southern and southeastern part of the basin. The coal seams are less than 2m and are commonly associated with carbonaceous mudstone. Frequently, the upper and the lower boundaries are marked by coal seams. The average thickness of the unit is not more than 7m.

Unit II (Lower Oilshale): Oilshale, carbonaceous shale coally shale and organic rich mudstone are the major components of the unit. Thin mudstone and coal lenses are present here and there. The coally shale, always at the bottom, is limited in the southern part of the basin. Intercalation of sandston and mudstone are present in the south, southeast and north eastern part of the basin. Total maximum thickness of the unit reaches upto 35m.

Unit I (Lower Sandstone): Lies on both the lower basalt and the PreCambrian crystalline basement. Lenses of conglomerate (< 0.5m), and sandstone bed form a number of cycleswith thin mudstone beds and coal lenses (< 0.3m), in the eastern part. In the northwest, the unit is represented by thin (< 3m), sandstone beds. In the east (Geda Block), its maximum thickness is measured to be more than 35m.

Figure 8. A typical section of Geba basin.
(vertical scale 1:500)

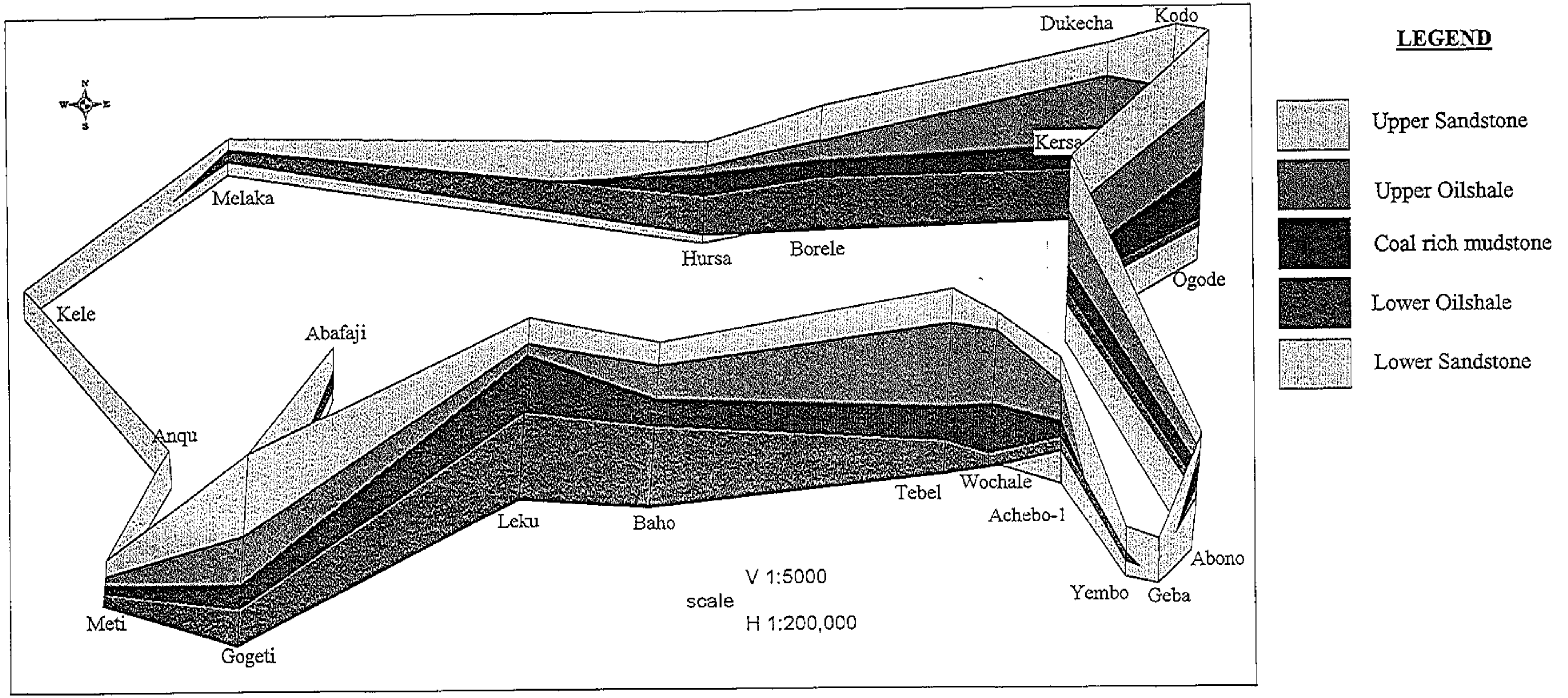


Fig.9 Fence diagram of Geba Basin showing the distribution of the major sedimentological units, constructed from selected stream sections (the streams are shown in Fig. 3).

paleotopography of the basin. In the Geda Block its estimated average thickness is between 10 and 15m. It includes conglomerates, coarser sandstone, mudstone and thin coal seams. In the east, it shows poorly defined mudstone-sandstone cycles while in the northwest there is no mudstone and coal beds. No visible fossil has been observed in this unit. Each lithofacies found in this unit is described below.

Conglomerate: Thin conglomeratic beds are often found associated with sandstone beds. One meter conglomeratic bed is observed in the lower part of the unit in the west (Abafaji stream). In the east, it appears at different levels of the succession always with thickness of less than 1m. Compositionally, the gravels are oligomict, containing only quartz, with size range between granule and pebbles. These larger clastics are subangular-subrounded, and amount to be >50%, with less proportion of coarser sand. The coarser sand grains found in between the gravels are mainly of quartz and K-feldspars. In a vertical section, commonly the beds show fining upward trend and grade to sandstone. In the section where it is found in the lower part of the unit, the lower contact was not visible.

Coarser sandstone : This rock is the major component of the unit. It is commonly massive and poorly sorted. In some cases, however, either it shows a fining up-ward trend or is intercalated by fine sandstone. In the Geda Block, this lithofacies alternate with mudstone lithofacies varying in thickness from 0.5 to about 5.0m. In the west such cyclic occurrence is not present, instead, thin coarser sandstone beds (<3m) underlie the whole sediment. In places, it includes pebbles of mudstone.

Compositionally, it is feldspathic sandstone (subarkose), (Pettijohn,1984). Under microscope, its contains mainly quartz grains (>80%), and minor feldspars (8-15%). Rare amount of rock fragments which could be volcanics, with fine pyroxene grains are noted (<1%). It is remarkably porous estimated as high as 10%, and the porosity increases outward from the basin. Within the basin, the common cement is clay but, at the southeastern corner, sparry calcite cement is observed. The grains are angular to subangular. The common feldspar variety is microcline and are usually finer.

Mudstone: Mudstone exclusively occurs in the eastern part of the basin alternating with the coarser sandstone lithofacies. Commonly it is lightblueish gray in color, without any visible fossils. But, few beds of carbonaceous mudstone are seen to have leaf fossil prints. Many of the beds are clayey with rare visible quartz grains and mica flakes. Some beds, however, found in the lower part appears to be silty. Except few beds, which display weak lamination in their upper part, in many cases this lithofacies appears to be massive. Individual bed thickness reaches as high as 2m.

Coal : Few thin coal seams (<0.5m), are observed in the lower sandstone. They are also restricted in the eastern part of the basin. More frequently they are incontact with mudstone than the sandstone. The maximum thickness of the coals observed in this unit is 0.5m (Muchuchato stream), and are lenticular.

3.1.2 Depositional environments of unit I

Based on the nature and lithologic assemblage, unit I is interpreted to represent braided river sediments. Proximal and distal braided river deposition have been noted in the northwestern and southeastern (eastern) part of the basin respectively.

Proximal braided river deposits: The thin coarser sandstone beds observed in the northwestern part of the basin are considered to mark the upper course of a braided river. The beds have a limited lateral extent in a north-south direction, indicating that they were confined in an east-west trending river channel. The angular nature of the grains with the presence of

the feldspars implies the nearness of the source area. The metamorphic terrain found north and northwest of the basin, within a short distance, should be main provenance of the sediments. The architectural elements of the system (e.g. island bars), are not well recognized. The absence of such facial components and thinness of the lithofacies, may be due to the omission of the central axis of the system by erosion.

Distal braided river deposits: The thick succession of the lower sandstone unit in the eastern part of the basin, represents distal braided river deposits. Thin conglomeratic layers represent channel lag deposits, while the thick, massive sandstone beds mark longitudinal bars of the braided river. Thin beds of mudstone (<0.5m), and the associated coal lenses, are developed on the top of the bars. Thin, laminated, finer sandstone beds are formed due to waning flow. The frequent occurrence of the fine sediments with coal stringers, as a whole, implies the existence of repeated periods of overflows. It is known that coal seams in the active braided plain regime are commonly thin and laterally limited, due to a fast shifting and short-lived over bank settings (Collinson, 1996). The mudstone pebbles observed in the sandstone beds confirm such rapid channel and bar shifts.

3.2 UNIT II (LOWER OILSHALE LITHOFACIES)

3.2.1 Lithofacies

This unit is widely developed in the basin. It is seen to overlay either Unit I (Lower sandstone), or the lower basalt, or the metamorphic basement, where ever they occur. The contact between this unit and unit I is sharp, whilst its contact with that of the lower basalt and the metamorphic basement is unconformable. Its maximum thickness reaching as much as 34m is measured in borehole 6, at Wittete Block. Thick successions of the unit estimated to be 27m (Baho stream), were observed in outcrops; in western part of the same block.

A minimum thickness of 1.5m is observed in Kersa-1 stream, Geda Block. Generally, in the Geda Block it shows a sharp drop in thickness (commonly < 3.0m), and is represented only by oilshale facies. In the northern part of the basin, Didu block, it thickens east ward from 1m in Meleka stream (west), to about 15m in Borele stream (east). In the Yayu Block, it is exposed in a few stream sections (Gogetti, Leku, Wobbo stream), and is estimated to be less than 20m. Hence, in a north-south direction, it increases south wards, and in east-west direction, it increase east wards sharply diminishing under the Geda Block. The lower oilshale includes seven rock types and each rock type is described in accordance with the standard classification scheme of carbonaceous sediments (Pettijhon, 1984). The classification scheme is given in Fiure 10.

Coally shale:This lithofacies is often observed in Wittete Block, occupying the bottom part of the unit. It lies unconformablly on the highly eroded lower basalt and metamorphic basement. It is absent above the Lower Sandstone Unit. Its upper contact with the carbonaceous shale and oilshale is sharp. It is characterized by paper fissility and friable nature. Compositionally, it may range between cannel shale and bone coal. It bears visible coalified grass and leaf sapropelites. Their color varies from light brownish gray to dark brown. Thick lamination is the common, structure. Visible plant fragments include leaves and grasses, and are often coalified. Fish fossil is also rarely found. In a vertical section, it is observed to occur at any stratigraphic position in the unit from bottom to top. Its contact boundaries are sharp, with a common bed thickness less than 2m.

Organic rich mudstone : This rock occurs as a lens throughout the unit. But, the thickest section is exposed in Tebel stream measured to be 2.5m. It is intercalated with very thin bands of mudstone (<5cm) and the maximum individual bed thickness is 60cm. It has light brownish gray to light olive greenish gray color with less organic matter content than the oilshale and carbonaceous mud. Thus compositionally, it is estimated to be comparable to black shale (<20%, organic matter content). It has slippery surfaces and poor fissility. Its bottom and top contact is sharp.

Interbedded sandstone and mudstone : This succession is observed in the southeastern part of the basin (Achebo-1, Achebo-2 and Wuchale streams, borehole 3, 6 and 11), in the northeastern part of the basin (Dukecha stream), and in the south- southwestern part of the basin (Leku stream and Wittete west creek). The maximum thickness of the succession is observed in Wuchale stream measured to be 16m. In the southeastern and northeastern part, the rock includes alternating beds of sandstone and mudstone. Whereas, in the southern part it is represented by massive coarser sandstone. This massive sandstone appears to be thick in the Leku stream, estimated to be 10m, and decreases to the east. In the other case, both fine and coarser sediments are present and individual beds are measured to a maximum thickness of 2m. Generally, the composition of the sandstone beds is estimated to be subarkose consisting of angular to subangular quartz grains and minor K-feldspars. Both fine and coarser varieties are present. The fine sandstone beds show a laminar structure, while the beds of coarser sandstone are commonly thickly bedded and massive. Mudstone beds are gray in color, not thicker than 2m, and are clayey with rare visible quartz grains. Normally, they are massive but some times show weak lamination. Few lenses of coals are also observed in this lithofacies.

Coal: Coal seams in the lower oilshale unit are not common. They are not extensive and thick, usually measured to be less than 0.6m. The coal seams have a dull luster and dirty nature even grading down to bone coal. Commonly, the seams have sharp contacts.

Siltstone: This rock in this unit is restricted only in the Didu Block (Jejeba and Hursa streams). It is gray to brownish gray in color. Its maximum thickness is 2m and is sharply distinct from other lithofacies. In the field, it is seen that quartz is the major component with some amount of organic admixtures to darken its color.

3.2.2 Depositional Environments of Unit II

The sediments of unit II are interpreted to represent lake, marshes, and fluvial environments. Marshy and fluvial sediments are observed in restricted parts of the basin, indicating that there was temporal decreasing of water level in these parts.

Lake Deposits: Sediments of oilshale, Carbonaceous shale and Coally shale are interpreted to be formed under lacustrine environment. Thick lamination as a common feature may be attributed to a relatively shallow lake condition. All are formed under reducing condition with minimum supply of clastics. For the formation of coally shale and few coal seams high in put of plant fragments to the coastal area is necessary. In the case of oilshale high proliferation of phytoplankton is essential in a relatively deep and segmented water mass (Tucker, 1988).

Fluviatile Deposits: The sandstone, mudstone and coal beds found in this unit are interpreted as a fluviatile deposits. The thick coarser sandstone observed in the south (Leku stream and Wittete west creek), may mark channel sediments. The other deposits occurred commonly in association of sandstone, mudstone and coal lenses, observed in the southeast and northeastern part presents both channel and over bank conditions.

Marshy area (Paludal) Deposits: The organic rich, massive to weakly laminated mudstone represents a marshy area deposits. Its small thickness and limited distribution (Tebel stream), explains poor development of the environment. In Wuchale stream (immediate east of Tebel stream), there exist a thick (16m) sandstone-mudstone succession in the same unit, along the same level of stratigraphy. Therefore, this marshy area was developed in association with streams. Its color and its association of oilshale may suggest high water level and reducing condition.

3.3 Unit III (COAL RICH MUDSTONE , MIDDLE UNIT)

3.3.1 Lithofacies

This unit comprises mainly beds of mudstone, carbonaceous mudstone and coal lithofacies. Distinctly, it is thin with a common thickness variation between 3 and 6m. Inspite of its thinness, however, it covers the major parts of the basin forming a marker unit between the lower and upper oilshale. It covers 176 sq km. The locality where unit III is totally absent is the northwestern part of the basin. Its thickness exceptionally, increased in the south and southeast corner. In these parts, the unit ranges from 11 to 16m including a thick succession of sandstone and mudstone beds (in borehole 2, 6 & 11; and in Leku and Kersa-1 streams).

Coal: 5 to 6 coal seams are present in this unit. The thickness of the coal seams varies from few tens of centimeters (15-20 cm) to about 2m. Commonly, the coals are columnar with regularly spaced joints. They are black to brownish black in color and have fairly brilliant luster. Their contacts are sharp and no rootlets have been observed near the contacts.

Carbonaceous mudstone : Commonly, carbonaceous mudstone accompanies with coal beds indicating a gradual enrichment of organic matter and a gradual on setting of the coal forming condition. They are rich in plant fragments (commonly leaves), with a color variation of light brown to dark brown. The color variation is a function of organic content (darkness increases with the amount of organic matter). However, according to the classification scheme of Pettijohn (1984), these beds may fall in the range of black shale and bone coal. The maximum organic content estimated is 20-30%. Commonly they are massive and clayey. They have sharp or graditional contact with the organic poor mudstone. Usually, they are measured in a range less than 0.5m.

Mudstone: This rock can also be found in contact with the coal seams but, the association with the coal seams is less frequent than the carbonaceous mudstone. The mudstone beds are gray and clayey with minor visible quartz and mica flakes. Thick beds as much as 2m are common. Specially, it is well developed in the southwestern part of the basin (Yayu Block), where it represents the unit exclusively. In this part, this facies is measured to be 6m. In places, the mudstone beds show weak lamination.

Fine to medium sandstone: This is observed only in Tebel stream. Its maximum thickness is not more than 1m. It has been traced for about more than 30m along down stream direction. It shows cross-lamination and form load cast (ball cast) structure in the underlying mudstone bed. It is poor to moderately sorted with subangular-subrounded grains. Compositionally, it is roughly estimated in the field to be subarkose with quartz (>75%) and feldspars (10%).

Interbedded sandstone and mudstone : Occurrence of coarser sandstone in unit III is rare. But, a thick succession of sandstone and mudstone beds is observed in the southeastern part of the basin. This succession developed over a thin coal rich mudstone horizon with a thickness of more than 10m. In Kersa-1 stream, Geda Block, it is seen to lie on a coal and mudstone succession. In this section, the bottom part of the interbedded succession is marked by conglomerate. The thickness of individual bed reaches up to 3m, with sharp contacts. It also includes thin beds of fine sandstone and coal (<0.3m). Commonly, the fine sandstone shows laminar structure whereas, the coarser sandstone and mudstone beds appear massive. The sandstone beds consists mainly of quartz and minor amount of feldspar grains indicating that they are subarkose sandstone.

