ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

THE POSSIBLE CAUSES OF THERMAL VARIATIONS OF COALS IN DILBI-MOYE BASIN

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THE POSSIBLE CAUSES OF THERMAL VARIATIONS OF COALS IN DILBI-MOYE BASIN, JIMMA ZONE, OROMIA NATIONAL REGIONAL STATE, SOUTHWESTERN ETHIOPIA

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BY

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Praise the Lord, O my soul. O Lord my God, you are very great; you are clothed with splendor and majesty.

Psalm 104:1

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ABBREVIATIONS

m: Meter

km: Kilometer

km^2: Square kilometer

UTM: Universal Trans Mercator

Kcal/gm: Kilocalories per gram

d.m.m.f: Dry, mineral matter free

m.m.m.f: Moist, mineral matter free

Btu/lb: British Thermal Unit per Pound

ASTM: American Society for Testing and Materials

ABSTRACT

The coal deposit of Dilbi-Moye Basin in southwestern Ethiopia, between 7^0 $21^{'}$ 49" - 7^0 $24^{'}$ 31" N latitude and 36^0 $50^{'}$ 21" - 36^0 $52^{'}$ 54" E longitudes was studied with regard to sedimentological, geochemical, depositional environments and possible causes of thermal variations of the basin, which have a total area of 31.94 km^2.

The chemical analyses of the coal samples for the proximate, calorific value and sulfur content of the coals, different graphs are plotted versus each other to depict the coalification pattern, and the possible thermal variations of the Dilbi-Moye Basin.

From the analyzed coal samples result, the rank of Moye Sub-Basin coals range from sub-bituminous to high volatile A bituminous coals; whereas the Dilbi Sub-Basin coals range lignite B through high volatile B bituminous coals. The majority of the coal seams in the Moye area exhibited higher ranks due to the proximity of volcanic extrusions.

There is no uniform increment of the calorific values and decreasing of the ash content or vice versa in the Dilbi-Moye coals. However, in some cases, it is observed that as the calorific value increases, the ash content also increases and vice versa, across the basin.

Therefore, the possible causes of the thermal variations of the coals of the basin might be in most cases the organic matter (genesis) of the fossil fuel and/or environment of deposition and partially the inclusion of inorganic material into the coal. However, in some coal seams, the increment of the calorific value emerges from the near-by trachytic or rhyolitic sills that cooked the underlying seams to have high heating values.

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1. INTRODUCTION

1.1 GENERAL

Coal is found on every continent, and world coal reserves exceed 1 trillion tons. However, the largest reserves are found in the U.S., former Soviet Union, and China. The U.S. and former Soviet Union each have about 23% of the world's reserves, and China has about 11%. China, however, is the world's lead producer followed by the United State (Internet access).

Inter-Trappean coal and oil shale-bearing sediments are widely distributed in the Dilbi-Moye, Lalo-Sapo, Yayo, Sola, Chida, Chilga, Mush Valley, Wuchale, Arjo and Nejo Basins (Bae et al., 1989; Wolela, 1991; 1995; Miniye, 1992; Getahun et al., 1993; Kibrie and Gashawbeza, 1997; Kibrie, 2000). The Ethiopian coals and oil shales are mostly found and interbedded with Cenozoic volcanics of the Ethiopian plateau (Miniye, B., 1992). Some are associated with the sediments that occur between the Mesozoic continental clastics and the Cenozoic volcanics or associated with the Precambrian basement rocks (Wolela, 1991; 2007, 2008). Inspite of, their varied geological occurrences, all these coal-bearing sequences are younger in age than the coal measures of Gondwanaland or those of Western Europe (Miniye, 1992).

Until recently, the direction of the study of mineral resources by the Geological Survey of Ethiopia (GSE) focused on the Precambrian basement terrain of the country to assess for gold and associated minerals. However, later on, as the result of the shortage of oil supplies and the foreseeable decline in biomass fuels in the country divert the attention to the need to find these alternative oil fuels and other renewable energy sources. From global viewpoint, coal and oil shale has long been of interest as a direct resource for energy and as a possible source rocks for hydrocarbons.

Our country, Ethiopia, with its lowest per capita energy consumption of 300 kg organic energy, spends a large share of its total foreign earnings for imported fuels. This imported fuel is very insignificant that biomass fuels cover more than 90% of the total energy consumption (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 oil shale 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 hydropower in order to minimize the rate of deforestation.

As observed from the previous exploration works the fixed carbon, volatile matter, calorific value and ash contents of coals of the project area differs from borehole to borehole and from one corner to the other. Therefore, systematic study of the possible causes of thermal variations of coals of the basin is very important in view of planning to be used for necessary application.

The scope of this study is to assess the possible causes of thermal variations of coals of Dilbi-Moye Basin by using the geochemical analyses results of the subsurface geological data of the basin so far obtained through different exploration stages, surfacial and core coal samples analyses, which were carried out by the author.

1.2 LOCATION AND ACCESSIBILITY

The project area is situated in Deddo District, Jimma Zone of Oromia National Regional State, southwestern Ethiopia (Fig 1-1). The project area is bounded by 07^0 21' 49" - 07^0 24' 31" N latitude and 36^0 50' 21" - 36^0 52' 54" E longitude. Access routes to most parts of the study area are very limited. However, very few secondary routes depart off from Jimma-Chida road link Dilbi with the northwestern, southeastern and western parts of the project area. The project area is accessed by 333 km asphalt road from Addis Ababa to Jimma, 48 km due south of Jimma to Dilbi and 10 km west of Dilbi to Moye is accessible by dry weather road. Dilbi and Moye can be reached on all-weather gravel road and very rough dry-weather road using four-wheel drive vehicles respectively.