3.3.2 Depositional Environments of Unit III

Unit III is mainly deposited in a meandering river condition. The flood plain deposits are easily identified. The coarser components of the channel sediments, however, are not well preserved. Some sandstone beds observed in the southeastern part of the basin are considered to be examples of lateral accretion.

Flood plain deposits: Beds of mudstone and carbonaceous mudstone with the peat beds (coals) are accumulated as a vertical accretion deposits in low energy flood basins and back swamps (marshes), far from active channel. Well preserved plant fossils together with thinly laminated mudstone reflect slow deposition from suspension (Bustin and Palsgrove, 1997). The rare occurrence of large visible mineral grains in the mudstone beds could also be attributed to the fact that they are deposited at a distance from the stream channel. A thin fine-medium sandstone, exposed in Tebel stream, represents an isolated crevasse splay. Cross lamination in this facies express weak strength of the stream, and its small thickness indicates a short period of deposition.

Stream channel deposits: As it is mentioned above, there is no clear record of stream channel sediments exposed (may be due to erosion by Geba River). However, the sharp-based conglomeratic sandstone beds that rest on mudstone, may be taken as channel deposits formed by crevassing of a major river channel (Collinson, 1996). The succession of interbedded sandstone and mudstone, as a whole, represents parts of the flood plain which were proximal to active channels. They frequently received coarser sediments during over bank flooding.

3.4 UNIT IV (UPPER OILSHALE LITHOFACIES)

3.4.1 Lithofacies

Unit IV is also widely developed in the basin but its thick succession is limited to the southwestern and southeastern part (Fig. 9). In outcrops, even the southwestern thick succession seems to be local. Commonly Unit IV has sharp boundaries with the underlying and overlying units. The maximum thickness observed is in borehole 5, measured to be about 70m. It incorporates six types of rocks.

Olishale: This is the principal sediment in the unit. Generally, it appears to be thickly laminated and highly fissile. Its color ranges between brown and dark brown with plant fragments (commonly leaves). Thin (~1m), beds of paper fissile varieties are observed in places. Detail outcrop logging of the unit along Tebel stream, shows that the oilshale beds are normally less than 1m. The total succession of the unit is normally interbedded by lenses of (< 5cm), either mudstone, siltstone, or sandstone. They also alternate with carbonaceous shale and coal. The oilshale beds have sharp contacts with all lithofacies but, with carbonaceous shale, some times they show a graditional change.

Carbonaceous shale: Comparable to bone coal, these sediments are widely developed in this unit than in the Unit II. The thickness of the beds is commonly in a range of less than 0.5m (commonly <0.3m), forming dark bands in the succession of oilshale. Usually, the carbonaceous shale accompany the coal seams, either intercalating the seams or marking a transitional gap between the oilshale and coal beds. Characteristically, they are thickly laminated and includes visible sulfide minerals.

Coal : Generally, the coal beds in unit IV are thick and apparently extensive. The thickness ranges between 0.8 and 2m. 4m thick coal seam measured in the Tebel stream section (Wittete Block). Commonly, several coal seams are found in the upper part of the unit. The coals are brownish black with fairly black luster. In outcrops, the coal seams show columnar nature, and in hand specimens they fall apart in a plane parallel to bedding indicating that they are thinly bedded. Minute, lenticular vitreous bands (at a scale of 1 cm length, and few mm thickness), appeared in the atrital media.

Organic rich mudstone: This lithofacies is observed in a restricted area at the boundary of Yayu and Wittete Blocks. It is exposed in a single outcrop located east of Dogi Stream Bridge along Addis Ababa-Metu main road. In a vertical section, it is overlain by thinly laminated (paper fissile), 1.5m thick oilshale bed. Its downward continuation is not visible. It includes several beds of sandstone mudstone, and coal lenses. In the outcrop, it is measured to be about 12m. The maximum thickness of individual beds is not more than 2m. Its color is dull brownish gray with weak and thick laminations.

Sandstone: A number of sandstone beds are found in the upper oilshale unit. Commonly, the beds are less than 1m in thickness, and often show upward fining sequence. In borehole 5, the sandstone attains a thickness of 12m including both fine and coarser sandstone beds. In the coarser variety, the grains are subangular-subrounded. Compositionally, the rocks are estimated in hand specimens to be subarkose. Quartz is the predominant framework grains with minor amounts of feldspar grains (K-feldspar). The fine sand exhibits laminar structure.

Here also quartz is the major component.

Mudstone: Abundant mudstone beds ranging in thickness from centimeters to 2m are present. They are either associated with the sandstone and coal beds or occur separately. Thin lenses of mudstone (<10 cm), are seen in the Tebel stream to intercalate with all sediments, rhythmically. Its color varies between gray and light yellowish gray. The thicker beds commonly appear to be massive with visible grains of quartz. The beds have sharp boundaries.

3.4.2 Depositional Environments of Unit IV

The sediments of unit IV suggest depositional environments of lake and marshe areas.

Lake environments: The Oilshale, carbonaceous shale and the associated coal seams are considered to be lake sediments. In comparison to the previous lake sediments (unit II), these sediments are assumed to be deposited in a relatively deep water condition. Particularly, those of thinly laminated (paper fissile), oilshale beds are typical of higher depth. Rhythmic segmentation of the succession, by mudstone, however, may mark a continuous filling of the lake by the process of siltation to form the mud lenses. The oilshale bed thickness between two mudstone bands may be correlable to the corresponding amount of subsidence. Direct association of the oilshale with such humic coal seams, together with the absence of rootlets (and seat earth), suggest alochthonous origin for the coals. Plant fragments were drifted from marshes and flood plains around the lake to the bottom of the lake, which is of high reducing condition. Abundant plant fragments in the oilshale beds is a positive evidence for such high supply of plant debris to the lake. The thickness of the coal seams and their occurrence seem to be a function of block faulting (Korkmaz, 1994). The coal seams of the unit thought to be extensive over Wittete and Geda Blocks. The thickest coal seam (4m), is accumulated in the eastern part of Wittete Block, where the thickest succession of the unit is confirmed both in outcrops (Tebel stream), and in boreholes (BH-5). In the Didu Block, on the other hand, the upper oilshale is thinner and no abundant seams have been found.

Marshy environments: Thick mudstone beds (measured up to 2m), occurred in the unit, sometimes associated with coal seams, are developed in marshes that may be formed at the margins of the lake. They have spares occurrence and vary in their organic matter content. The organic matter content may be due to the variation of either the local pH or level of the water table (Krevalen, 1961; Ceciel et al., 1979). A restricted thick (~12m), succession of organic rich mudstone beds, with coal lenses and medium-coarse sandstone, is observed in the western margin of Wittete Block. The associated sandstone beds in this section may be due to smaller stream channels. Whereas the organic rich mudstone and thin coal beds are formed, overbook, in a highly reducing marshy environment. The thick and weak lamination of the mudstone in this section, indicates there was an important water influence, in this area.

3.5 UNIT V (UPPER SANDSTONE)

3.5.1 Lithofacies

Unit V consists of conglomerate, sandy gravel, cross bedded sandstone, fine sandstone, siltstone, mudstone and reworked tuffaceous sediments. Three independent deposits of the coarser sediments (conglomerate, sandy gravel, the cross bedded sandstone), have been found in the western, northeastern and southeastern parts of the basin. The individual coarser deposit laterally replaced by finer sediments; basin ward and merges to each other. The unit, therefore, shows such a configuration that conglomerates and sandstones at the margin, and silt and mudstones at the central part of the then lake. The sandstone in the western part of the basin is well exposed and traced along Yayu and Wittete Blocks. An other good exposures of sandstone are limited to the northeastern part of the basin and appear to be of small scale. The southeastern one is observed in boreholes. The maximum thickness of the unit measured in borehole 5 is 52m. The contact between this unit and unit IV is sharp.

Conglomerate: This lithofacies is observed at the top part of the unit in the southern part of the basin (borehole 5 & 10). Its maximum thickness in borehole 5 is about 6m. It is mud supported and friable. Compositionally, it is polymictic, including basaltic rock fragments and intraformational mudclasts. There are also coarser and angular to subangular quartz grains. The rock fragments are subangular to subrounded, with a size of less than 4 cm (granule gravel or very fine gravel). Such components of gravel are estimated to be more than 50%. Horizontal bedding in the cores is manifested by partitions perpendicular to the core axis. Its color varies from gray to reddish gray. Particularly, its upper part is dominantly reddish which may be due to the backing effect of the overlying basalt (Zenebe, et al., 1998). Intercalations of finer sediments are often present. It has sharp contact with the underlying conglomeratic sandstone.

Sandy gravel: In this rock, the gravel-sized fragments are in amount less than 30% with a large proportion of coarser sand grains (60-80%). This sediment is observed both in boreholes and outcrop sections. In the boreholes, it is measured to thick about 6m. But in the outcrops it is not exposed well. In the northeastern part, Dukecha stream, it is observed as large blocks and boulders only. Quartz grains are the only larger clastics in the stream sections (oligomict). In the boreholes, on the other hand, the gravel-sized fragments are basalt and mud rock fragments with minor quartz grains (polymict). The gravels are granule (fine gravel), in size and are subrounded to rounded. The sand portion is coarser to very coarse, consisting mainly of quartz and minor feldspar (K-feldspar). Its composition is estimated in the field to be subarkose. Structurally, it seems thickly bedded and its bottom contact is graditional.

Cross bedded coarser sandstone: This rock have been observed in all three sites: in the western, northeastern and southeastern parts of the basin. The western sandstone is thicker than the others and is estimated in Gogetti stream to reach 30m. Local quarries, in this area are used to exposed the sandstone well. In the northeastern part (Dukecha stream), it is estimated to be not more than 10m, and in the southeast, it is measured to be 14m (borehole 5). In its lower part, it is thickly bedded; in its middle part it shows small scale (~30 cm), cross bedding; and in the upper part it is thinly bedded. Locally, it includes thin beds of conglomerate, carbonaceous shale and even dirt coal lenses (<20 cm). Compositionally, the sandstone in the Dukecha stream appears to be quartz arenite. It contains quartz as much as 95-97%, feldspars 3% and porespaces between 1 and 2%. The grains are subangular-subrounded cemented by silica. In the western part of the basin, however, the sandstone appears to include more feldspars (>10%), and compositionally, estimated to be subarkose. Furthermore, at the top of the western sandstone there is a 4m mudstone. Within the mudstone, there is an intercalation of 0.5m oilshale. The mudstone is light yellowish gray to yellowish brown, massive with rare faint laminations. It is clayey in which visible minerals are not found, and is friable. The oilshale bed is light brownish gray in color, thickly laminated and poor in plant fragments.

Fine sandstone: In the western margin of Wittete Block (Baho stream), this lithofacies is observed to have a sharp contact with the overlying coarser sandstone beds. In this section, it is interbedded with siltstone and silty carbonaceous shale. Further east, in Tebel stream, however, such intercalations are not observed. In the northeast (Dukecha stream), this facies is partly exposed below the coarser sandstone. In this case it appears to be massive, but in the former section it shows compositional lamination by alternation of dark and light bands. Compositionally, the rock is believed to be orthoquartzite. But, such dark and lighter bands may mark organic rich and organic poor layers, respectively. Texturally, it is well sorted. In Tebel stream its exposed thickness is measured to be 3m. But, the maximum thickness is thought to reach as much as 10m. In all outcrops its lower contact is not visible.

Siltstone and mudstone interbeds: These roacks are found in the Wittete, Geda and eastern part of Didu Block. The two sediments are observed in association, commonly in the eastern central part; and separately, elsewhere. Individual beds of siltstone and mudstone could measure up to 3m (even possibly more). Generally, the thicknesses of individual bed and the sequence as a whole increases east ward. The maximum thickness of the siltstone-mudstone succession is measured in borehole 11 to be 33.7m. However, in the west part of the Wittete it may be below 5m (Baho stream). From borehole data, thick succession of the rocks seem to follow the east-west axis of Wittete Block and decreasing due north and south. The siltstone beds commonly appear to be massive, gray to light gray, rarely including coal lenses. In hand specimens, quartz is the only dominant component. The mudstone beds are also massive, gray in color and are clayey. No visible fossils have been found.

Reworked tuff : This facies is frequently observed at the upper part of the sedimentary sequence, and underlying the upper basalt. The reworked tuff beds are observed on a number of sections in southern Wittete Block, northern Geda Block and eastern extreme of Didu Block. In well exposed sections of Tebel (southern part) Kodo and Ogode streams, (northeastern part), it attains a maximum thickness of 8m. It is also observed in boreholes with smaller thicknesses. Compositionally, it appears to range between vitric tuff and lithick tuff. In the northeastern part of the basin, it includes angular to sub angular quartz grains, glassy fragments (black in color), and feldspars. In the southeastern part (Tebel stream), it includes rounded basalt fragments. Commonly, it is thinly bedded. But, in a relatively thick sections it seems to loose the bedding nature downwards, and appears to be massive. Intercalations of carbonaceous mudstone and coal lenses with thin beds of ash, are observed in the lower part. Its color is variable with dark appearance. But frequently, it is observed to be weathered with a rusty to light yellowish color. The color of the ash beds is light gray or/and light bluish gray. These beds are usually measured to be less than 1m. They look silty and are loosely consolidated. Lenses of coal (~10 cm), are repeatedly observed in these beds (Birbir stream).

3.5.2 Depositional Environments of Unit V

Having a typical upward coarsening sequence and basin ward fining nature, unit V is interpreted to represent a lake delta. As the action of waves and tides is negligible in lakes, the entire facies assemblage of unit V presents mainly fluvial influences. The unit records a regressive sequence and the last phase of deposition in the basin.

Delta Plain Deposits: Conglomerates, conglomeratic sandstone, and coarser sandstone are interpreted to represent the delta plain. Restricted occurrences of these sediments in the west, northeast and southern part of the basin corresponds to the principal delta plains. The conglomerates are considered to be proximal mouth bar conglomerates. The coarser sandstone with the accompanied conglomeratic lenses are deposited in distributary channels. A detailed analysis of cross bedding could give further information about the nature of the channels. The associated mudstone and oilshale beds found at the top of the western sandstone are accumulated in interdistributary areas. Specially, the existence of oilshale in a mudstone explains that such interdistributary areas have been submerged, at least locally, to the extent of oilshale deposition.

Prodelta Deposits: The fine silt and mud beds, which occurred in the eastern part of the basin are deposited from suspension. The compositional lamination reflects fluctuation in rivers to transport sediments. Preservation of such lamination suggest anoxic bottom water that laminae are not disturbed by bioturbation (Reading and Collinson, 1996)

4. GEOLOGIC HISTORY

The metamorphic basement of Geba Basin is a part of Mozambique belt that underwent through complex orogenic processes until late Proterozoic-early Paleozoic time (Davidson, 1983; Teklewold and Moore, 1989). Peneplanation of the basement may have taken place in the period between early and late Paleozoic (Kazmin, 1972).The absence of any other older rock unit between the basement and the lower basalt signifies further continuation of uplift and erosion, generally, in the region, and particularly, in the study area, until late Eocene. Even later on, erosion remained stronger and persistent to wash out the lower basalt (leaving only thin remnants). This intensive erosion has culminated in the study area by inception of east-west trending faults associated with crustal subsidence to retain some thin remnants of the lower basalt and to begin with an accumulation of the coal bearing sediments.

4.1 TECTONIC EVOLUTION

In the east-west (east-northeast - west-southwest), trending Geba Basin, the east-west faults are prominent and tectonically important elements. In fact, regional occurrences of east-west trending faults in the western Ethiopian Plateau have long been noted (Kazmin, 1972; Mohr, 1974). The Ambo-Addis Ababa fault, Jima-Tepi fault, Gojeb and middle Sagan Valley faults are among these major faults. Commonly, the east-west trending faults in the Plateau which are accompanied by late-Tertiary volcanics had brought no significant crustal displacement (Mohr, 1974; Tsegaye, 1995). Tsegaye (1995) has determined the age of the central volcanics that define the east-west lineaments in central Ethiopia by K/Ar method, generally, to be less than 10Ma. Moreover, no sedimentary basin development is known to associate with these lineaments. The east-west trending faults of the Geba Basin, however, are apparently different in that-

a) they associate with older rock units (late Eocene - early Miocene)

b) they retain a thick coal and oilshale bearing clastic succession

(i.e., associated with basin development).

Hence, the east-west trending Geba Basin faults are deduced to be different from that of regionally well known younger east-west faults. Most likely, Geba Basin faults are assumed to be localised which might have been generated from older regional tectonic movement as minor faults.

Based on the basement morphology, Davidson (1983) suggested a regional uplift in the south western Ethiopia, that began shortly after the inception of the main undivided volcanic succession of Omo Project area (lower basalt in this study). The uplift is concave north east which starts from Sidamo going to the west through the northern part of Gamo Gofa and Kefa, then curved to the north in Illubabor. On the basis of the distribution of the volcanics, Davidson (1983) also noted that the rate of the uplift varies from place to place and occurred periodically throughout the Oligocene and early Miocene. Further more, the same author explained the absence of pre-Oligocene volcanics in the north western part of the Omo Project area (west of the study area), to be due to erosion caused by this uplift. The existence of thin remnants of lower basalt in the Geba Basin, probably, confirm this fact. If this is true, then, the basic idea is that the east-west trending Geba Basin faults were minor faults that have been generated by such uplift at an angle of 90°. Estimating the extent of formation of such minor faults may usually be difficult and varies as a function of the intensity and scale of the tectonic episodes. In any case, this type of dislocations cannot extend for long distances and are known to be local. In the case of

Geba Basin, the east-west trending faults run for a distance of 32-34kms and are truncated by a north-south (north-northwest - south-southeast), trending eastern fault boundary. This longitudinal fault seems to be regional. In the south, outside the basin, it is observed to have controlled the trend of the Geba River. Other north-south faults are also observed east of the surveyed area exposing the crystalline basement near Bedele town. In origin, these northerly trending faults might be related with the Tertiary uplift (mentioned above), or can be pre existing structures. In the Geba Basin, however, the eastern fault boundary acted as a passive sliding surface for the subsiding basin floor. The western fault boundary of the basin, on the other hand, does not show any regional continuation outside the basin and is not continuous. It is not well defined in the north, but only in the southern part. Taking such limited extension and poor development into account, the western boundary fault is not believed to be of the same origin with that of the eastern one. Instead, here it is explained to be due to the failurity of elastic property of a strained basin floor. Owing to the fact that the first thick sediment accumulation had started in the eastern part of the basin coupled with an east ward inclination of the basement, it is believed that at the early stage of the basin formation, subsidence has principally occurred in the eastern part. As the basin floor was subjected to a continuous subsidence in the east, therefore, it bend elastically in the west. Finally, as the subsidence continued, the bended slab will fail to retain the elastic strain and deformed in brittle way giving rise to the western fault boundary. Hence in its expression the western boundary fault is not as such sharp and continuous like that of the eastern fault. The well development of the western fault boundary in its southern part (near the southwestern corner), should be due to later movements in Yayu Block.

Figure 11 presents an empirical development of the basin. From this one can see that, the basin is formed by the interaction of east-west trending faults against a north-south trending fault, in the eastern part. But, the actual east-west trending boundary faults of Geba Basin are not uniformly straight both in the north and south. In the northern boundary, they form a continuous cliff from east to west. In the southern boundary, however, they show left-hand shift. Such pattern of the faults, in the south, seems to be important for fragmentation of the basin floor giving rise to the present blocks morphology. The fragmentation of the basin floor was previously noted by Kibrie and GashawBeza (1997). They realized four fault blocks termed as Yayu, Wittete, Geda and Didu Blocks. These blocks were important to accomplish further subsidence by block adjustment, providing maximum space for the sediments. Based on the distribution of the sediments and their thickness variation on each block, it is believed that Yayu, Wittete and Geda Blocks are tilted outwards from the center. But, the Didu Block inclines mainly to east with relatively slight basin-ward tilt. In relation to this, the northwest-southeast minor faults observed in the southern part of the basin, are also important. In this part of the basin, they are observed to occur between blocks and controlling the trend of major tributaries of Geba River without extending to north (in the Didu Block). There is no evidence whether they regionally extended outside the basin or they may be older. Instead, they are believed to be formed by the subsidence along the southern left-hand shifted boundary fault. Figure 12 may illustrate the idea.

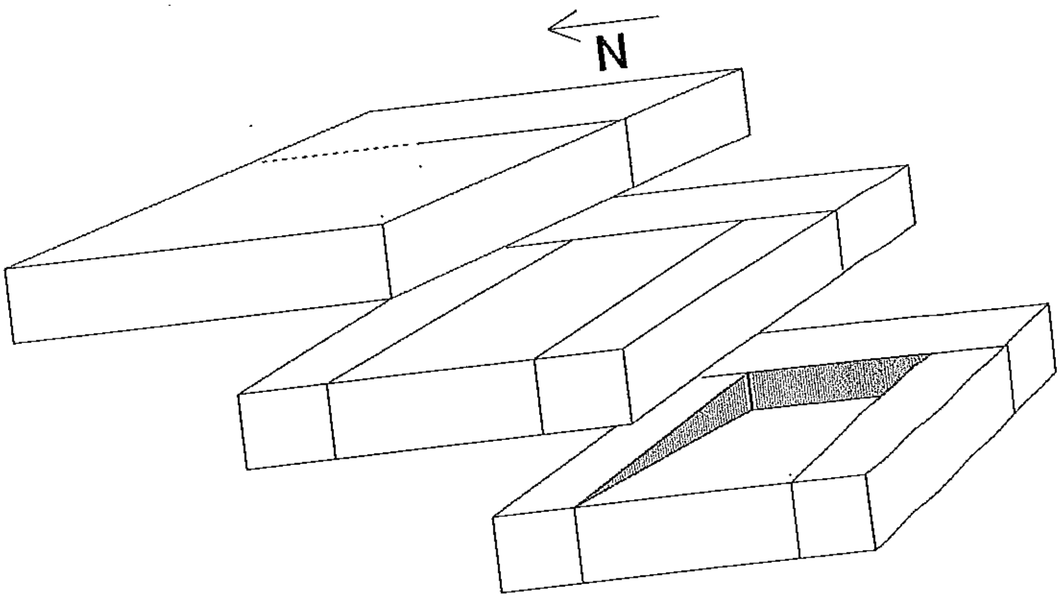
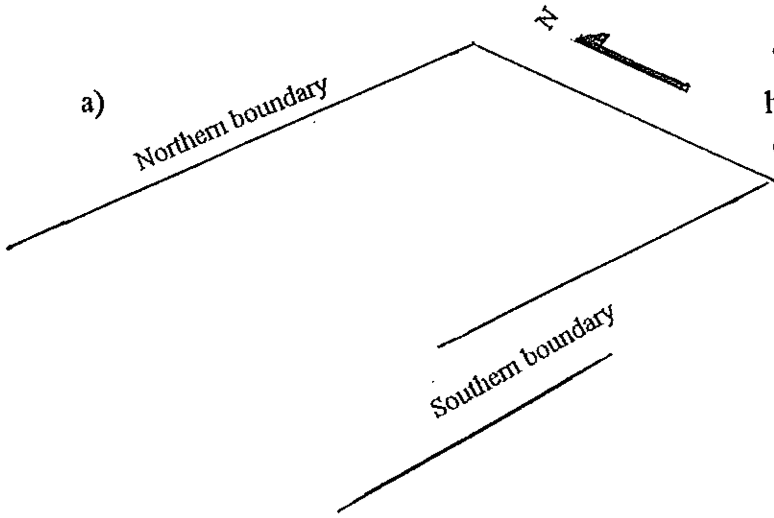
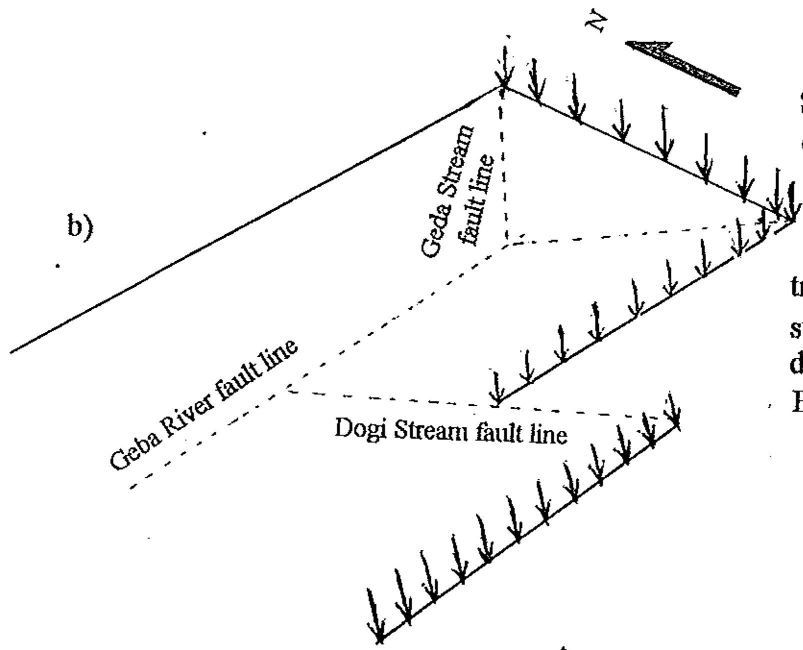


Figure 11 An ideal diagram showing the begininig of subsidence in the Geba Basin (not to scale)



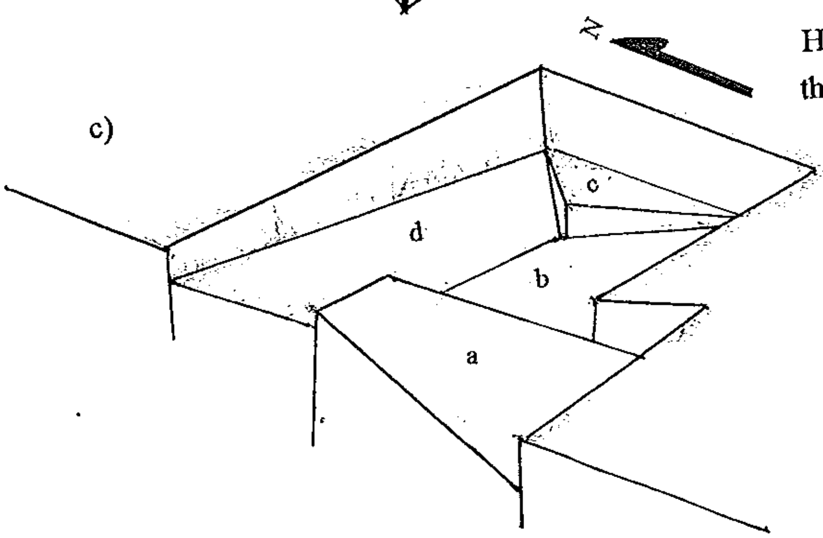
The northern and southern fault boundaries have different pattern, in that the former is continuous while the later is discontinuous and left hand shifted.

The eastern fault boundary could either predate or syndate the E-W faults.



Subsidence took place mainly in the eastern and southern boundaries of the basin.

The doted lines represent different trends of the resulting faults (caused by t[illegible] subsidence) corresponding to the present day pattern of block faulting in the Geba Basin.



Hypothetical, present day morphology of the basin floor below the sediments. Due to the subsidence occurred in the eastern and southern boundaries, the Yayu, Wittete and Geda Blocks are tilted outwards, whereas the Didu Block inclined eastwards.

Figure 12 A schematic diagrams showing fragmentation of Geba Basin.

4.2 DEPOSITIONAL HISTORY

The sedimentary succession of Geba basin marks a clastic fill constituted mainly by the influence of river and permanent water body (lake); alternatingly. The lower sandstone unit (unit I), underlying the whole sedimentary sequence, is the first sediment lain by eastward flowing braided river. Thin sandstone beds of the unit in the northwestern part of the basin represent remnants of the proximal succession, while the thick sandstone beds with thin conglomerate, mudstone and coal lenses present are interpreted as distal braided river deposit. In a general consideration of the unit, the thin coarser sandstone beds with a narrow distribution in the northwest, and the thick succession of interbedded fine and coarse sediments in the east, indicate that a confined stream in the west has passed to an open and low lying condition. Furthermore, the east ward thickening of the unit implies an eastward inclination of the original basin floor. The inclination should be substantial to develop the braided river system. Figure 13 a) presents a simplified block diagram illustrating the deposition of this unit onto an idealized paleomorphology of the basin floor.

Unit II, comprising mainly oilshale, coally shale, carbonaceous shale and organic rich mudstone, indicates the on set of a lake condition in the basin. Major subsidence of the basin floor should have taken place mainly in the eastern part, in order to dam the water input. Then the lake had been formed and advanced to the west where the oilshale sediments were deposited on the basement rocks. From the thickness variation of the unit, this fault, which was responsible for the damming might have developed longitudinally around 36°E. Specifically, the thick sandstone-mudstone succession with a NNE-SSW trend, associated

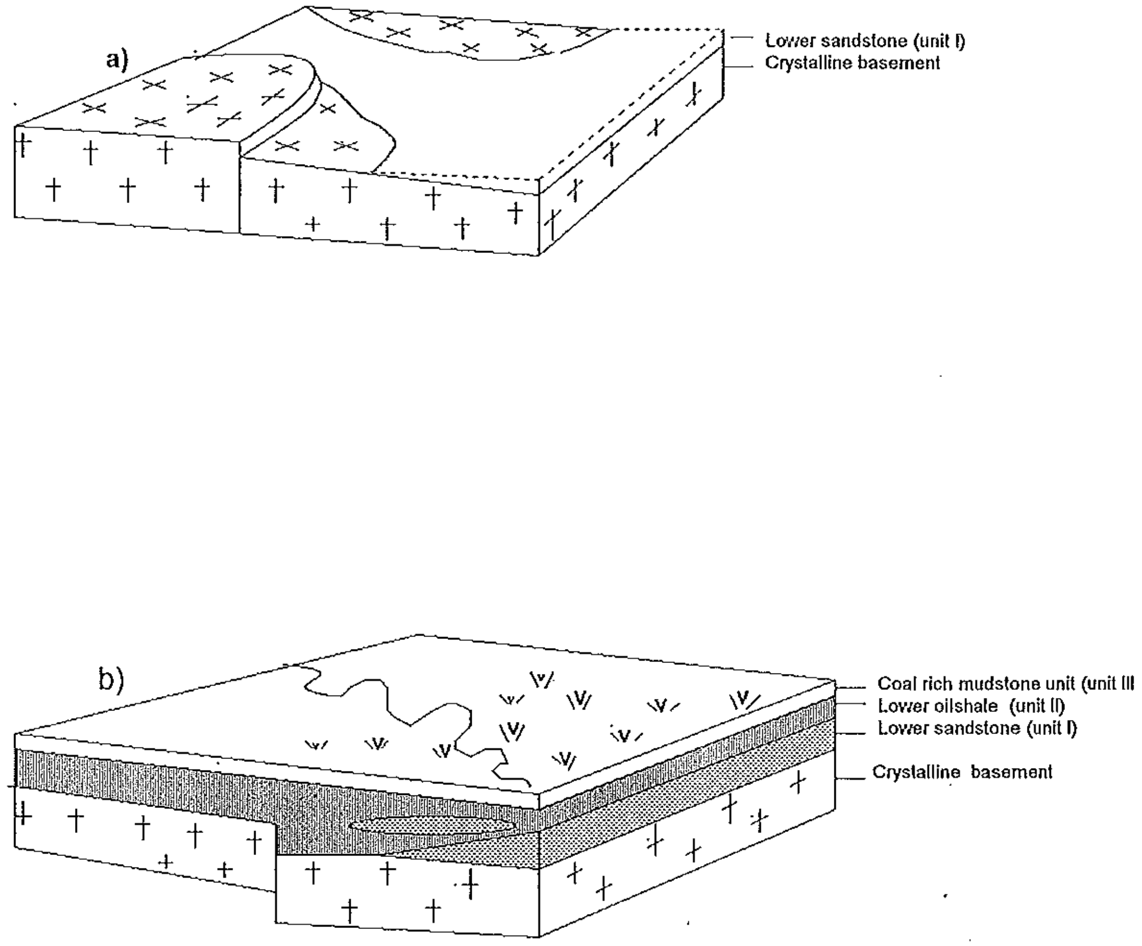


Figure 13 Simplified depositional models of a) the lower sandstone (Unit I), and b) the coal rich mudstone (Unit III), with a possible corresponding idealized paleotopography of the basin floor and vegetation distribution.

with this unit in the east, apparently marks the area of the fault. As to the provenance of the sandstone beds of this succession, they could be derived from the uplifted blocks of the basin floor, affected by the same fault. In the Wittete Block, the total thickness of the sediment and the abundance and thickness of the coal seams decrease sharply, in the area east of this fault. The wide occurrence of unit II confirms that the lake had covered most part of the basin, except the northwestern corner (which is believed to have been highly elevated). In this part of the basin, the unit pinched out indicating that the lake did not invade it. In the rest part, relative uplift and subsidence of the blocks govern the maximum and minimum thickness of the unit on each block. Outward inclination of Yayu Block, gave way to the thickening of the unit southwards in this block. Westward inclination of Wittete Block is recorded by a thick succession of the unit in the western part of the block. Similarly, eastward inclination of Didu Block is also reflected by a continuos increment of its thickness in the same direction. Thin oilshale beds of the unit observed in the Geda Block, on the other hand, suggest little or no subsidence of the block during this time.

Ceasing of this lake, most likely by siltation, is followed by a meandering river condition and accumulation of the Coal Bearing Mudstone Unit (Unit III). In this case, most part of the basin floor is assumed to have nearly flat topography (Fig 12 b). The absence of this unit again in the northwestern part, however, explains the fact that this part of the basin still remained elevated. The prevailing flat topography in the rest part of the basin, however, favoured the accumulation of 3-6m thick mudstone succession with abundant fresh water marshes for peat swamp development. The marshes are believed to support non-woody, herbaceous plants; such as grasses, reeds and rushes (see section 5.5). The development of these marshes seem to be limited to the east as the coal beds are rare or absent in Yayu and the western Didu Block (in this unit). This may be due to poor development of coal forming condition in this part. In the eastern part, on the contrary, the characteristic color of the mud rocks which is gray, coupled with abundant preservation of the organic matter in the form of coal confirm a water-logged condition and reducing pore water (Collinson, 1996). The channel sediments of the meandering river are not well preserved in Geba Basin. However, it is estimated to coincide with the present Geba River channel. The occurrence of the associated sandstone beds limited in the southeastern part of the basin is conformable with this assumption.