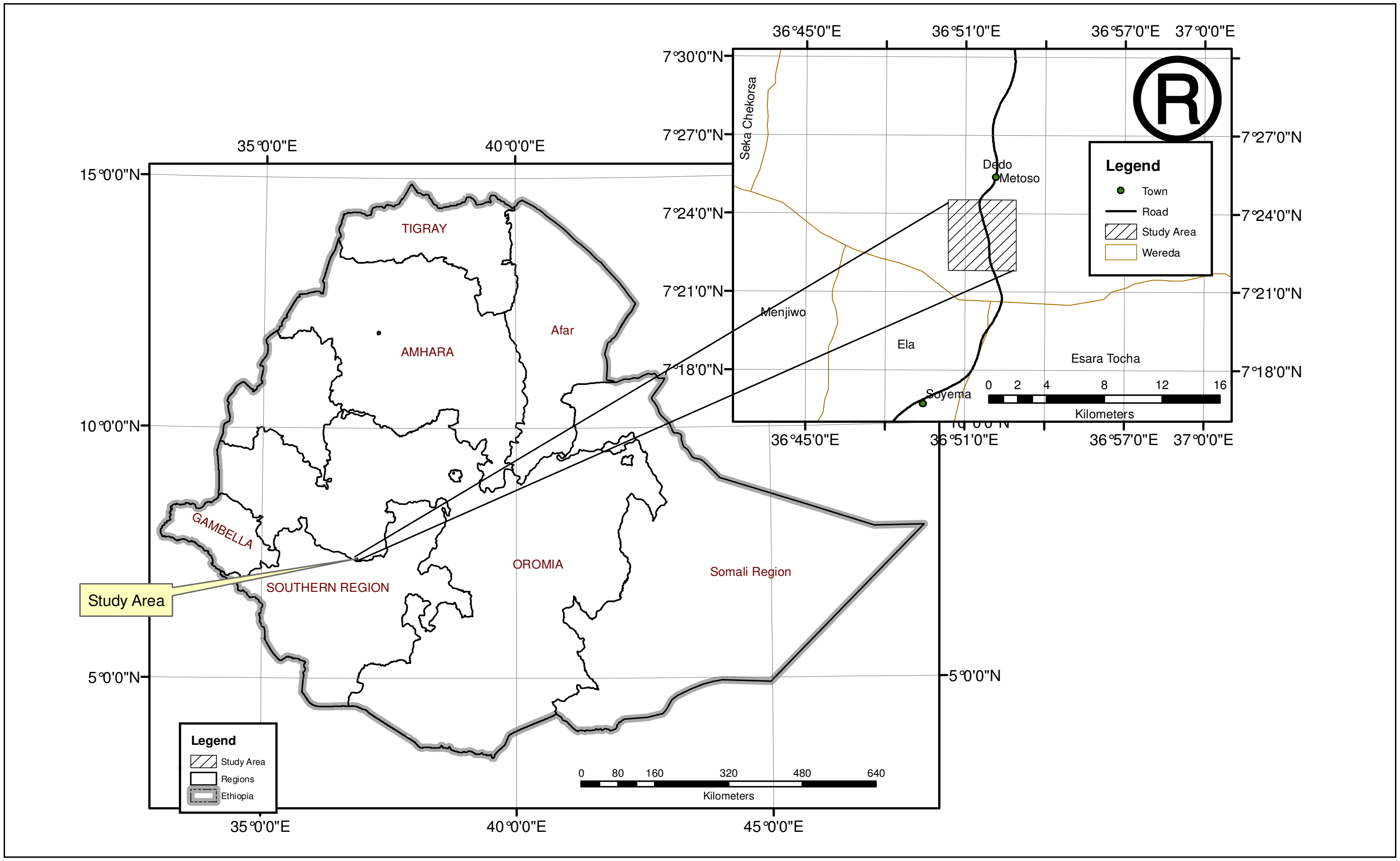


Fig. 1-1 Location map of Dilbi-Moye Basin

1.3 PHYSIOGRAPHY AND DRAINAGE

Physiographically, the surveyed area is a part of the southwestern plateau bordered by relatively rugged mountain ranges raising up to 2650m. The western part of the basin has relatively low relief as compared to the eastern part; steep slops and cliffs are common on faulted volcanic units. On a regional scale, the project area is characterized by a rugged topography, with blocks of mountain ranges, plugs and highly dissected valleys. The coal and oil shale bearing sedimentary sequences occur within a graben, of topographic elevations ranging between 1500m and 2650m (Getahun et al., 1993) above mean sea level. The graben is an obsolete Eocene rift and occurs as one of the small northwest-southeast trending grabens on the western Ethiopian plateau. On the west, the basin is bounded by highland, which raises abruptly to 2650m above mean sea level. The physiography of the region is controlled by the pre-rift tectonic and volcanic development of the southwestern plateau and partly by the East African Rift System. The area can be divided into two broad physiographic regions: the southern lowlands, at about Gojeb valley and the topographic highs to the northern part. The formation of this topographic variation is characterized to renewed faulting activity associated with the Late Tertiary volcanism (Miniye, 1992).

Several perennial and intermittent streams entering into the Gojeb River (Diddibo, Gonfa, Ramate, Bilacha, Laga Missie, Yebba and Okoshe) drain the area in approximately N-S direction. The drainage pattern is mainly of parallel dendritic type and rarely trellis (Bae et al., 1989; Getahun et al., 1993).

1.4 CLIMATE AND VEGITATION

Similar to the most part of the southwestern plateau high lands of Ethiopia, the area is characterized by warm and, humid subtropical climatic conditions. Two seasons of rainfall are known in the region, namely: Summer season, June–September and spring season, March-April with a mean annual rainfall of 1,600 mm distributed in two seasons, with dry periods of 6 to 7 months. The warmest season (25^0c) is November-March; the mean temperature on the plateau is 5^0c (Miniye, 1992). The annual average precipitation is 220.48 mm, annual maximum precipitation is 430.1 mm and monthly maximum precipitation is 48.2 mm.

Thick forests namely: Geta, Moye, Barsisi and Mencho are located within the radius of 5 km. Dilbi is poor in natural vegetation, but Moye is covered with thick tropical rain forest (Miniye, 1992). The natural vegetation is exceptionally diverse; thick tropical forest in the north passes to accacia trees, thorny bushes and tall elephant grass cover in the south.

1.5 PREVIOUS WORK

Prior to the study undertaken by the Geological Survey of Ethiopia, very little detail of the geology was known about the study area. Occurrence of the 3m thick coal at Dilbi-Moye Basin was first reported by Ethiopian Water Works Construction Authority (EWWCA) in 1984 while drilling for ground water.