Deposition of unit IV marks restoration of the lake condition once more in the basin. But, the lake does not seem to be extensive as the previous one. Thickness of unit IV decreases westward and was not observed west of the Hursa stream, in the Didu Block. Some relatively thick sections of this unit, observed in the Yayu Block, are believed to be localised. Its thickness increases towards east. The unit attains a maximum thickness of 37m in the Wittete Block, as measured in borehole 5. The thickness variation of the unit indicates another syndepositional eastward inclination of the Wittete, the Geda and the Didu Blocks. However, the rate of subsidence in the various blocks was not uniform. Steep east ward inclination of the Wittete Block, for instance, is expressed by thick succession of lake sediments in the east and marshy sequences in the west (indicating that the western margin of the block had been sub aerial). Similarly, relatively poor development and preservation of the unit in the Geda Block explains mild subsidence of the block. The relatively thick and extensive coal beds of the upper oilshale compared with the thin and rare development of coal seams in the lower oilshale, indicate that either there were no sufficient plant materials or there were no convenient coal forming conditions, during the first lake.

During deposition of unit V, sediment supply was so high in Geba Basin than the subsidence to fill the space available forming fast prograding deltas. Thus, unit V (upper sandstone), by its nature, represents a regressive sequence formed by a minimum of three lake deltas in the western, northeastern and southeastern parts of the basin. As the deltas prograde the lake diminished continuously east wards. Clastic materials transported from the surrounding area entered to the basin along the three directions. This confirms that the Geba Basin was an isolated basin almost surrounded by positive topography and the regions found to the west, northeast and south of the basin are the principal source of detritus (Fig. 14). With this context, the northern and southern sequences are of particular importance. The northern sequence envisaged that there existed a separating block between Sese River sediments (located north), and that of Geba Basin(Fig. 6). However, they can Possibly be contemporaneous. The southern delta sequence, marking the last marginal sequence in this part of the basin, also confirms that the basin does not extend southwards. As the effect of waves and tides is negligible in lakes, the deltas are river dominated types. The association of basaltic rock fragments and reworked tuffaceous sediments with this unit, generally, shows the inception of upper basalt. Particularly, the abundant occurrence of basaltic fragments in the southeastern delta indicate a northward advancement of the upper basalt volcanism, starting from the south. Intercalation of the reworked tuff with other sediments may signify an intermittent extrusion of the basalt. But, the upward increase of tuffaceous beds and basaltic rock fragments in the unit, is correlable with increasing intensity of the volcanism, with time.

In summary, the geologic history of Geba Basin comprises a series of geological processes including uplift, erosion, faulting, sedimentation and Volcanism. The major processes have been shown in figure 15, in reference to geological time, and can sequentially, be listed as follows:

1. Uplift and peneplanation of the metamorphic basement.
2. Volcanism of the lower basalt (late Eocene to early Oligocene).

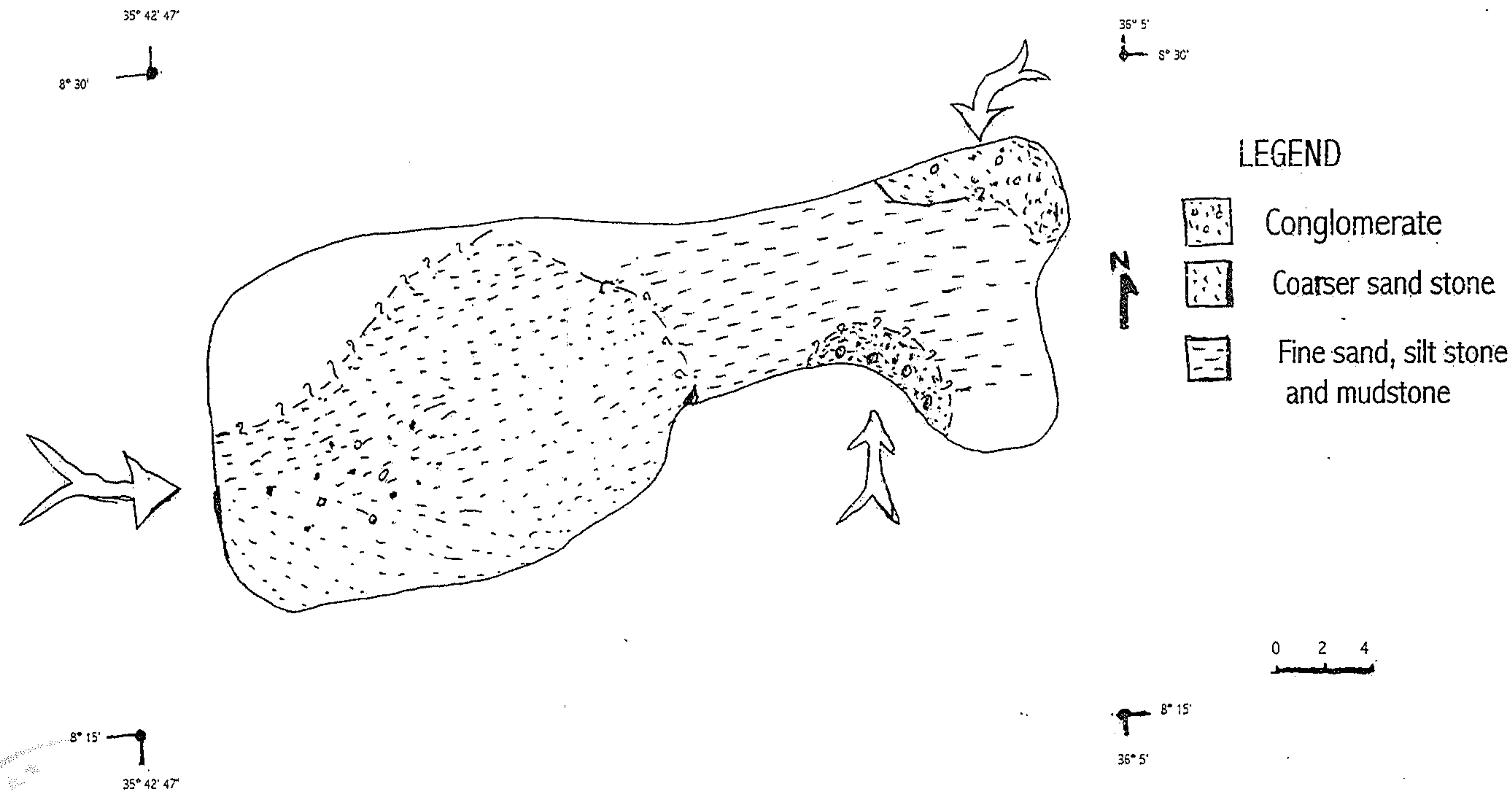


Figure 14. Textural distribution and possible source area suggested for upper sandstone unit.

3. Uplift and erosion of the lower basalt.

4. East-west fracturing and downwarping of the basin.

5. Accumulation of coal and oilshale bearing sedimentary sequences.

6. Volcanism of the upper basalt (late Oligocene to early Miocene).

7. Reactivation of faults to produce the present morphology of the basin.

Taking the age of the two basaltic units (upper and lower) in to account, the Geba Basin sediments are estimated to range from middle-late Oligocene to early Miocene. During this period, other coal and oilshale bearing sediments might have been deposited contemporaneously in other basins in Western Ethiopia. This may include deposition in the nearest Sese Basin and even farther (e.g. Arjo, Nejo and Mendi coal occurrences).

Era	Period		Symbols	Major Geologic Features
Cenozoic	Quat.			▪ Recent Erosion and reactivation of faults, giving rise to the present morphology of the basin.
Cenozoic	Tertiary	Pliocene, Miocene		
Cenozoic	Tertiary	Miocene / Oligocene		▪ Outporing of basalt comparable to Makonnen basalt (Upper basalt)
Cenozoic	Tertiary	Oligocene		▪ Filling of the basin by coal and oilshale bearing sediments. ▪ Fructuring and subsidence forming an E-W Geba Basin
Cenozoic	Tertiary	Oligocene		▪ Uplift and erosion causing the lower basalt to be washed out.
Cenozoic	Tertiary	Oligocene / Eocene		▪ Outporing of basalt comparable to Ashangei group. (Lower basalt)
Cenozoic	Tertiary	Eocene, Paliocene		▪ Generally uplifting, erosion and peneplanation. ▪ There could be a local development of coarse fluvial sediments.
Paliozoic to Mesozoic				
Pre - cambrian	Proterozoic			▪ High grade gneisses; east west bloaks (units) are surrounded by the ones whose deformational trends are north south (Mozambique belt)

Fig.15 Major geological events occurred in in the Geba Basin with their chronological sequence.

5. COAL

Coal sediments are widely developed in the Geba basin, and do not exhibit any type of compressional deformation as the case is with other sediments. They show a simple three dimensional geometry (i.e., horizontal to sub horizontal). Their thickness, abundance and continuation appears to be affected by both syn- and post-depositional faulting. Specially, block faulting seem to be the most important to control their thickness, distribution and quality. Minor faults within the blocks caused slight local inclinations and omission of beds. Description of the coal beds is proceeded by grouping them in terms of the associated facies. The sedimentological units that hosted one or more coal seams are used as coal zones (Cameron, 1993). Although, there are coal seams in all the units, the ones presented here are those in upper oilshale (Unit-IV), coal rich mudstone unit (Unit-III), and lower oilshale (Unit-II). Except for few lenses of coal, the coarser sediments (the two sandstone units) are generally devoid of any economical coal beds.

The Geba Basin coals are generally brownish black in color, and are bloky to columnar. Although not prominent, they also frequently fall apart along a plane parallel to the bedding. They crack on drying. No rootlets were observed in association with them. Most frequently, the organic content of the associated fine sediments increase towards the coal beds and grades to carbonaceous mud and carbonaceous shale. The common partings within the coal beds are also layers of such finer sediments. Sandstone layers within the coal beds are practically rare.

A close observation along the bedding surface of the coals commonly reveals the presence of small sized round shaped leaf fragments (<1 cm in diameter). In addition, the common components of plant fossils found in the mudstone and oilshale are grass and leaf fragments.

5.1 DISTRIBUTION

Coal is spatially distributed throughout the basin associated with almost all facies. Thick beds and abundant occurrence of the coals however, generally are limited to the east. In a vertical section, coal beds are observed from bottom to top especially at the middle part of the succession, within the upper oilshale (Unit-IV), mudstone unit (Unit-III), and lower oilshale (Unit-II). In boreholes, about 17 coal beds have been encountered (borehole 5), within these units ranging in thickness from 0.3 to 2.2m. They account for about 10% of the section.

Table 2 summarizes the distribution of the coal beds throughout the basin, with their outcrop thickness and associated units. Table 3 the presents the distribution of the seams in some boreholes, with their depth and associated facies. Comparing the coal occurrences within the three units, coal beds in the mudstone unit are abundant with apparently lenticular geometry. On the contrary, coals in the upper oilshale are not so abundant but seem to be relatively thick and extensive. The thickest coal bed, measuring 4.0m, is located in the upper part of the upper oilshale, in the southeastern part of the basin. The lateral continuation of this coal bed can be traced as far as Wuchale stream (~1km) to east. But, to the west, it has no clear extension observed both in boreholes and

near by stream sections. A 1.5 meter coal bed observed in the upper oilshale of Baho stream may be the extreme western continuation of this coal bed. In the area between Baho and Tebel Streams, the upper part of the sedimentary sequence(including the 4m coal bed) was not observed. Thus, Post- depositional uplift and erosion seem to affect the westward continuation of the coal seam. Even, in the Wuchale stream, the 4m coal seam is seen to be splited by more than 1m mudstone bed. The lower oilshale possesses thinner coals with a substantial amount of detrital sediment intercalations.

5.2 CHEMICAL ANALYSES

Compositionally, coal does not contain only pure carbon, but includes different organic (volatile and non-volatile) and inorganic compounds. The relative abundance of such components defines the coal in its type and rank, and is mainly related to different processes in the coal formation stages. There are two stages of coal formation: Biochemical stage and geochemical stage (Tatsch, 1980). The biochemical stage takes place at the initial accumulation period of peat. During this stage, various kinds of plant debris (stem, leaves, resinous materials...) are accumulated to a coal forming area and decomposed by the action of micro-organisms to peat. The preserved plant part and the extent of its degradation, largely determines the coal type. The type of coal in turn, governs its technological application. For example, a coal used for smelting may not be preferable for gassification or liquefaction (Gibson, 1979).

Table 2 coal beds distribution in different facies in the Geba Basin (sign '>' is used to indicate that the reported thickness represents the exposed part of the unit).

Block	Stream section	Coal zone (facies)	Thickens of the zone (m)	Number of coal beds	Thickness of the coal beds (m)
Yayu Block	Gogetti	Upper sand Mudstone	30 6	 1	 0.5
	Leku	Mudstone	19.5	1	0.5
	Saki	Upper sand. Upper oilsh	~25 7	2 4	0.1-0.16 0.1-1.2
	Wobbo	Upper sand Mudstone	21 2.1	1 1	0.5 0.6
Wittete Block	Acebo-1	Mudstone Lower oilsh.	8.3 3.6	5 1	0.3-1.0 0.15
	Achebo-2	Lower oilsh	11.6	1	0.6
	Baho	Upper sand. Upper oilsh. Mudstone Lower oilsh.	>5.4 >9.1 7.8 >21.6	1 2 3 3	0.4 0.6-1.0 0.5-1.5 0.2-0.3
	Birbir	Volcaniclas. Lower oilsh.	4.5 >7	1 1	0.3 1.0
	Negade	Mudstone Lower oilsh.	3.45 16.00	4 1	0.3-0.6 1.75
	Tebel	Upper sand Upper oilsh. Mudstone	7 24.5 9.5	1 3 5	0.3 0.3-4.0 0.15-0.6
Geda Block	Kersa-1	Upper oilsh. Mudstone	>11.95 >12.8	1 4	0.25 0.3-0.6
	Muchuchato	Upper oilsh. Mudstone Lower oilsh.	>24.7 4.6 4.0	2 4 1	0.2-1.0 0.25-1.0 0.5
	Kodo	Upper sand. Upper oilsh. Lower sand.	>12.2 >9.5 >5	1 1 1	0.2 2.0 0.3
	T. haymanot	Upper oilsh. Mudstone	9.4 2	2 2	0.2-0.9 0.3-1.3
	Kersa-2	Upper oilsh. Mudstone	12 6.6	2 4	0.4-1.2 0.65-1.5
	Ogode	Upper oilsh. Mudstone	18 9.1	2 1	0.3-1.3 0.8
	Kersa creek (a small creek b/n Kersa-1 & Kersa stream)	Upper oilsh. Mudstone Lower oilsh.	15 2 >30	1 2 4	0.4 0.65-1.0 0.3-0.8
Didu Block	Gogetti-2	Upper sand.	>4.7	1	0.2
	Jejeba	Mudstone Lower oilsh.	6.5 13.5	4 3	0.2-1.0 0.2-0.65
	Borele	Mudstone Lower oilsh.	4.5 15.0	3 2	0.5-1.0 0.15-0.5
	Kusi	Mudstone Lower oilsh.	>5.5	3	0.3-1.5
	Hursa	Mud unit Lower oilsh.	>6.5 12.4	2 2	0.5-0.6 0.5-0.8

By increasing depth, the action of bacteria will be ceased and followed by the geochemical stage. In the geochemical stage, heat and pressure are important factors to determine coal rank. Rank of a coal refers to the degree of maturity (coalification) and is traditionally expressed as lignite (brown coal), bituminous and anthracite.

In this work, the nature of Geba coals are evaluated by a combination of proximate analysis, determination of heat value, and specific gravity.

5.2.1 Proximate Analysis

Proximate analysis of coal presents the relative abundance of light organic compounds (volatile matter), non-volatile organic components (fixed carbon), water content (moisture), and other inorganic mineral constituents left after combustion (ash); in percentage. This type of analysis is very important and practical to evaluate coals. By applying some mathematical corrections to compensate the mineral matter, proximate analysis is used to compare the organic content of different coals so that it enables one to have a systematic classification.

The proximate analysis of Geba coals comprehends samples from the outcrop sections and boreholes. The results are presented both in dry basis and in dry, mineral matter free basis (Table 3, Appendices A&B).

Moisture

The Geba coals show a large range of difference in their moisture content ranging from 4 (Wobo stream) to more than 34% (Negade stream) (see the apendix). The average moisture content of all coals in the basin seem to fall between 17 and 19% (Table 3). In all the units (coal zones) there is a general eastward increment of moisture content in the basin. Hence, high moisture values appear abundantly, in the Geda Block (>17%). In most cases, the individual stream sections show downward decreasing of moisture, except in Dukecha and Muchuchato streams. In Dukecha stream the moisture content of the coals in the mudstone unit is larger than that of both the overlying and the underlying oilshale units. In Muchuchato stream, the coals in the mudstone unit have large values than those in the overlying upper oilshale. The rest show definite decrease of moisture downward along the sections. Repeated minimum moisture content appeared in the Yayu Block.

Volatile Matter

Determination of the amount of volatile components indicates that the Geba coals are generally, of higher Volatile matter content. In average, they contain volatiles more than 27% (dry basis). On mineral matter free basis, they range commonly between 41-57%. For the upper oilshale coals, high volatile content are found abundantly in the east (32-37% dry basis). For those of the mudstone facies, two higher values (35.1 and 36.3% dry basis) appear in the Yayu Block. Normally, high volatile matter content is typical of low rank coals (Van Krevalen, 1961; Gibson, 1979), and has a relation with the yields of tar and gas when the coal is heated in the absence of oxygen.

Table 3 The average chemical analyses of coal samples from different coal zones and blocks of Geba Basin

Coal Zone	Block	Stream Section	Proximate Analysis (%)						Tot. Sulf. (%)	Heat Valeu	
			Dry, basis				Dry, mmf ba			Dry Basis (Kcal/Kg)	Mmmf Basis (Btu/lb)
			moist	volatile	fixed c	ash	fixed	volatil			
Upper Oilshale	Yayu	Wobo	4	28.9	30.1	36.1	53.2	46.83	1.5	6530	19406.78
		Saki	13.46	22.55	22.83	41.29	54.1	45.95	0.8	3008.64	9057.04
	Wittete	Baho	6.5	24	27.5	41.35	55.7	44.29	1	4445	12957.65
		Tebel	18.59	28.29	28.03	24.61	51.8	48.16	1.8	3794.49	9380.44
		Wittete west cre	15.7	40.69	33.09	16.62	51	49.04	1.7	4059.14	8924.11
	Geda	Kersa-1	19.6	32.5	36	12	53.4	46.59	0.1	4522	9352.26
		Kersa-2	19.13	35.85	34	11.68	49.9	50.12	0.2	4872.25	10057.43
		T. haimanot	17.3	33.03	31.2	18.48	49.8	50.16	0.1	4921.25	11259.86
		Muchuchato	18.4	37.63	31.53	12.53	46.3	53.73	0.2	4960.67	10337.4
		Ogode	18.93	36.6	26.5	17.97	42.9	57.08	0.3	4397	9841.8
	Didu	Dukecha	17.27	30.33	28.7	24.4	50.9	49.06	0.2	3638.67	8913.51
Coal Rich Mudstone Unit	Yayu	Meti	10	35.1	46.9	6.2	56.8	43.2	2.5	2420	4602.92
		Gogetti	7	36.3	40.2	15	52.8	47.23	2.3	8400	18181.27
	Wittete	Baho	8.2	27	30	33.8	54.6	45.44	1.1	6000	17085.39
		Negade	14.71	38.9	30.57	16.77	45.3	54.72	1.5	4099.18	8965
		Achebo-1	17.34	27.44	21.44	33.81	46.6	53.39	0.2	3132.71	8849.62
	Geda	b/n ker.-1 & Ker.	19.8	35.35	30.85	13.95	47.4	52.57	0.2	4635	9821.46
		Kersa-1	17.13	28.06	25.5	29.4	50.6	49.41	0.5	3360.33	8857.81
		Kersa-2	17.97	27.7	24.83	29.29	49.3	50.74	0.4	3419.43	8626.04
		T. haimanot	17.95	29.72	27.35	25.03	50.1	49.88	0.2	3903.25	9593.34
		Muchuchato	19.65	26.53	21.92	31.95	47.4	52.58	0.3	2999	8199.77
	Didu	Dukecha	18.61	29.61	26.39	25.28	48.7	51.34	0.4	3704.33	9205.62
Lower Oilshale	Wittete	Baho	12.83	44.21	37.58	5.39	46.3	53.7	0.9	4810.1	9194.51
		Birbir	7.75	35	23	33.46	42.7	57.3	2	2862.97	8051.94
		Negade	12.64	39.14	34.86	12.37	47.2	52.77	0.8	4182.4	8687.45
	Diduu	Dukecha	14.6	29.5	28	28	46.8	53.19	0.2	3753	9684.77

Fixed carbon

The Geba coals bear fixed carbon ranging from 21 to 46% (dry basis), and from 42-58% (dry, mineral matter free basis). Such low fixed carbon, specifically, less than 69% dry, mmf basis, imply a low rank of coalification (ASTM classification). On a dry basis, higher values (40.2 and 46.9%), appeared in the mudstone facies Yayu Block, decreasing east wards. For those coals in the upper oilshale this trend seem to be in opposite.

Ash

In general, the Geba coals have high ash; mostly >15% (dry basis). Of the 108 selected outcrop samples, only for 21 samples the ash is less than 15% (at random distribution). In other Words, more than 81% of the samples show values larger than 15%, and still more than 50% of them again contain ash greater than 30% (dry basis).

The maximum ash content value reaches as high as 57% (dry basis), for upper oilshale coal samples of the Baho stream (Wittete Block). The lowest ash content amounting to 3.31% (dry basis), was noted in the upper oilshale facies; in the 4m thick coal bed. Normally, the distribution of high and low ash values in the basin, seem to be random. Even in a single bed, it is hard to define the general trend of ash variation. Commonly, there are large differences among two vertically consecutive samples. In their average values, those of the upper oilshale coals located in the Geda Block (east) have distinctly relatively lower ash content. They range between 11 and 18% (dry basis). Fore the mudstone facies, few coal samples from the Yayu Block (west) exhibit lower values (6.2 and 15%). The mudstone facies coals taken from Geda Block also display lower ash values than that of the Wittete Block (see Appendix A). A coal bed exposed in Saki stream (Yayu Block), with a thickness variation between 1.5 and 2.0m appears to show peculiarly high amount of ash. It is situated in the upper oilshale and extends for more than 300m as confirmed by trenches. Its ash content decreases basin ward ranging from 35 to 51% in the south and between 25 and 49% in the north (Appendix A).

5.2.2 Total Sulfur

The total sulfur of the Geba Basin coals exhibit some sort of difference among the outcrop and borehole samples. The analysis of the outcrop samples is markedly lower than that of the boreholes. Most of the outcrop samples contain sulfur in amount generally less than 3% (dry basis), with still major population less than 1% (Appendix A). Borehole data, on the other hand, indicates that the existence of sulfur in the coals reaching as high as 6.2% (dry basis) (BH-3). Most of the core samples possess sulfur in amount >1%. In a vertical section, the distribution of total sulfur both in the outcrop and borehole samples, seems somewhat irregular. However, ill defined vertical variation of total sulfur distribution show that the larger values frequently occur in the lower part of the successions.

On the other hand, the data difference between the outcrop and the boreholes, may be attributed to the original lateral variation of sulfur among peats. This may also be due to local pH variation. Most of the sulfur in coals is believed to come from the peat forming plants themselves (King and Renton, 1979). Additional sulfur from sulfates of the peat water, can Possibly be fixed by the action of sulfur reducing bacteria (Tatsch, 1980; Tucker, 1989). In the Geba coals, there is no visible sulfide minerals observed.

5.2.3 Calorific Value

Up on burning, the coals of the project area give rise to a common heat value range of 7,900-11,000 Btu/LB, moist mmf basis (2000-5100 Kcal/Kg, dry basis). Few anomalous samples, however, can appear with higher or lower values (see appendices A&B). Table 3 presents the average heat values of the coals classifying them in sedimentological units (coal zones) and blocks, with respect to the individual stream. These values vary from 8,051 to 11,252 Btu/lb, moist mmf basis (2862-4960 Kcal/Kg, dry basis). As to their distribution, the upper oilshale coals appear to have abundant samples with high heat values. Specifically, those in the Geda Block reported the calorific values generally greater than 9262 Btu/lb, moist mmf basis (4292 Kcal/Kg, dry basis). In the case of mudstone facies, coals of the whole blocks seem to be comparable, but still relatively larger values are commonly found in the Geda Block. Owing to the fact that heat energy of coals is retained by their organic matter components (Renton, 1979), high heat values in the Geda Block may suggest well preserved organic matter in this part of the basin. In addition, calorific value of coals may also vary with their rank (Gibson, 1979; Royen and Bowles, 1952). However, the observed variation of heat value in the Geba basin, does not imply any significant trend of lateral rank variation.

5.2.4 Specific Gravity

The specific gravity of the coals ranges from 1.28 to 1.8 gm/cc. The density variation of the coals seems random having some relation with ash content. Usually, coals with less than 20% (dry basis) ash have density values between 1.3 and 1.4 gm/cc. But, those with larger than 20% ash appear to be more denser reaching as high as 1.8 gm/cc. Some exceptions, however, in both cases are present.

5.3 COAL PETROGRAPHY

Petrographically, coal includes different discrete entities, which are the coalified remains of various plant tissues that have been contained by the plant at the time of peat formation (Galloway and Hobday, 1983). Each intity has its own characteristic morphology, hardness and optical properties with different chemical nature and technological behavior in coal utilization. These organic components known as 'macerals', are analogous to minerals of inorganic rocks. The Stope's-Heerlen system adopted at the 1935 Heerlen Congress, classified these coal macerals into three major groups: Vitrinite, Liptinite (Exinite) and Inertinite (Davis, 1984).

In addition to the macerals, coal petrography can also describe the type, amount and distribution pattern of the inorganic constituents of a coal. The common minerals embedded in coals are clays, quartz, pyrite and carbonates (Renton, 1979). The associations between mineral matter (carbominerite) and the macerals, defines the microlithotype. Such association of organic and inorganic components determines the quality and performance of the coal.

5.3.1 Maceral Groups

Petrographic analysis have been carried out on outcrop and core coal samples of the basin. The core samples were collected from borehole 3, 5, and 6. They are analyzed at Coal Quality Laboratory of Shandong Bureau of Coal Geology, China. The outcrop samples, 12 in number, are taken from the 4.0m coal bed and analyzed by C&N coal cunsultancy, South Africa. Petrographic studies revealed that

Huminite macerals by far dominate the organic forms of Geba coals with a very little amount of inertinite (<7%). Figure 13 and Table 4 present the relative abundance of the three maceral groups while detail petrographic analysis of the coals is given in Appendix C. The following is a brief consideration of each maceral group of the coals.

Huminite: huminite is equivalent maceral group to vitrinite in higher rank coals consisting of three sub-groups: humocollinite, humodetrinite and humotelinite. Of the three sub-groups, humocollinite is the preponderant of Geba coals. The two macerals of humocollinite: gelinite and corpohuminite are present, usually, with a higher proportion of the former variety. The second abundant sub-group is humodetrinite represented mainly by attrinite. Comparing humodetrinite to the humocollnite, it accounts to still very small proportion. Humotelinite is generally rare in the coals; and frequently, ulminite macerals appear to dominate over textinite.

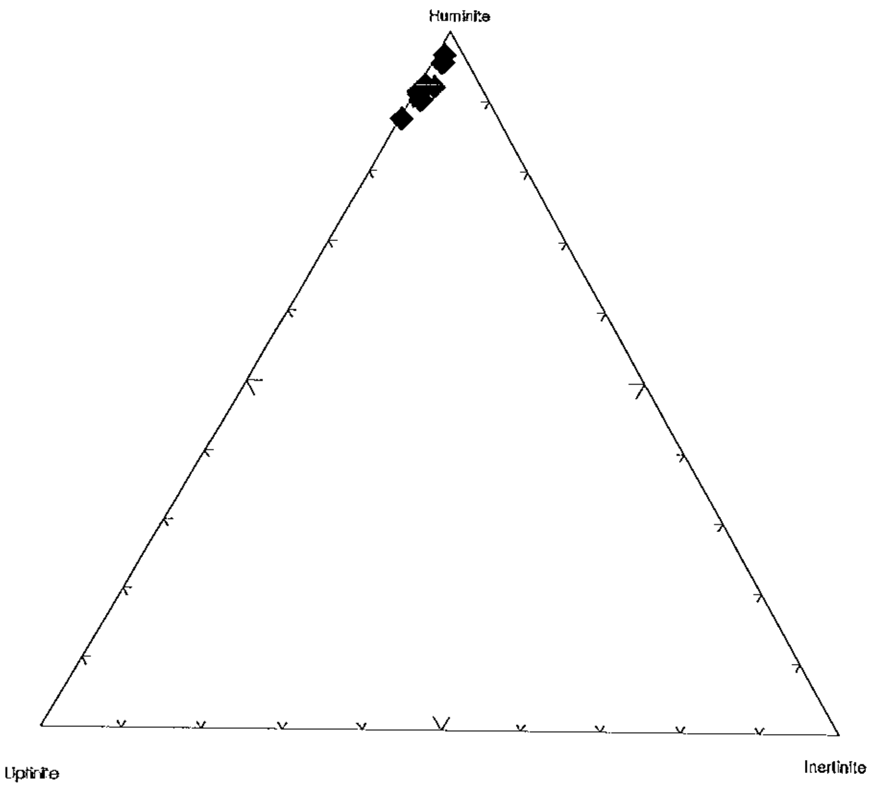


Figure 16. Ternary plot showing the relative abundance of maceral groups in the Geba coals

Table 4. The relative abundance of major maceral groups

Samples	Huminite	Liptinite	Inertinite
YP-BH5-47,48	95.5	3	1.5
YP-BH5-93,94	92.3	6.9	0.8
YP-BH5-96,98	95.4	3.3	1.3
YP-BH6-7,8,9	96.6	2.4	1
YP-BH6-15,17	87	12.2	0.3
YP-BH6-41	92	5.9	2.1
YP-BH3-20,21,22,24,25	90.1	8.4	1.5
YP-BH3-35,37	91.3	8.3	0.4
YP-BH3-68,69	90.9	8.4	0.7
YP-BH1-37,38+YP-BH5-85,86+ YP-BH6-27	90.1	8.7	1.2

Liptinite (Exinite) : the common liptinite maceral observed in the borehole samples is tenuicutinite. Minor sporinite (+ microsporinite), and rare resinite, alginite and bituminite disseminated in the ground mass. Commonly, bituminite form laminar structures. The gross liptinite macerals determined by Chineese is much lower (<10%) than that of the outcrop samples determined by the South African coal cunsultancy (10-23%).

Inertinite : the petrographic analysis on the coal samples of the boreholes shows that sclerotinite is the main inert macerals. In borehole 5 and 6, it is commonly associated with fusinite and semi-fusinite, while in borehole 3, it associated with tenuifusinite. Determination of this maceral group by the South African Coal Cunsultancy, for the outcrop samples, reaches as high as 7% (vol.), whereas that of the boreholes does not exceed 2.1% (vol.) (China National Complete Plant Import-Export Corporation). In the case of the outcrop samples, the maceral group have been subdivided into reactive macerals and inert-inertinites and the former are calculated to be more than 95%.

5.3.2 Mineral Groups

Mineral group analysis is an important analysis that helps to estimate the economical advantages of the coal deposits and determine the processes for benefications (Davis, 1984). This study indicates that inorganic minerals in the Geba coals are abundant, distributed in the beds with different amount and forms. In the borehole samples, they are estimated to constitute 8.6-23.5% of the coals. The major inorganic components of the coals distinguished are clays, quartz and pyrite. In any case, the former two are very dominant occurring finely disseminated between the macerals and even some times, as large grains. In relative
abundance, they are estimated between 88 and 97% of the inorganic matter in the 4.0m coal bed, and between 76 and 82% in the boreholes.

Pyrite, the third common mineral occurs in different forms. Commonly, it is framboidal, spherical and euhedral. It varies in amount from 0 to 2.2%. It is finely distributed, and some times it appears to be massive. Minor amounts of carbonates are found at the bottom part of borehole 5 (1.6%) and at the upper part of borehole 6 (rare).

5.3.3 Microlithotypes

The manner of distribution of the macerals throughout the coals and the way in which different maceral groups are associated with each other varies. For instance, a certain amount of vitrinite may occur in a coal forming relatively thick bands or finely disseminated throughout the bed. Determination of such association of macerals in coal at microscopic level defines the microlithotype present. As the macerals themselves are often regarded as an equivalent to the minerals in other inorganic rocks, the microlithotypes may be considered as equivalents to the discrete beds, lenticles or laminae, made up of different mineral combinations (Davis, 1984). The nature and abundance of a certain lithotypes in a coal may considerably affects some physical characteristics and technological behaviors.

In the case of Geba coals, the South African coal cunsultancy analysis distinguishes vitrite-like lithotype (huminite) in a range of 12.8-36.8% (vol.), intermidiate-likegroup (i.e. particles, some of which are huminites while others are fusinite) 10.8-65% (vol.), and inertite (mainly fusinite, semi-fusinite and sclerotinite) 0-4.3% (vol). The borehole analysis on the other hand, reports that vitrite is the dominant microlithotype in all boreholes. In both cases, sapropelic particles are distinguished to have considerable amount (about 10 and 6% (Vol.) respectively).

5.4 RANK CLASSIFICATION

Coal widely varies in its constituent plant types, degree of preservation, amount and type of inorganic matter incorporated, tectonic and thermal conditions of the peat forming environment. Thus, different styles of grouping of coals seem to be possible such as based on 1) the constituent plant material (type), 2) degree of impurity (grade), 3) degree of metamorphism (rank), 4) the percentage of volatile matter (volatiles), 5) the ability to form coke (coking property) (Tatsch, 1980). Of these, rank classification is more powerful and widely applicable. The two widely known methods of coal rank classification are the American Society for Testing and Materials (ASTM), and the International System (Tatsch, 1980).The ASTM classification is based mainly on the fixed carbon content (mmf), and heat value (British Thermal Unit). According to the scheme, the coals with >69% of fixed carbon are classified by their fixed carbon content on a dry basis. But, coals with less fixed carbon, on the other hand, are classified in accordance with their calorific value on moist basis.