Systematic studies with production of several unpublished reports were conducted since 1984. Some of these included reconnaissance mapping (Heemann and others, 1984); semi-detail geological mapping (Asefa and others, 1987); detail mapping (Shigut, 1988; Miniye and others, 1988); geochemical studies (Beicip,1988); and palynological studies (Amoco, 1988); detail mapping and preliminary to detail prospecting (Bae and others, 1989; Bae, 1991); sedimentological, geochemical and petrographic studies (Miniye, 1992) and chemical characteristics of Ethiopian coals (Tesfaye and others, 1992). Tesfaye Lemma et al. (1992), the chemical analyses and characterization of a geological and exploratory investigation for possible coal reserves; an overview on geographical distribution, geological setting and geochemical characteristics of Ethiopian coals and oil shales (Wolela, 1992b) and significant coal deposits and their economical and mining possibilities in Ethiopia (Wolela, 1992b). Review on coal and oil shale reserve estimation of Dilbi area (Zewdineh, 1992) and (Alula and others, 1992) carried out the geological studies of Sola area.

Among the studies undergone so far, the prominent one is the geological explorations including reconnaissance, regional and detail mapping that has been carried out by the Geological Survey of Ethiopia (Bae et al., 1989; Getahun et al., 1993; Wolela, 1991, 1995, 2006, 2007, 2008). The potential area, where economical coal and oil shale resources occur, was delimited using prospecting criteria and 26 boreholes (Table 1-1 and Fig. 1-2) with a total depth of 5,171.50m.

From the study work, over sixteen (16) coal seams having thicknesses ranging from 0.3m to 2.3m are discovered at Moye Sub-Basin. These coal seams appear in sets, within the three major coal-bearing units. Preliminary exploration indicates that the reserves are close to 27,545,298 tons. Similarly, three coal seams are discovered in the coal-bearing interval at Dilbi with thicknesses varying between 0.4 and 2.4m. Preliminary studies have confirmed total coal reserves of 14, 016,730 tons at Dilbi.

Based on these results and recommendations forwarded by Getahun et al. (1993), a detail geological and geophysical exploration works on 3.5 km^2 area has been carried out at Moye Sub-Basin for the purpose of energy use in the cement factory by the Derba-East Africa Coal Mining PLC. During this study, 20 exploratory boreholes (Table 1-1 and Fig. 1-2) with a total depth of 2,334.08m, geological core descriptions, graphic logging, sampling, and in-hole geophysical logging were accomplished. Out of the 20 drilled boreholes, 13 have been found intersecting a number of economical coal seams ranging in thickness from 0.45 to 2.15m. From this study, the coal reserve of the Moye

Sub-Basin is estimated to be 4.5824 Mt, of which 0.6411 Mt is the proved reserve and 3.9413 Mt is the controlled (probable) resource.

Table 1-1 The x, y, z coordinates of bore holes drilled by Geological Surveys of Ethiopia and Derba-East Africa Coal Mining PLC

Borehole	Coordinates			Sunk by
	X	Y	Z	
10	260526.84	815187.82	2032.76	Geological Surveys of Ethiopia
18	259428.74	814577.24	1793.60	"
19	259934.04	815770.99	1986.53	"
20	259170.84	813776.84	1720.63	"
21	258907.70	813931.18	1656.19	"
26	260383.41	816149.32	2088.52	"
30	259682.36	815041.27	1821.61	"
2	264303.99	816781.62	2193.11	"
5	263261.67	815235.92	2198.32	"
6	263759.61	816983.59	2272.85	"
7	265222.51	817458.47	2219.76	"
8	263042.92	816709.07	2319.70	"
11	264536.82	817417.95	2220.84	"
12	265069.15	818189.65	2268.02	"
15	262500.00	819250.00	2360	"
16	264100.12	815331.33	2183.13	"
17	263557.16	816037.49	2206.92	"
25	260000	816500	2100	"
2C	258870.982	814181.223	1683.89	Derba-East Africa Coal Mining PLC
4C	259062.855	814420.05	1739.54	"
4E	259272.316	814309.839	1766.82	"

4G	259563.102	814168.686	1759.03	Derba-East Africa Coal Mining PLC
4I	259875.22	814016.626	177309	"
6C	259149.638	814748.516	1755.79	"
6G	259735.204	814368.004	1798.48	"
6I	260019.74	814266.63	1828.12	"
8C	259324.51	815046.66	1765.71	"
8E	259623.308	814854.197	1792.74	"
8G	259882.004	814675.467	1831.68	"
10G	260026.78	814989.907	1884.59	"
10I	260234.04	814736.674	1913.62	"
12C	259564.28	815518.83	1869.99	"
12E	259874.27	815301.5	1911.60	"
12G	260137.616	815092.44	1915.44	"
14C	259606.56	815944.3	1918.35	"
14G	260247.18	815563.26	2009.03	"
16E	260178.319	815874.513	2054.37	"
16G	260435.729	815661.026	2073.37	"