The rank of coal expresses its degree of coalification (metamorphism). According to ASTM classification, a coal rank increases progressively in a series from lignite through sub bituminous and bituminous to semi anthracite and anthracite. Rank of coal is a function of heat and pressure that act up on the coal after peat formation. Of these two factors, the former is believed to be outstanding (Tatsch, 1980). With increasing rank, carbon content of the coal increases while oxygen and hydrogen decreases, and heat value increases (Gibson, 1979; Tatsch, 1980).

5.4.1 Rank Determination by Chemical Analysis

The chemical nature of Geba coals have been discussed in section 5.2. They are generally, of high ash content with low to medium sulfur, low fixed carbon and high volatile matter. This all indicates that they are of low rank coals. Particularly, having than 69% dry mmf, tells that they are definitely below high volatile bituminous rank (ASTM). Coupled with this, limitation of their heat value (<12,000 Btu/lb moist, mmf), limits them in a range of lignite to subbituminous coal. Rank determination for each sample is given

in the appendices A and B. This determination shows that subbituminous C is the common rank of Geba Basin coals. Some samples appear, in fact, to be of higher rank (i.e., subbituminous B, subbituminous A, and even high volatile A bituminous). The physical characters and vitrinite reflectance (see below), however, confirm the definite low rank coalification of the coals. They are brownish black in color and cracked on drying. Retention of some visible plant fragments, by itself, demonstrates less humification of the coals.

5.4.2 Rank Determination by Reflectance

The reflectance of macerals, expressed in percentage, is a proportion of incident light reflected from a plane polished surface under specified conditions of illumination. The reflectance property is related to the aromaticity of the organic compounds in the coal (Galloway and Hbday, 1983; Davis, 1984). It increases in intensity progressively for all macerals as the rank of coal increases. But, the reflectance of vitrinite maceral is changed at a more or less constant rate, and hence, is widely used as an index for coal rank (Galloway and Hbday, 1983). Table 5 gives ranges of mean maximum vitrinite reflectance (R max.) corresponding to principal ASTM rank designations. The Geba coals have mean vitrinite reflectance below 0.4%R0. They range from 0.32-0.39%Rm, which corresponds to lignite-lower boundary of subbituminous rank of the ASTM scheme. Hence, they are deduced generally, to have underwent a slight organic metamorphism.

Table 5 Vitrinite reflectance limits (in oil) and ASTM coal rank classes (after Davis, 1984)

Rank	Maximum reflectance (%)
sub-bitutuminous	<0.47
high volatile bituminous C	0.47-0.57
high volatile bituminous B	0.57-0.71
high volatile bituminous A	0.71-1.10
medium volatile bituminous	1.10-1.50
low volatile bituminous	1.50-2.05
semi anthracite	2.05-3.00 (approx.)
anthracite	>3.00 (approx.)

Comparing the two results of rank determination both by reflectance and by the chemical analysis, for the Geba coals, appear to be nearly similar. However, it is known that rank determination by reflectance is normally less sensitive in the lower rank coals (Davis, 1984). Davis (1984) reasons out two factors that limit the application of this method in the lower rank coals (lignite and sub bituminous coals):

a) their softness causing them difficulties to have a smooth surface of reflectance and

b) nearly similar optical characteristics of the true vitrinite (huminite), and inertinite macerals making the selection of vitrinite to be hard.

5.4.3 Coalification Pattern of Geba Coals

The major population of the sample studied in the Geba Basin are at the level of subbituminous rank. Minor lignites with few high volatile A bituminous coals occurred in a random distribution. Of the subbituminous coals, those of subbituminous C are the

dominant and subbituminous A are few. Table 6 lists the average rank of coals in some streams with respect to the coal zones (units). From the table, it is difficult to see the normal depth-rank relationship. Except in Dukecha stream, there is no rank increment with depth. Indeed, a number of stream sections display a definite downward decreasing of coal rank (e.g.: Kersa-2, Teklehaimanot and Muchuchato Streams). Such pattern of coalification does not signifies the importance of heat of burial. Instead, it points to a manner of heat transmission starting from the top down along the sedimentary pile. Therefore, the overlying basalt appears apparently important to play a significant role in the coalification process. As it is observed from the table, the lateral variation of the coal rank in the basin is very irregular. This variation of the coal rank believed to be due to lateral variation of the coal zones in their depth from the upper basalt. For the coals of the same facies, that of higher rank coals should be more closed up to the upper basalt to receive high amount of heat. Local uplift and erosion of the top part of the sediments took place before the extrusion of upper basalt, may cause such variation. The case in Negade stream exemplified this fact, in which all coals of mudstone and lower oilshale units are at rank of subbituminous C.

Table 6 Patterns of average coal rank observed in some streams

Stream Section	Coal Zones (Facies)	Average Rank (ASTM)
Baho	Upper oilshale Mudstone Lower oilshale	Subbituminous A High volatile A bituminous Subbituminous C
Negade	Mudstone Lower oilshale	Subbituminous C Subbituminous C
Kersa-1	Upper oilshale Mudstone	Subbituminous C Subbituminous C
Kersa-2	Upper oilshale Mudstone	Subbituminous B Subbituminous C
Tekle Haimanot	Upper oilshale Mudstone	Subbituminous A Subbituminous B
Muchuchato	Upper oilshale Mudstone	Subbituminous B Lignite
Dukecha	Upper oilshale Mudstone Lower oilshale	Subbituminous C Subbituminous C Subbituminous B

5.5 ORIGIN OF THE COALS

Subgroup macerals humocollinite and humodetrinite are the major petrographic components, of which the former is highly dominant. The maceral of humocollinite (gelinite and corpohuminite) are colloidal gels derived from the break down of ligno-cellulosic tissues by bacterial, fungal, or chemical action. They always precipitated and filled cell lumens or cracks and other cavities. Humodetrinite, on the other hand, encompasses a mixture of finely communited plant materials of various origins such as grass, leaves, reeds, or finer fragments of stems. They are typical of transported plant debris, often occurring in detrital admixtures (back ground), with other macerals and minerals. Association of lipid substances (such as Bitumen) with these macerals, as observed in the Geba coals, is commonly known (Davis, 1984).

The very minor huminite variety in the coals is humotelinite characterized by variable degrees of retention of cell structure. Humotelinite, as they are found in brown coals, are believed to be derived from coniferous wood (Sweet and Cameron, 1991; and their references). Angiospermious wood is more easily decomposed so that much of it appears in the humodetrinite. Thus, the scarcity of humotelinite may indicate the original little contribution of coniferous wood in the Geba coals. Fragments of leaves and grasses observed in handspecimens support the fact that angiospermous plants were the principal donors of materials to the peat swamps.

The abundant occurrence of humocollinite signifies intensive degradation in the original peat swamp, which could either be biological or chemical. The quality of Geba coals (high ash and medium to high sulfur), particularly, those from Wittete Block are infavour of biochemical degradation. Ceciel et al., (1979), suggested that pH condition of the swamp is an important factor governing the microbial degradation of the accumulated plant debris together with ash and sulfur content of the resulting coal. Renton and Cecil (1979), show that the critical pH value for coal forming environment is 5. Increasing of pH values beyond 5, will increase the level of microbial activity and precludes preservation of sufficient organic matter to form a coal. Further extreme degradation of peats may result in the formation of coal partings. By studying modern peat swamps, Cecile et al., (1979) demonstrated that low-ash peat (2-4%, dry basis), is associated with low pH (3-4.5), and high ash peat (>50%, dry basis) is associated with nearly neutral pH. Similarly, the sulfur content of coals decreases at low pH conditions, as it dose not allow the sulfate-reducing bacterial activity and fixation of sulfur and iron as iron sulfides. Such strong relationship of pH condition with preservation of organic matter and inorganic minerals, is the basic principle of « A Chemical Coal Model » proposed by Ceciel et al., (1979). In this model it is believed that the inorganic portion of the swamp plants from which the peat was derived, are principal sources of coal ash and sulfur (Renton and Ceciel, 1979).

With few exceptions, most of the Geba Basin coals (>80%), are high ash coals (>15%, dry basis). Particularly, the southeastern Geba coals (Wittete Block), have high ash and medium to high sulfur (1-7%, dry basis). This quality of the coals explains their deposition might have taken place under higher pH condition (., >4.5), with intensive microbial activity. The coals in the Geda Block, which have distinctly low ash and sulfur contents, may signify the presence of locally different geochemical environments within the basin. Probably, variation in rate of subsidence, among the blocks is the main factor to cause such differences of geochemical environments. The field data confirm that the Geda Block has undergone through little subsidence during deposition of the lower oilshale. Even later, in the case of mudstone and upper oilshale units, its rate of subsidence should have to be small and continuous to maintain a favorable geochemical realm for the formation of better coal seams. Replenishment of the coal forming geochemical environment with relatively oxygenated and near neutral water seem to cause degradation of the organic matter in the Wittete and Yayu Blocks. High rate of subsidnence in these blocks could also cause high rate of influxes to increases the clastic admixture and hence, the ash content. The existence of anomalously high ash coal bed with basin ward decreasing of ash content in Saki stream, Yayu Block, confirms this fact.

The general low inertinite content of the coals demonstrates the swamps were not significantly dry (Van Krevalen, 1961). Specially, their representation mainly by sclerotinite supports this idea. Sclerotinite is a maceral that is attacked by fungi before it is transformed into inertinite. The common liptinite is teniucutinite (cutinite). This may indicate that to some extent the climate was dry in which the plants were with thick cuticle layer to prevent intensive evaporation (Davis, 1984). Rare alginite may point to shallow, fresh water condition.

6. CONCLUSION AND RECOMMENDATION

This work has confirmed that the coal and oilshale bearing Geba sediments are of Middle Oligocene to Early Miocene age. They are deposited in an east-west trending intracratonic rift basin, that may have evolved locally, from contemporaneous regional tectonic episodes, as a minor associated feature. Their depositional environment ranges from fluviatile to lacustrine. Under fluvial conditions a number of coal seams have been formed in flood plain and marshy areas. Under lacustrine condition, several thick coal seams (>1m), have been formed in a reducing condition.

The results of the proximate, calorific and petrologic analyses show that the coals of all facies have nearly similar properties. But, that of the Geda Block coals appear to be relatively of higher quality. The fixed carbon of Geba Basin coals is always below 69% (dmmf basis), with a calorific value ranging between 7900 and 11000 Btu/lb (mmmf). Their mean random vitrinite reflectance value varies from 0.32-0.39% R. These all parameters indicate that the coals are transitional to subbituminous C in rank. The pattern of coalification indicates that the rank of the coals has been influenced mainly by the overlying basalt (upper basalt).

The coal deposit in the eastern part of Wittete Block (southeastern part of Geba Basin), is currently studied in detail for fertilizer production by Coal Phosphate Fertilizer Complex Project (COFCOP), Ministry of Industry. Ammonia is the most important component to be extracted by gasification from the coals for fertilizer production. Although, the high ash and high moisture contents of the coals could incured additional cost, the production may be achieved by Lurgi gassification. This gasfire operates at high pressure (3 Mpa or 30 bar). It can successfully work with coal of virtually any rank from lignite to anthracite having ash and moisture contents as high as 35% (Cudmore, 1984).

In a general consideration, the Geba Basin coals seem to be fairly suitable for energy. Their modal heating value, which ranges between 3000 and 5000 Kcal/Kg may allow these coals to be used for local thermal power generation. Some anomalously high heat energy values reported from Yayu Block, should also be studied in detail. In any case, priority must be given to those of low sulfur and low ash coals with high calorific value that occurred in the Geda Block. In this block the upward increment of coal quality is also interesting for open cut mining. Even for those high sulfur coals, benefication may not be so expensive, as the petrographic analysis reveals that the common form of sulfur is pyritic sulfur.

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Appendices

Appendix A1 Chemical analyses of coal samples taken from Upper oilshale Unit

Block	Stream se	Sample No.	Proximate Analysis						Tot. sulf. (%)	Heat Value		Rank (ASTM)
				Dry Basis			Dmmf Basis			Dry Basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	
			mois.	volat.	f. car	as	f. car	volat.				
Yayu	Saki	HUGK-73-88	22.7	26.8	16.7	33.9	41.1	58.88	0.4	2610	7437.07	Lignite
		73-1-88	20.5	26.3	51.1	37.3			0.6	2454	7389.59	Lignite
		73-2-88	10.8	18	30.5	25.8	50	49.98	1.5	5440	13626.42	Hv B bit
		73-3-88	19.6	21.4	31.6	35.5	75.8	24.24	1	3111	9081.66	Mv bit
		73-4-88	18.4	24.8	16.3	39.3	41.7	58.29	0.4	2420	7561.9	Lignite
		73-6-88	22.7	19.5	18.9	39.9	55.4	44.57	0.4	2100	6632.56	Lignite
		73-88	11.1	19.4	20.3	49.2	57.1	42.87	0.8	2170	8328.31	Subbit.C
		74-0-88	4.5	27.6	31.4	35.6	55.4	44.56	1.5	9100	26852.77	Hv A bit
		74-4-88	9.3	24.6	20.2	45.2	48.4	51.58	0.7	2660	9358.14	Subbit.C
		74-5-88	8.7	20.8	21.7	48.5	56	44.05	0.5	2420	9148.7	Subbit.C
		74-7-88	7.1	21.8	22.7	48.5	56.3	43.71	0.7	2660	10063.52	Subbit.B
		74-8-88	8.6	20.2	20	51.2	55.7	44.34	0.6	2150	8654.5	Subbit.C
		74-9-88	11	22	23.6	42.9	55.7	44.33	1	2900	9732.7	Subbit.B
	Wobbo	41B-88	4	28.9	30.1	36.1	53.2	46.83	1.5	6530	19406.78	Hv A bit
Wittete	Tebel	119c-88	19.2	29.5	31.4	19.2	52.7	47.27	2.2	4091.04	9297.72	Subbit.C
		119c-2-88	18	29.2	25.6	27.3	49.2	50.78	2.5	3615.55	9235.04	Subbit.C
		120-1-88	15.2	25.4	24.6	34.8	52.6	47.39	1.68	3595.03	10392.3	Subbit.B
		120-1-1-88	18	34.2	17.9	29.9	36.1	63.9	1.2	3330.08	8856.9	Subbit.C
		120-2-88	22	31	34	12.9	53.6	46.43	1.98	4361.49	9127.14	Subbit.C
		120-2-2-88	19	28.8	31.4	20.8	54.1	45.94	1.56	4012.85	9321.76	Subbit.C
		120-3-88	17.4	19.4	22.4	31.4	46.4	53.58	1.8	3219.57	8766.5	Subbit.C
		120-3-88	27.5	31.3	37.9	3.31	55.4	44.6	2.1	4662.58	8804.1	Subbit.C
		120-3-2-88	27.6	25.1	38.9	8.31	62	37.96	2.01	5115.88	10130.22	Subbit.B
		120-4-1-88	14.9	37.4	24.4	23.4	41	58.97	2.8	3532.35	8493.69	Subbit.C
		120-4-3-88	19.6	36.3	32.1	12	48	52.04	2.18	4298.2	8882.92	Subbit.C
		120-5-88	11.8	40	24.4	23.9	39.3	60.73	1.45	3554.3	8612.8	Subbit.C
		120-6-88	22.4	27.7	28.8	23.2	55.3	44.71	2	3871.3	9294.1	Subbit.C
		120-8-88	19.4	23.4	18.4	38.8	47.8	52.21	1.03	2447.14	7572.36	Lignite
		120-10-88	17.8	30.9	32.3	19.1	52.8	47.22	1.84	4106.61	9317.04	Subbit.C
		120-11-88	15.9	19.8	18.2	46.2	53	46.97	0.43	2375.74	8525	Subbit.C
		120-12-88	14.9	39.6	30.2	13.4	42.9	57.15	1.44	4316.6	9079.83	Subbit.C
	Baho	W6-2-88	8	18	16	57.2	53.3	46.7	0.7	1690	7948.72	Lignite
		W6-4-88	5	30	39	25.5	58.1	41.89	1.2	7200	17966.6	Hv A bit
Geda	Kersa-2	YKGK-41-4-89	21.7	36.3	36	6	50.2	49.85	0.1	4849	9333.62	Subbit.C
		41-5-89	19.2	38.2	33.1	9.6	47	52.97	0.2	5117	10277.7	Subbit.B
		41-6-89	15.1	36.5	35.1	16.3	52.2	47.81	0.1	5073	11083.8	Subbit.A
		41-7-89	20.5	32.4	31.8	14.8	50.1	49.86	0.4	4450	9534.61	Subbit.B
	Kersa-1	45-1-89	19.6	32.5	36	12	53.4	46.59	0.1	4522	9352.26	Subbit.C
	Tekle Hai	36-2-89	17	32.4	33	17.6	51.6	48.4	0.1	4468	9930.07	Subbit.B
		36-3-89	17.1	34.9	35	13	50.9	49.14	0.1	5176	10840.28	Subbit.B
		36-4-89	16.2	26.7	24.3	32.8	50.3	49.72	0.2	5117	14271.13	Hv A bit
		36-5-89	18.9	38.1	32.5	10.5	46	53.39	0.1	4924	9997.97	Subbit.B
	Muchuch	56-1-89	16.8	38.2	27.9	17.1	43.2	56.85	0.3	4826	10658.55	Subbit.B
		56-2-89	19.3	37.2	34.9	8.9	49.1	50.88	0.1	5153	10262.81	Subbit.B
		56-3-89	19.1	37.5	31.8	11.6	46.5	53.46	0.1	4903	10090.84	Subbit.B
	Ogode	129-0-89	18.6	36.6	24	20.8	40.7	59.26	0.2	4292	9964.61	Subbit.B
		129-1-89	21.5	35.7	30.2	12.6	46.6	53.36	0.6	4445	9262.14	Subbit.C
		129-2-89	16.7	37.5	25.3	20.5	41.4	58.61	0.2	4454	10298.65	Subbit.B
Didu	Dukecha	136-1-89	18.1	31.1	33	18.3	53.2	46.85	0.2	4240	9512.04	Subbit.B
		137-1-89	19.4	34.7	30.2	17.2	48.7	51.29	0.1	3685	8146.51	Lignite
		137-2-89	14.3	25.2	22.9	37.7	51	49.03	0.2	2991	9081.97	Subbit.C