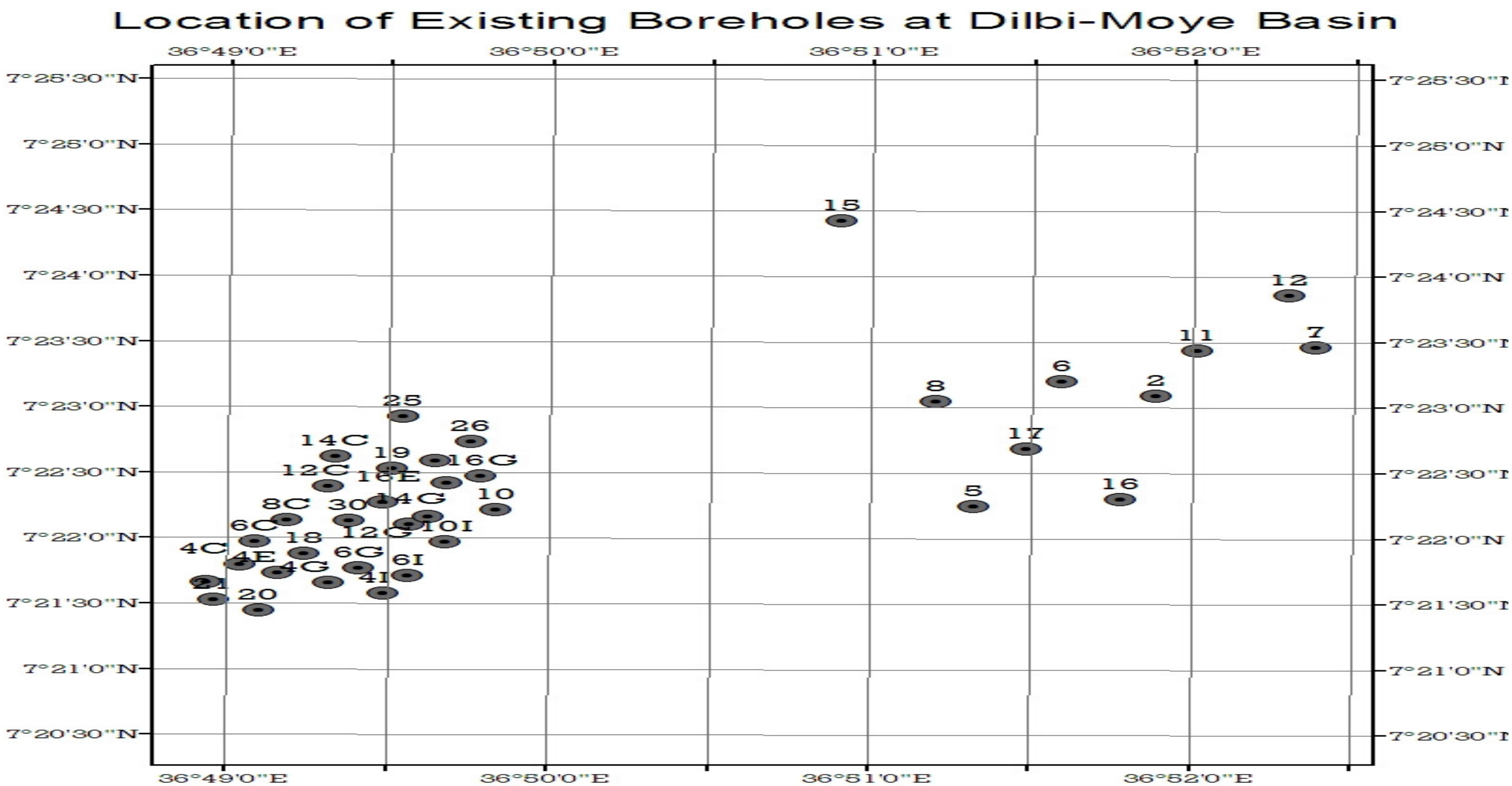


Figure 1-2 Location Map of Dilbi-Moye Boreholes

1.6 OBJECTIVE

General Objective:

The purpose of the study is to depict the possible causes of the thermal variations of the coals in Dilbi-Moye Basin.

Specific Objective:

The specific objective of the project is by reviewing secondary and primary data, undergoing geological fieldwork and analyzing the field data to,

- study the stratigraphy/sedimentology of the basin,
- assess the depositional environment & facies changes of the basin,
- evaluate the thermal characteristics of coals in the Dilbi-Moye Basin,
- analyze the vertical and lateral thermal variations of coals in the basin.

Project Justifications:

Many geological works such as: regional and detail mapping, different levels of exploration works, drilling of boreholes, geochemical analyses, sedimentological study, palynological analysis and reserve evaluation, etc...., have been carried out on the Dilbi-Moye Basin. From the geochemical analyses results so far carried out by different bodies, thermal variation of coals is observed in the basin. However, no body has shown any attempt to analyze the thermal variation of the coals of the basin until now. Therefore, the author has decided to assess the possible causes of the thermal variations of coals in the Dilbi-Moye Basin, to contribute some thing to the geo-scientific knowledge of the area not touched so far, based on the previously and recently carried out chemical analyses results of the coals.

2. METHODOLOGY

To meet the objective mentioned above, the presently and previously analyzed core coal samples results of selected boreholes of the basin are used for the thermal variations evaluations of coals of the basin. In addition to this, the systematic subsurface logging and correlation of the existing stratigraphic sections of the basin has been carried out.

For this purpose, four boreholes (BH 1, 2, 6 and 11) from Dilbi and three boreholes (BH 19, 18 and 21) from Moye Sub-Basins have been selected based on the presence of relative chemical analysis results and representation of the boreholes in the basin used for evaluating the possible causes of thermal variations of coals in the Dilbi-Moye Basin.

Surface Sampling

Outcrop sampling of coals and rocks from different streams and cut-valleys were made for petrographic and chemical analyses. During the field work season fifteen outcrop coal samples and twelve rock samples were collected from the field.

Subsurface Exploration Works done by Geological Survey of Ethiopia

Subsurface investigation has been carried out by Geological Survey of Ethiopia (1988-1990) at Dilbi-Moye Basin by drilling 26 boreholes. The location of each borehole is given in Table 1-1 (UTM), and their relative position is shown in Fig. 1-2.

Laboratory Procedure

Both coal samples taken from outcrops and cores are submitted to the Central Laboratory of the Geological Survey of Ethiopia. Depending on the analysis required, data gap and financial capacity three outcrop coal from the field and six core coal samples, which were obtained from the Geological Survey of

Ethiopia, were chemically analyzed for proximate, calorific value, total sulfur content and density to evaluate the thermal variations of coals of the basin. In addition to this, out of the samples collected from the field, two rock samples were analyzed petrographically and described physically.

The chemical analyses, which were carried out, by grinding the samples to the standard size of 200-mesh size and it encompasses proximate, calorific value, total sulfur and density analyses. Among these geochemical analyses 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 Dilbi-Moye coals comprehends samples from the outcrop sections and boreholes. The results are presented both in dry basis and in dry, mineral matter free basis (Tables 4-1A, 4-1B, 4-2A and 4-2B).

In the study area, thirty-two (32) coal samples (23 previously and 9 recently analyzed) representing three major coal groups are examined. All samples, which are previously analyzed, and the six (6) core coal samples recently analyzed are composites of economically significant seams from Moye and Dilbi areas; whereas the three (3) samples recently analyzed are outcropped samples both from Dilbi and Moye areas. The core samples are collected across the seam sections by core sampling methods. All the analyses are carried out on an air-dry basis to achieve effective equilibrium with temperature and humidity of the laboratory atmosphere. Among these presently analyzed core and outcropped coal samples, 3 core and one outcropped coal samples are discarded due to their unsatisfactory results. However, three (3) core coal samples and two (2) outcropped coal samples recently analyzed were fulfilled the standard. Therefore, by excluding the two (2) surfacial analyzed coal sample results, totally twenty-six (26) core coal samples were used for the thermal variation analysis of the research Thesis.

In the study, the proximate and heating value tests are obtained by the use of methods detailed in, American Society for Testing and Materials, ASTM 1989 (Appendix A). Standard test methods to determine the inorganic residues such as ash, are made by burning the coal under rigidly controlled condition of sample weight (1 gm), temperature (700-750^{0}C), time (1 hr), atmosphere of adequate air circulation, and electrical muffle furnace as determined by D3174-89 (ASTM, 1989). The inherent moisture, in the coals is determined by establishing weight loss of the sample by drying in furnace of 1 gm of sample for 104 to 110^{0}C temperature in accordance with D3173-87 (ASTM, 1989). The test method for volatile matter is made by establishing the weight loss resulted from heating of 1 gm of sample to 900^{0}C ± 10^{0}C for 7 minutes. The measured weight loss is corrected for moisture as determined in test method D3175-89 (ASTM, 1989). The fixed carbon content is determined by the difference from 100% of the sum of moisture, ash, and volatile matter values [100-(M+A+V.M)].

The total sulfur, are determined in high temperature combustion method by burning 1 gm of sample at a temperature of 1350^{0}C and the products of combustion are observed in hydrogen peroxide, which effects further oxidation of sulfur to sulphate. The sulphate is then determined volumetrically (Pretor, 1987).

The calorific value determinations are made by complete combustion in oxygen of coal in bomb calorimeter under pressure of a weighted sample (1 gm). It is computed from temperature observations made before, during, and after combustion and making proper allowances for the heat controlled by other processes as determined by D3286 (ASTM, 1989).

The classification of the coals, ASTM D-388 (ASTM, 1989) are according to their volatile matter and fixed carbon contents calculated to air dry and mineral matter free bases. Moist refers to the coals inherent moisture, and mineral matter is calculated from the coal ash and sulfur contents.

The rank of coals for the recently analyzed samples is determined by using the proximate analysis and calorific value result of the core coal samples based on the American Society for Testing and Materials (ASTM, 1989), (Appendix A), at dry, mineral-matter free and moist, mineral-matter free state.

Thermal variation analysis of coals

Vertical thermal variation analysis is made for each selected borehole depending on each coal seam vertically. Based on the available data, ash content (%) vs calorific value (Btu/lb), depth (BH-coal seam) vs calorific value (Btu/lb) and depth (borehole-coal seam) and ash content (%) vs calorific value (Btu/lb) were carried out.

Lateral thermal variation analysis is undergone in two ways. The first way is the evaluation of the coal seams according to their equivalence and similarity one by one from borehole to borehole. The second method is by observing the general trend of the graphs of different parameters across the basin from end to end.

The coal seams are categorized in groups in accordance with their stratigraphic position as group 1, for the lower most coals, group 2, for the middle, and group 3, for the top most, which are classified by Geological Survey of Ethiopia (Getahun et al., 1993).

Each coal group consists of coal beds as many as six (6) and the individual coal seams are also designated by consecutive number 1, 2, 3, ..., starting from the lower coal seam upwards. The coal seams and the coal groups among boreholes are correlated, and the chemical analysis result of a single coal seam at any arbitrary point within a borehole is given by showing the borehole number, coal group number and coal seam number, in a respective order (eg: 21-1-5 means BH 21, coal group 1 and coal seam 5).

3. GEOLOGY

3.1 REGIONAL GEOLOGICAL SETTING

The geology of Ethiopia is comprised of three major geological terrains, namely: the Proterozoic crystalline basement, Late-Paleozoic to Mesozoic marine and continental sedimentary rocks and Cenozoic, basic and felsic volcanic and associated sedimentary rocks (Mengesha et al., 1996). The general framework of southwestern Ethiopia includes Precambrian crystalline basement, affected by the Pan African Orogeney, overlain by Tertiary volcanics.

Precambrian

In the southwestern Ethiopia, crystalline basement is exposed in some parts of Ilubabor and southwest Kefa, and in Gamo Gofa. The metamorphic basement rocks in Ilubabor and southwest Kefa are separated from the later, by the lower Omo River valley. The basement rocks in the lower Omo are exposed locally at lower elevations as small windows along the bases of rift escarpment. Similarly, disposed basement outcrop has been reported in the gorge of the middle Omo River (Davidson et al., 1983).

Paleozoic and Mesozoic Sediments

A few outcrops of the Karoo system have been identified at Gilo and Kari in southwestern Ethiopia. Regionally, Mesozoic sediments, are absent in western Ethiopia indicating a synchronous regional uplift in this part (Kibrie, 2000). Similarly, in the study area, there are no exposed older rock units going down beyond Cenozoic volcanics.

Cenozoic Rocks

Pre-Oligocene basalts were recently discovered in southwestern Ethiopia in Kefa province, where a group of "Early Flood Basalts" display K-Ar ages within the interval 53.2 to 37.2 m.y. (Davidson, 1983; Davidson and Rex, 1980).

The Aiba Basalt equivalent rocks occur in the Omo River Basin where K-Ar ages of 34-30 Ma (Oligocene age) have been reported. These basalts were mapped by the Omo Project team as a single unit with "Early Flood Basalts", which are presumably the same as the Ashangi Basalts. No unconformity was reported within the succession, (Kazmin, 1979a).

Alaji Formation (Oligocene- Miocene age) volcanics are outcropped in the Omo River Basin of southwestern Ethiopia such that large volumes of ignimbrites, tuffs, pyroclastics and trachytes found in the upper portion of the "Early Flood Basalts" (Davidson et al., 1983). The "Plateau Basalts" resting directly on the basement display a K-Ar ages between 31.9 to 28.0 m.y., are also correlated with the Oligocene Alaji (Kazmin, 1979a).

According to Davidson (1983), the Cenozoic stratigraphy of southwestern Ethiopia, from youngest to oldest is as follows:

- Pyroclastic cones and basaltic flows of the Bulal plain and the Korat range (Late Quaternary),
- Tepi basalt (Early Quaternary),
- Fedjej basalt (Early Pliocene),
- Phonolites of the Woito river basin 16 Ma age (Middle Miocene),
- Salic Flows and Pyroclastic Rocks 18.2 Ma (Middle Miocene),
- Mixed basaltic, intermediate and salic volcanic rocks (Late Oligocene - Late Miocene),
- Plateau Basalts 31.8 to 28 (Middle Miocene),
- Early Flood Basalts 53.2 to 37.2 (Eocene), and
- Basement (Pre-Palaeogene)

3.2 GEOLOGY OF DILBI-MOYE BASIN

Dilbi-Moye Basin is a small rift basin preserving thick Cenozoic strata. The basin is fault bounded, at least on its western rim, presumably forming a half graben. There is a suspicion about the basin, which might be due to the response against to the initiation of an extensional tectonic phase almost related to the proto Ashangie Rift development during Early Tertiary (Getahun et al., 1993).