Appendix A2: Chemical Analyses of Coal Samples Taken From Coal Rich mudstone Unit

Block	Stream Section	Sample No.	Proximate Analysis (%) As Received Basis mois.	volat.	f.car.	ash	Dnmf Basis f.car.	volat.	Tot Sul. (%)	Heat Value Dry Basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	Rank (ASTM)
Yayu	Gogetti	HUGK-35B-88	7	36.3	40.2	15	52.8	47.23	2.3	8400	18181.27	Hv A bit.
	Meti	97B-88	10	35.1	46.9	6.2	56.8	43.2	2.5	2420	4602.92	Lignite
Wittete	Achebo-1	YKGK-22-4-89	13	27.2	19	40.2	44.3	55.7	0.1	2875	9147.2	Subbit.C
		22-3-89	17.6	29.1	25	28.3	48.3	51.73	0.2	4136	10725.23	Subbit.B
		22-1-89	10	29	19.3	41.7	43	57.04	0.1	2947	9653.19	Subbit.B
		21-8-89	18	27	19.9	35.1	45.2	54.78	0.3	2703	7818.18	Lignite
		21-7-89	22.3	26.4	19.5	31.8	48.4	51.64	0.1	2884	7905.79	Lignite
		214-89	20.4	27.3	22.9	29.7	46.4	53.64	0.5	32225	8299.83	Subbit.C
		21-3-89	19.5	26.1	24.5	29.9	50.9	49.14	0.1	3159	8397.93	Subbit.C
	Negade	HUGK-124-2-8	13.7	43.7	36.4	6.22	45.9	54.11	1.5	4826	9315.09	Subbit.C
		124-3-88	16	36.2	29.2	18.6	45.8	54.23	1.05	4071.9	9170.66	Subbit.C
		124-4-88	11.4	28.1	15.8	44.5	43.4	56.64	0.47	2429.9	8414.55	Subbit.C
		124-5-88	13.9	44.1	36.3	5.65	45.7	54.3	2.02	4821.3	9243.8	Subbit.C
		124-6-88	17	42	34.1	12.8	49.7	50.3	2.18	4311.41	8998.64	Subbit.C
		124-7-88	16.2	39.3	31.6	13	45.5	54.5	1.98	4134.57	8648.25	Subbit.C
	Baho	W6-5-88	8.2	27	30	33.8	54.6	45.44	1.1	6000	17085.39	Hv A bit.
Geda	B/n Kersa & Kersa-1	YKGK-105-1-89	19.6	37	30.5	12.9	45.9	54.09	0.1	4778	9993.49	Subbit.B
		105-3-89	20	33.7	31.2	15	48.9	51.06	0.2	4492	9649.42	Subbit.B
	Kersa-	46-1-89	17.3	25.4	26.8	30.5	54	46.02	0.4	3283	8811.19	Subbit.C
		46-2-89	18.4	30	21.3	30	43.3	56.67	0.2	3191	8495.78	Subbit.C
		46-3-89	15.7	28.8	28.4	27.7	52.5	47.53	0.9	3607	9266.46	Subbit.C
	Kersa-2	41-9-89	24.5	31.5	30.5	13.6	50.3	49.72	0.6	4052	8547.42	Subbit.C
		41-10-89	23.2	30.6	25	28.3	54.2	45.82	0.3	3381	8763.97	Subbit.C
		41-12-89	13.5	27.4	25.9	33.2	51.2	48.8	0.2	3450	9682.96	Subbit.B
		41-13-89	16.5	23.3	26.1	25.1	46.5	53.53	0.9	3891	9611.6	Subbit.B
		41-14-89	14.9	24.4	15.2	45.5	42.3	57.69	0.1	2240	7927.17	Lignite
		41-15-89	14.1	26.3	18.5	41.2	44.7	55.27	0.2	2804	9094.06	Subbit.C
		41-16-89	15	27.4	20.8	36.9	46.1	53.89	0.1	3061	9160.93	Subbit.C
		41-17-89	19	27.4	27	26.7	51.9	48.14	0.3	3297	5521.34	Lignite??
	Tekle Haimanot	36-7-89	16.1	36.8	31	16.2	46.7	53.29	0.1	4645	10135.86	Subbit.B
		36-9-89	18	32	24.1	25.9	44.6	55.36	0.2	3951	9874.58	Subbit.B
		36-10-89	19.2	28.7	32.3	19.9	54.6	45.45	0.3	4049	9284.15	Subbit.C
		36-11-89	18.5	21.4	22	38.1	54.6	45.42	0.1	2968	9078.75	Subbit.C
	Muchuchato	57-1-89	12.7	24.3	15.6	47.4	43.3	56.74	0.2	2158	7957.28	Lignite
		57-2-89	18.3	23.1	19.9	38.8	50.2	49.81	0.6	2593	8027.35	Lignite
		57-3-89	17	30.6	29.7	22.8	50.9	49.08	0.2	4027	9616.85	Subbit.B
		57-4-89	24.5	27.8	27.1	20.6	51	49.02	0.3	3485	8066.51	Lignite
		57-5-89	18.5	25.7	17.2	38.7	43.1	56.9	0.3	2534	7834.22	Lignite
		57-6-89	26.9	27.7	22	23.4	46.1	53.92	0.4	3197	7696.42	Lignite

Appendix: A2 continued

Block	Stream Section	Sample No.	Proximate Analysis (%) As Received Basis mois.	volat.	f.car.	ash	Dmmf Basis f.car.	volat.	Tot Sul. (%)	Heat Value Dry Basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	Rank (ASTM)
Didu	Dukecha	137-4-89	15	30.7	25.5	28.8	47.4	52.65	0.2	3954	10331.73	Subbit.B
		137-5-89	20.5	34.5	34.2	10.8	50.5	49.52	0.3	4798	9778.16	Subbit.B
		137-6-89	16.8	30.4	25.4	27.4	47.4	52.58	0.2	3717	9502.99	Subbit.B
		137-7-89	29.4	33.2	33.1	4.3	50.3	49.75	0.3	4392	8289.32	Lignite
		137-8-89	23	31.5	28.6	17	48.8	51.19	0.2	3899	8595.85	Subbit.C
		137-9-89	13.2	28.3	18.2	39.4	41.2	58.8	0.4	3210	10061.16	Subbit.B
		137-10-89	23.4	25.8	23.2	27.6	49.7	50.26	0.6	3073	7874.89	Lignite
		137-11-89	13.6	26	20	40.4	46.7	53.27	0.1	2855	9117.39	Subbit.C
		137-11-89	16.9	25.3	29.2	28.5	55.9	44.14	0.1	3057	7949.1	Lignite
		137-14-89	13.7	30.5	31.4	24.3	52.4	47.63	0.4	4249	10372.86	Subbit.B
		137-15-89	19.7	29.3	24.9	26.1	48	52.04	0.8	3680	9225.16	Subbit.C
		137-16-89	18.1	29.8	23	29.1	45.8	54.23	0.9	3568	9368.88	Subbit.C

Appendix A3: Chemical Analyses of Outcrop Coal Samples collected from Lower Oilshale Unit

Block	Stream Sec	Sample No.	Proximate Analysis (%) As Received Basis moist.	volat.	f.car.	ash	Dmmf Basis f.car.	volat.	Tot. Sulf. (%)	Heat Value Dry Basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	Rank (ASTM)
Wittete	Baho	W7-4-88	12.8	44.2	37.6	5.39	46.3	53.7	0.85	4810	9194.51	Subbit.C
	Negade	HUGK-125-1-88										
		125-2-88										
		125-3-88	12.6	39.1	34.9	12.4	47.2	52.78	0.76	4182.4	8687.45	Subbit. C
	Birbir	B109-88	8.65	34.9	23.3	33.2	42.3	57.71	1.76	2863.9	8014.9	Lignite
		B109C-88	6.85	35.2	24.3	33.8	43.1	56.89	2.18	2862.04	8088.98	Lignite
	Achebo-1	YKGK-21-1-89	13.4	23.1	12.8	50.7	40.4	59.62	0.8	2027	8054.91	Lignite
Didu	Dukecha	137-17-89	15.4	30.1	27.6	26.9	49.7	50.28	0.1	3831	9720.41	Subbit.B
		137-18-89	13.8	28.9	28.4	29.1	43.9	56.1	0.3	3675	9649.12	Subbit.B

Appendix-B

Appendix B1: Chemical analyses of coals from borehole1

Coal Zone	Depth interval	Thickness of the coal zone	Sample No.	Proximate Analysis (%)						Tot. Sulf.	Heat Value		Rank (ASTM)
				Dry Basis				Dmmf Basis			Dry basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	
				mois.	volat.	f.car.	ash	f.car.	volat.				
Upper Oilshale			YP-BH1-8-90	19.6	35.8	31	13.6	47.34	52.66	0.9	4493	9482.84	Subbit.C
			9	17.9	34.5	28.9	18.7	46.45	53.55	1.3	4345	9826.76	Subbit.B
			10	15.5	20.2	14	50.7	46.91	53.09	0.9	2940	11641.89	Subbit.A
			12	19.1	23.6	18.2	39.1	47.46	52.54	1.3	4500	7773.88	Lignite
			18	15.7	34.7	30.5	19.2	48.11	51.89	1.4	4488	10203.08	Subbit.B
			19	15.8	34	32.9	18.2	51.18	48.82	1.7	4631	10391.44	Subbit.B
			20	9.9	23.9	18.1	48.1	47.85	52.15	1.3	2453	9491.63	Subbit.C
			21	10.9	30.4	19.4	39.4	41.88	58.12	1.1	3165	9926.11	Subbit.B
			22	17.2	33.3	22.9	26.7	42.66	57.34	1.4	3600	9106.41	Subbit.C
			25	10.6	24.4	15.2	49.8	43.21	56.79	2.2	2220	8669.63	Subbit.C
			26	11	31.5	27.6	29.9	49.43	50.57	3.5	3858	10290.97	Subbit.B
			27	14.1	28.5	21.4	36.1	46.14	53.86	2.3	3197	9440.24	Subbit.C
			28	12.7	30.6	22.1	34.6	44.53	55.47	1.4	3361	9666.67	Subbit.B
			29	11.8	31.8	22.5	33.9	43.92	56.08	1.9	3467	9858.2	Subbit.B
			30	13.8	28.5	22.1	35.6	46.64	53.36	1.6	3356	9824.95	Subbit.B
			31	13.8	29.7	18.1	38.4	40.8	59.2	2	3002	9234.89	Subbit.C
			37	16.5	29.2	20.8	33.5	44.19	55.81	1.1	3194	9008.38	Subbit.C
		26.2	38	14.5	38	32.3	15	46.79	53.21	1.1	4818	10358.7	Subbit.B
Mud stone			49	17	36.8	31.7	14.4	47.59	52.11	3.5	4576	9769.51	Subbit.B
		5.97	50	10.1	38.8	31.3	19.8	46.45	53.55	5	4432	10185.32	Subbit.B

Appendix B2: Chemical Analyses of coals from borehole 2

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%)						Tot. Sulf. (%)	Heat Value		Rank (ASTM)
				Dry Basis				Dmmf Basis			Dry basis	Mmmf Basis	
				moistur	volatile	fixed c	ash	fixed c	volatil				
Upper Oilshale			YP-BH2-20-90	13.2	38.2	32.5	16.1	47.04	52.96	1.4	4905	10702.59	Subbit.B
			22	18.3	33.5	21.8	26.5	41.13	58.87	0.3	4240	10696.53	Subbit.B
			23	21	31.2	24.5	23.4	45.9	54.1	1.5	3703	8918	Subbit.C
			24	15.6	25.3	17.2	41.9	44.46	55.54	2.2	2561	8404.56	Subbit.C
			25	13.1	28.4	17.2	41.3	40.8	59.2	0.8	2877	9349.71	Subbit.C
			26	17.8	32.7	29.8	19.7	49.36	50.64	2.2	4130	9449.1	Subbit.C
			27	14.9	32.2	25.2	27.7	45.93	54.07	1.4	3838	9866.4	Subbit.B
			29	16.9	28.1	21.5	33.7	46.35	53.65	1.3	3198	9051.21	Subbit.C
			30	15.7	27.7	17	39.6	41.15	58.85	1.2	2828	8892.35	Subbit.C
			34	18.9	29.4	22.7	29	45.89	54.11	1.4	3318	8691.5	Subbit.C
			35	12.9	28.8	20.2	38.1	44.24	55.76	1.3	2845	8697.75	Subbit.C
	83.76		36	15.7	31.1	21.9	31.4	43.68	56.32	1.2	3443	9380.1	Subbit.C
	90.6	6.84	37	11.5	25.7	15.7	47.1	41.98	58.02	1.1	2501	9164.82	Subbit.C

Appendix B3: Chemical anlyses of coals from borehole 3

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%)						Tot. Sulf. (%)	Heat Value		Rank (ASTM)
				Dry Basis				Dmmf Basis			Dry basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	
				moisture	volatile	fixed ca	ash	fixed car	volatile				
Upper Oilshale	55.1	37.83	YP-BH3-11-90	27.1	34	22.6	16.4	41	59	0.3	3870	8464.44	Subbit.C
			20	23.7	39.2	25.2	11.9	39.8	60.2	0.7	4560	9420.24	Subbit.C
			21	20	37.1	22.3	21.8	39.62	60.38	1	4110	9679.88	Subbit.B
			22	24.1	42	27.5	6	39.71	60.3	1	4865	9365.39	Subbit.C
			24	22.8	37.5	24.3	15.5	40.26	59.74	0.5	4266	9223.67	Subbit.C
			25	20.7	31.3	19.3	28.7	40.16	59.84	1.4	3382	8819.58	Subbit.C
			34	18.6	28.4	17.6	35.5	41.23	58.77	1.9	2992	8728.92	Subbit.C
			35	20.3	32.6	22.9	24.2	43.01	56.99	1.5	3799	9260.85	Subbit.C
			40	14.5	29.8	17.3	38.4	40.3	59.7	6.2	2586.2	7883.09	Lignite
			41	19.8	27	21.7	31.7	47.8	52.2	2.4	3036	8294.23	Lignite
			44	14	26	15.8	44.8	42.3	57.7	1.3	2671	9317.88	Subbit.C
			45	17.1	28.1	20.7	34.3	45.55	54.45	1.4	3164	9061.21	Subbit.C
			46	18.1	30	22	30	44.71	55.29	1.3	3419	9104.67	Subbit.C
			47	21.7	32.6	28.4	17.4	47.99	52	1.4	4070	9020.39	Subbit.C
	92.93		48	21.7	33.9	32.2	12.2	49.71	50.29	1.4	4440	9206.28	Subbit.C
Mudstone	92.93	3.45	63	24.6	35	33.6	6.8	49.61	50.39	1.3	4713	9156.41	Subbit.C
			64	21.8	31.8	24.4	19.1	48.28	51.72	3.4	3771	8539.1	Subbit.C
	96.38		69	18.7	32.4	21.8				2.4	3405	8354.78	Subbit.C