Two major rock types: volcanics and sedimentary rocks exist in the Dilbi-Moye Basin (Figs. 3-1, 3-2, 3-2A, 3-3 and 3-3A). In addition to these, there are minor occurrences of pyroclastic rocks and sub-intrusives, which are known to exist in the study area.

Systematic detail mapping and sub-surface studies have shown that there are at least four major basic to acidic volcanic cycles named as lower, middle and upper basalts, and intermediate to silicic volcanics in the Dilbi Sub-Basin. Whereas, in the Moye Sub-Basin, Lower and Middle (?) basalts, and the associated intermediate to silicic volcanics are present (Bae et al., 1989; Wolela, 1991, 1995, 2004, 2006; Getahun et al., 1993). The coal-bearing, fluvio-lacustrine and volcano-clastic sedimentary rocks are found within this volcanic succession. The occurrence of volcanic flows beneath, within and over these sediments is the basis to define the Lower, Middle and Upper basalts in the stratigraphy of the basin.

The Dilbi-Moye Basin sediments were deposited in NNW-SSE trending graben. Distinctive continental sediments, deposited under widely variable environmental settings exist between composite lavas of basaltic composition. The Dilbi-Moye Basin sedimentation is supposed to have taken place in inter-volcanic basins of tectonic origin. Wide occurrences of volcanic flows beneath, within, and over the sediments could perhaps suggest events of pre, syn, and post, sedimentation and crustal instabilities respectively (Bae and Others 1988).

It is proved from the drilling log data that the main basin fill sedimentary sequence laid on the lower basalt. The components of the coal and oil shale bearing sequence were deposited with no marked evidence of unconformity in between. Coal and oil shale bearing sequence are without unconformity overlain by an approximately 40-250m thick succession of the middle basalt, the volcanic sediments and the upper basalt.

Based on the studies undertaken so far, many geoscientists, particularly Bae, (1991), have agreed upon and established the lithostratigraphic framework of the area (Fig. 3-4). Above all, since this stratigraphy is established based on the drilled boreholes data, I too agree on this already recognized stratigraphy of the project area, and listed as follow:

- Recent sediments, tuffs, and conglomeratic beds,
- Intermediate and silicic volcanic rocks,
- Upper basalt,
- Sediment II,
- Middle basalt,
- Sediment I, and
- Lower basalt.

3.2.1 Volcanic Rocks

The lithostratigraphy of the study area is made, by correlating several sections at outcrops, on a regional basis, and by making use of data from boreholes. Bae and Others (1989), established three phases of basaltic volcanism subdivided into lower, middle, and upper units, and two episodes of inter-basaltic sedimentation designated as sediments one and two occur in the area. The basalts overlying Sediment I could either be the middle or upper unit. Since the age dating is not done, distinctions among these basalts are very difficult because of textural and mineralogical similarities. However, for the purpose of mere simplification the overlying basalt (middle basalt at Dilbi area) is tentatively correlated with the upper unit of the central and northern parts of the area.

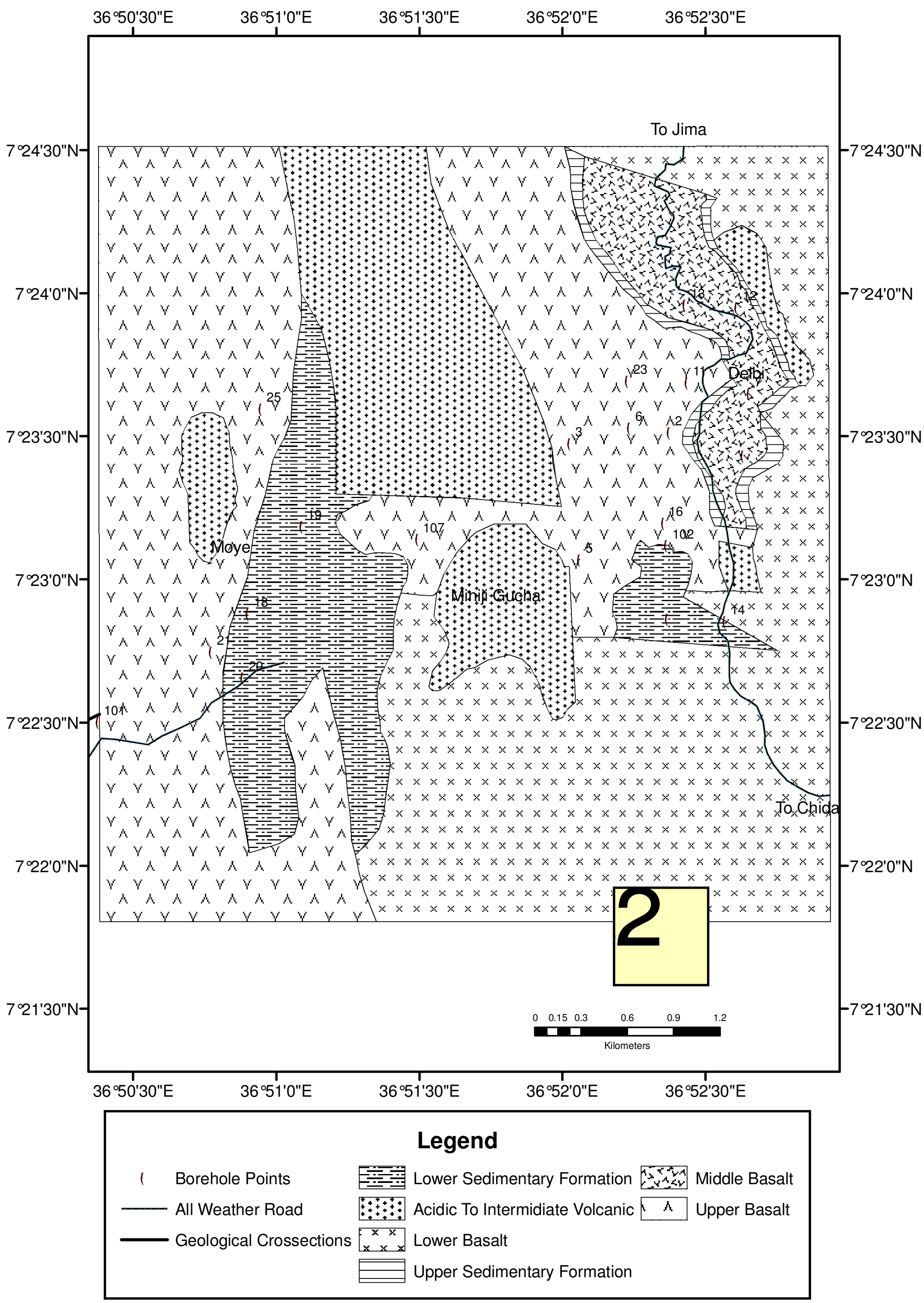


Fig. 3-1 Geological map of Dilbi-Moye Basin (modified after Bae et al., 1989)

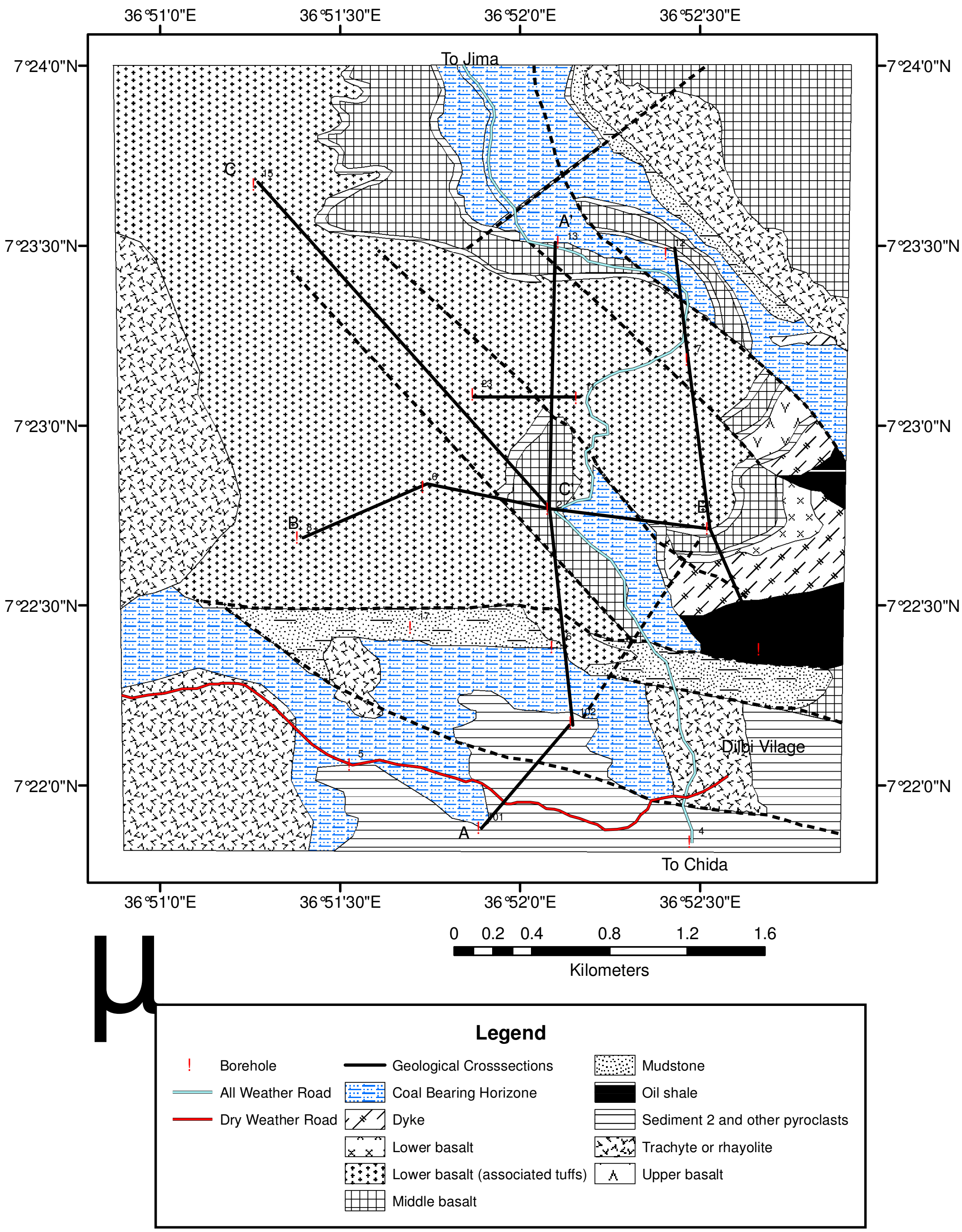


Fig. 3-2 Geological map of Dilbi Sub-Basin (after Miniye, 1992)