Appendix B4: Chemical analyses of coals from borehole 5

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%) Dry Basis moisture	volatile	fixed ca	ash	Dmmf Basis fixed car	volatile	Tot. Sulf. (%)	Heat Value Dry basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	Rank (ASTM)
Upper Oilshale	163.37	48.74	YP-BH5-49-90	18.4	37.3	26.3	18.1	42.52	57.48	0.9	4336	9705.82	Subbit.B
			56	18.6	33.2	22.9	24.3	41.72	58.28	1.3	3658	8925.79	Subbit.C
			57	16.3	29.3	15.2	39.2	36.98	63.02	1.8	8745?	27617.7	?
			67	25.9	36.4	28.6	9.2	44.79	55.21	1.4	4540.2	9074.21	Subbit.C
			69	14.5	31.4	23.8	30.3	45.51	54.49	2.2	3627.4	9715.94	Subbit.B
			70	16	29	15.8	39.3	38.19	61.81	1.2	2813.9	8796.17	Subbit.C
			71	18.1	38.1	20.4	23.4	36.16	63.84	1.5	3810	9178.62	Subbit.C
			72	19.3	30	15 9	34.8	37.02	62.98	1.2	4784	13845.85	?
			73	19.4	25.2	18.3	33.1	41.21	58.79	2.3	2903	8114.32	Lignite
			74	17.6	33.4	21.1	28	40.68	59.32	1.5	3533	9117.08	Subbit.C
			75	17.9	33.2	19	29.9	38.32	61.68	1.3	3453	9181.07	Subbit.C
			76	18.3	33.5	17.9	30.5	36.88	63.12	1.6	3280	8800.24	Subbit.C
			77	20.2	27.9	17.7	34.2	41.55	58.45	1.4	2966	8458.5	Subbit.C
			78	17.3	33.3	21.2	28.3	40.69	59.31	0.2	6536?	16954.85	?
			79	20.4	29.9	16.5	33.3	37.92	62.08	0.7	3046	8558.99	Subbit.C
			80	14.7	34.9	16.4	34	33.85	66.15	1.1	3526	10039.57	Subbit.B
			82	13.9	38	24.3	23.7	39.05	60.95	1.6	3039	7331.61	Lignite
			84	17.2	39.6	30.8	13.4	45.27	54.73	1.3	4847	10210.59	Subbit.B
			85	18.3	34.7	20.8	21.2	35.45	64.55	1	3660	8540.82	Subbit.C
	212.11		86	21	35.2	21.4	22.4	39.16	60.84	0.9	3721	8833.89	Subbit.C
Mudstone	212.11	5.39	93	17.6	33.7	19.9	29.2	39.36	60.64	1.7	3441	9047.39	Subbit.C
			94	25.2	32.7	29.6	12.6	48.68	51.32	1.6	4068.7	8471.13	Subbit.C
			96	19.1	37.2	28.6	15.2	45.08	54.92	4.8	4296.7	9258.78	Subbit.C
			97	18	34.9	19.2	27.8	37.3	62.7	3.4	3378	8677.73	Subbit.C
	217.5		98	22.3	36.2	21.8	19.7	39.03	60.97	3.4	3381	7697.85	Lignite

Appendix B5: Chemical analyses of coals from borehole 6

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%)						Tot.Sulf. (%)	Heat Value		Rank (ASTM)
					Dry Basis			Dmmf Basis			Dry basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	
				moistur	volatile	fixed c	ash	fixed c	volatile				
Upper Oilshale	71.3		YP-BH6-6-9	20.9	31.2	14.8	33.3	34.4	65.6	0.9	3072	8631.73	Subbit.C
			7	23.2	29.8	19	28	41.04	58.96	1.4	3271.6	8434.38	Subbit.C
			8	28.8	33.3	24	14	43.04	56.96	1.6	2391.4	5029.19	Lignite
			9	23.7	27.4	16	32.3	40.57	59.43	1.4	2900.4	8004.23	Lignite
			14	22.4	24.7	15.3	38.1	42.43	57.57	1.9	2376	7234.95	Lignite
			15	23.4	32.9	19.5	24.2	38.85	61.15	1.5	3503	8531.29	Subbit.C
		20.05	16	24	26.1	15.1	34.9	39.59	60.41	0.9	2737	7897.75	Lignite
			17	24.4	29.5	19.4	26.8	41.75	58.25	1	3265	8264.08	Lignite
			18	22.5	25.8	17.4	34.3	43.17	56.83	0.7	2683	7662.46	Lignite
			19	22	24.1	14.9	39	41.75	58.25	0.9	2493	7742	Lignite
			20	23.4	25.3	16.8	34.5	43.24	56.76	2.4	2501	7134.16	Lignite
			26	24.6	26.8	15.9	32.7	39.74	60.26	0.4	2879.4	8009.49	Lignite
			27	27.2	30.7	27.9	14..3	48.81	51.19	0.8	4053	8625.06	Subbit.C
	91.35		28	29	26.5	31.6	13.4	56.34	43.66	1.5	3950	8305.79	Subbit.C
Mudstone	91.35		38	25.9	32.7	21.3	20.1	40.89	59.11	1.6	3740	8593.44	Subbit.C
		11.42	39	27.1	29.2	31.3	12	52.53	47.77	1.3	4162	8603.57	Subbit.C
	102.77		41	19	38.4	22.8	19.8	38.46	61.54	2.5	4031	9232	Subbit.C

Appendix B6: Chemical analyses of coals from borehole:7

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%) Dry Basis				Dmmf Basis		Tot. Sulf.	Heat Value		Rank (ASTM)
				moisture	volatile	fixed car	ash	fixed ca	volatile	(%)	Dry basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	
			YP-BH7-17-90	25.8	28.7	19.4	29.3	45.82	54.18	1	3098	8149.83	Lignite
			24	30.2	34.9	25.6	26.1	61.8	38.2	0.6	4276	10725.8	Subbit.B
			27	27.5	30.6	19.1	23.5	40.76	59.24	1.4	3321	7999.73	Lignite
			33	23.6	27	15.1	34.4	38.73	61.27	1.6	2717	7762.79	Lignite
			34	28	35.2	23.7	13.3	41.36	58.64	1.7	3921	8232.35	Lignite
			37	21.1	25	15.1	38.8	41.23	58.77	2	2406	7422.46	Lignite
			39	24.5	28.5	15.1	32.1	37.17	62.83	1.4	2657	7299.57	Lignite
			40	23.3	25.8	17.2	33.7	43.11	56.89	2	2787	7866.56	Lignite
			42	24.8	30.5	19.3	25.3	40.49	59.51	1.2	3393	8396.83	Subbit.C
			43	26.7	32.4	24.3	16.1	43.69	56.31	1.4	4013	8813.95	Subbit.C
			53	29.1	33.2	26.7	11	45.51	54.49	1.5	4122	8414.02	Subbit.C
			54	30.5	30	25.8	13.6	47.31	52.69	1.2	3719	7837.21	Lignite
			57	25.7	27.8	17	29.5	40.4	59.6	2	2756	7250.6	Lignite
			58	24.2	24.8	15.2	35.9	41.51	58.49	2.1	2469	7223.57	Lignite
			61	19.5	26.9	17.8	35.8	42.78	57.22	1.1	2832	8303.31	Subbit.C

Appendix B7: Chemical analyses of coals from borehole 10

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%) Dry Basis mois.	volat.	f.car.	ash	Dmmf Basis f.car.	volat.	Tot. Sulf. (%)	Heat Value Dry basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	Rank (ASTM)
Upper Oilshale	98.3		YP-BH10-18-90	15.9	30	22.5	31.7	45.52	54.48	1.9	3405	9324.68	Subbit.C
			19	15.6	30.8	23.3	30.3	45.2	54.8	0.6	3619	9685.14	Subbit.B
			20	17.1	36	26.7	20.2	43.92	56.08	1.4	4365	10059.42	Subbit.B
		21.9	21	20.1	39.3	30.4	10.2	44.27	55.73	1	4839.6	9794.5	Subbit.B
			23	20.4	32.5	25.4	21.6	45.28	54.72	0.7	3986	9359.99	Subbit.C
			24	17.7	27.2	19.2	36	44.7	55.3	2.1	2960	8710.81	Subbit.C
	120.2		25	14.3	27.9	20.8	37	46.06	53.94	2.6	3041	9117.56	Subbit.C
Mudstone	120.2		31	16.6	37.7	25.5	20.4	41.65	58.35	0.7	3781	8727.5	Subbit.C
			32	14.7	33.2	18.7	33.4	38.7	61.3	5.6	2961	8298.77	Lignite
			33	14	29.7	17.2	39.1	39.54	60.46	1.6	2825	8797.68	Subbit.C
		5.1	35	14.8	35.6	21.4	28.1	39.46	60.54	3.6	3670	9496.08	Subbit.C
			39	13.2	33.1	18.3	35.4	38	62	2.5	3426	10004.64	Subbit.B
			40	14.1	34.5	19.9	31.5	38.7	61.3	2.7	3447	9411.69	Subbit.C
	125.35		43	17.7	32.5	19.5	30.3	39.69	60.31	2.5	3336	8922.31	Subbit.C
Lower Oilshale	125.35		44	17.7	31.9	20.2	30.3	40.86	59.14	0.8	2512	6704.97	Lignite
			45	20.8	25	17.3	37	44.28	55.72	0.8	2699	8084.23	Lignite
		22.68	46	17.4	36.8	26.9	18.9	43.49	56.51	2.2	4383	9911.33	Subbit.B
			48	16.4	27.4	18.1	38.1	43	57	1.7	2776	8481.78	Subbit.C
			49	16.7	35	27.9	21	46.8	53.2	4.4	3976	12635.34	Subbit.A
	148.03		50	18	32.7	27.6	21.7	47.75	52.25	3.2	3810	8954.55	Subbit.C

Appendix B8: Chemical analyses of coals from borehole:11

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%) Dry Basis mois.	Dry Basis volat.	Dry Basis f.car.	Dry Basis ash	Dmmf Basis f.car.	Dmmf Basis volat.	Tot. Sulf. (%)	Heat Value Dry basis (Kcal/Kg)	Heat Value Mmmf Basis (Btu/lb)	Rank (ASTM)
Upper Oilshale	77.56	5.74	YP-BH11-5-90	24.8	34.4	28.1	12.7	45.91	54.09	1.2	4302	8974.07	Subbit.C
			6	24.5	30.1	23.2	22.2	45.3	54.7	1.3	3466	8198.94	Lignite
			7	22.6	27.8	21.8	27.8	46.5	53.5	2.1	3110	7981.69	Lignite
			8	23.4	29.4	22	25.3	44.88	55.12	1.2	3574	8495.33	Subbit.C
			14	23.5	33.4	22.2	21	41.51	58.49	1.7	3770	8774.65	Subbit.C
			15	22.3	33.1	23	21.5	42.09	57.91	2	3750	8723.6	Subbit.C
			16	19.9	29.9	19.1	32	42.19	57.81	1.4	3239	8907.07	Subbit.C
			17	17.3	22.6	16	44.1	45.92	54.08	1	2520	8656.89	Subbit.C
			18	18.3	27.2	15.7	38.5	39.26	60.74	0.8	2842	8754.05	Subbit.C
			19	21.2	32.5	21	25.3	40.91	59.09	0.7	3656	8363.26	Subbit.C
			21	21.9	32.2	25.3	21.4	46.27	53.73	1.4	3720	8704.68	Subbit.C
			27	25.2	35.1	23.9	15.9	41.61	58.39	1	4076	8856.1	Subbit.C
	83.3		28	27.1	33.3	25.9	13.9	44.87	55.13	0.8	4111	8704.67	Subbit.C
Mudstone	83.3	6.6	34	23.6	38.8	29.8	7.9	44.13	55.87	1.6	4740	9329.95	Subbit.C
	89.9		35	20.9	37.1	28.7	13.2	44.7	55.3	2.9	4300	9026.62	Subbit.C

Appendix B9: Chemical analyses of coals from borehole:18

Coal Zone	Depth interval (m)	Thickness of the coal zone (m)	Sample No.	Proximate Analysis (%) Dry Basis mois.	volat.	f.car.	ash	Dmmf Basis f.car.	volat.	Tot.Sulf. (%)	Heat Value Dry basis (Kcal/Kg)	Mmmf Basis (Btu/lb)	Rank (ASTM)
Upper Oilshale	71	15.79	YP-BH18-1-90	20.3	37.1	22.6	20	39.01	60.99	1	4255	9773.92	Subbit.B
			2	24.7	39.2	27.6	8.5	41.89	58.11	1.2	4725	9388.86	Subbit.C
	86.79		3	22.2	29.4	18.8	29.6	41.12	58.88	0.5	3212	8496.83	Subbit.C
Mudstone	86.79	3.05	6	22.6	29.2	15.8	32.1	37.16	62.84	1.3	4391	12132.49	Subbit.A
			7	21.9	30.5	20.5	27	42.33	57.67	2.5	3274	8325.94	Subbit.C
			9	19.3	29	16.5	36.2	39.97	60.03	1.8	3106	9181.77	Subbit.C
			10	23.8	29.1	20	27.2	43.09	56.91	2	3295	8387.51	Subbit.C
	89.84		11	22.3	30.6	19.3	27.8	40.66	59.34	1.1	3410	8768.92	Subbit.C
Lower Oilshale	89.84	15.51	12	23.5	36.3	13	27.2	27.61	72.39	1.5	3435	8751.97	Subbit.C
	104.65		14	23.6	34.9	14.9	26.7	31.5	68.5	3.3	3329	8403.81	Subbit.C

Appendix C2: Detail Petrographic Description of Coals from Borehole 5

Facies (Coal zone)	Unit IV (Upper oilshale)	Unit III (Mudstone)	
Sample Number	YP-BH5- 47, 48	YP-BH5- 93, 94	YP-BH5- 96, 98
Organic Components	Huminite: - humocollinite: poregelinite & corpohuminite. - humodetrinite: present in a considerable amount. - humotelinite: generally little, of which ulminite is dominant and textinite is rare. Liptinite: -mainly tenuicutinite and microsporinite, with little resinite - Little sapropelic particles are found in the groundmass. Inertinite: - sclerotinite (little somi fusinite in groundmass)	Huminite: - humocollinite: dominantly telogelinite and corpohuminite. - humodetrinite: present - humotelinite: both textinite and ulminite are rare. Liptinite: - little sporinite and cutinite. - Alginite and banded bituminite are present. Inertinite: - Sclerotinite is the dominant.	Huminite: - humocollinite: poregelinite with little telogelinite and corpohuminite. -humodetrinite:present -humotelinite: generally rare, but ulminite dominates over textinite. Liptinite: - cutinite and microsporinite. - Minor alginite and finely banded, horse tail shaped bituminite are also present. Inertinite: - semifusinite and sclerotinite are dominant.
Inorganic Components	Clay: filler shaped Quartz: little Sulfide: grained and framboidal pyrite.	Clay: mainly grained, some are laminar. Quartz: Sulphides: mainly grained pyrite; little laminar type.	Clay: grain sized, laminar and cavity filling. Quartz: little. Sulfides: framboidal and nodular shaped pyrite. Carbonates: little.

Appendix C3: Detail Petrographic Description of Coals from Borehole 6

Facies (Coal zone)	Unit IV (Upper Oilshale)		Unit III (Mudstone)
Sample Number	YP-BH6-7, 8, 9	YP-BH6- 15, 17	YP-BH6- 41
Organic Components	<u>Huminite</u>: - humocollinite: corpohuminite (mainly phlobahinite) is very common with rare telgelinite. - humodetrinite: is mainly attrinite. - humotelinite: represented by rare ulminite. <u>Liptinite</u>: - tenuicutinite and sporinite are common with alginite and banded bituminite. <u>Inertinite</u>: -sclerotinite and little fusinite spliter.	<u>Huminite</u>: -humocollinite: mainly telogelinite with minor poregelinite and corpohuminite. -humodetrinite: rare <u>Liptinite</u>: - mainly tenuicutinite with very little resinite. - laminated bituminite is observed. <u>Inertinite</u>: -multicelled sclerotinite.	<u>Huminite</u>: -humocollinite: very dominant, represented by poregelinite, detrogelinite and corpohuminite. -humodetrinite: present. -humotelinite: generally rare,consisting of both ulminite and textinite. <u>Liptinite</u>: - tenuicutinite and microsporinite; alginite and bituminite are also present. <u>Inertinite</u>: -sclerotinite and semifusinite are observed in the ground mass.
Inorganic Components	<u>Clay</u>: grained and cavity filling. <u>Quartz</u>: little. <u>Sulfide</u>: framboidal and nodular shaped pyrite. <u>Carbonates</u>: rare	<u>Clay</u>: terrigeneous? <u>Quartz</u>: terrigeneous? <u>Sulfides</u>: framboidal pyrite	<u>Clay</u>: grained and lminar <u>Quartz</u>: present. <u>Sulfides</u>: grained and framboidal pyrite.

Appendix D

Analytical Procedure

All coal samples were chemically analysed at the central laboratory of EIGS. In all cases, the laboratory follows the ASTM analytical procedures.

Proximate analysis

Moisture: - the moisture content determined for the coal samples is total moisture.

Volatile mater: - coal heated to 950±25°c using a platinum crucible in a vertical electric furnace. The percentage loss of mass, less the percentage air-dried moisture gives the proportion of volatile matter present.

Ash: - the coal is heated slowly a ventilated furnace between 700 and 750°c, and held at that temperature until constant mass is developed. Expressing the residue mass as a percentage of the original coal represents the ash content of the coal.

Fixed Carbon: - is not determined directly, but is simply the difference, in an air-dried coal, between the sum of other components (moisture, volatile matter, ash) and 100%.

Total sulfur

The total sulfur content of the coal has been determined by "Eschka method", that involves oxidization of the coal at 800°c in magnesium oxide and sodium carbonate, followed by addition of barium chloride to form insoluble barium sulfate.

$$S + MgO \longrightarrow SO_2SO_3 + BaCl_2 \longrightarrow BaSO_4\downarrow$$

The mass of barium sulfate gives the total sulfur content of the coal.

Calorific value

The heat is determined by ignition of the coal samples under controlled conditions in parr bomb calorimeter.

Specific Gravity

The specific gravity of the Geba coal is determined based on the loss of weight when samples are immersed in a methanol.