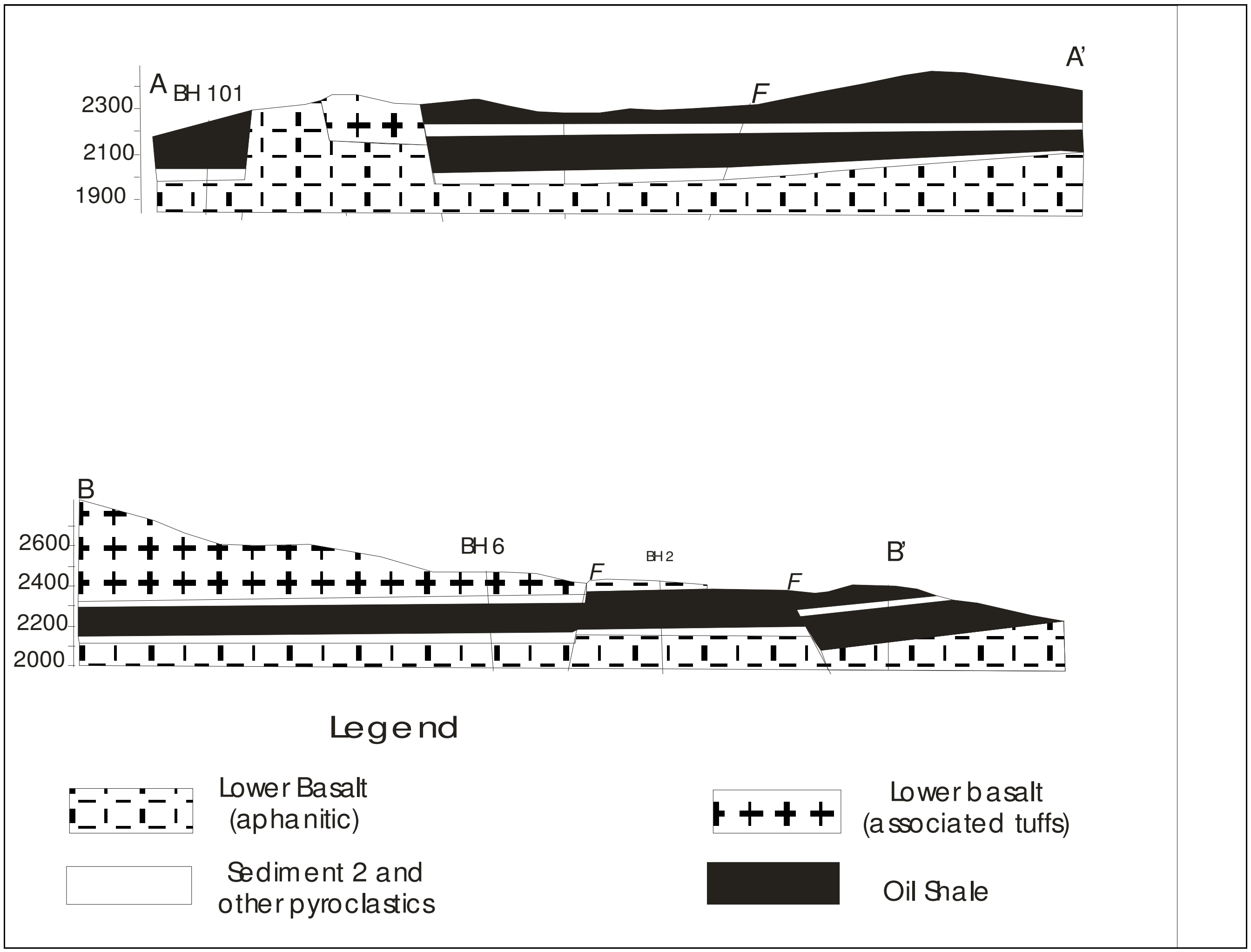


Fig. 3-2A Geological cross sections along boreholes in Dilbi Sub-Basin

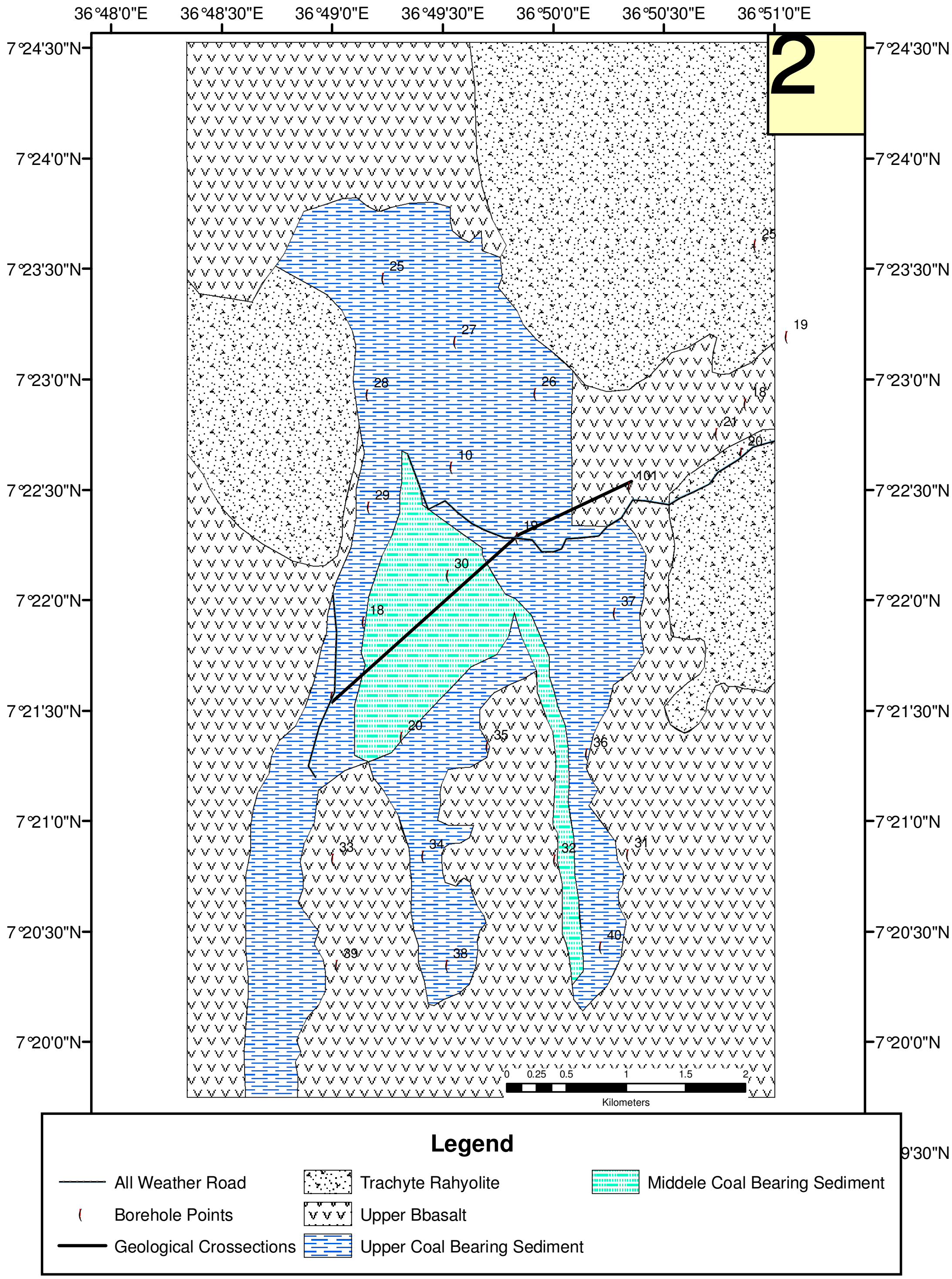


Fig. 3-3 Geological map of Moye Sub-Basin (after Bae et al., 1991)

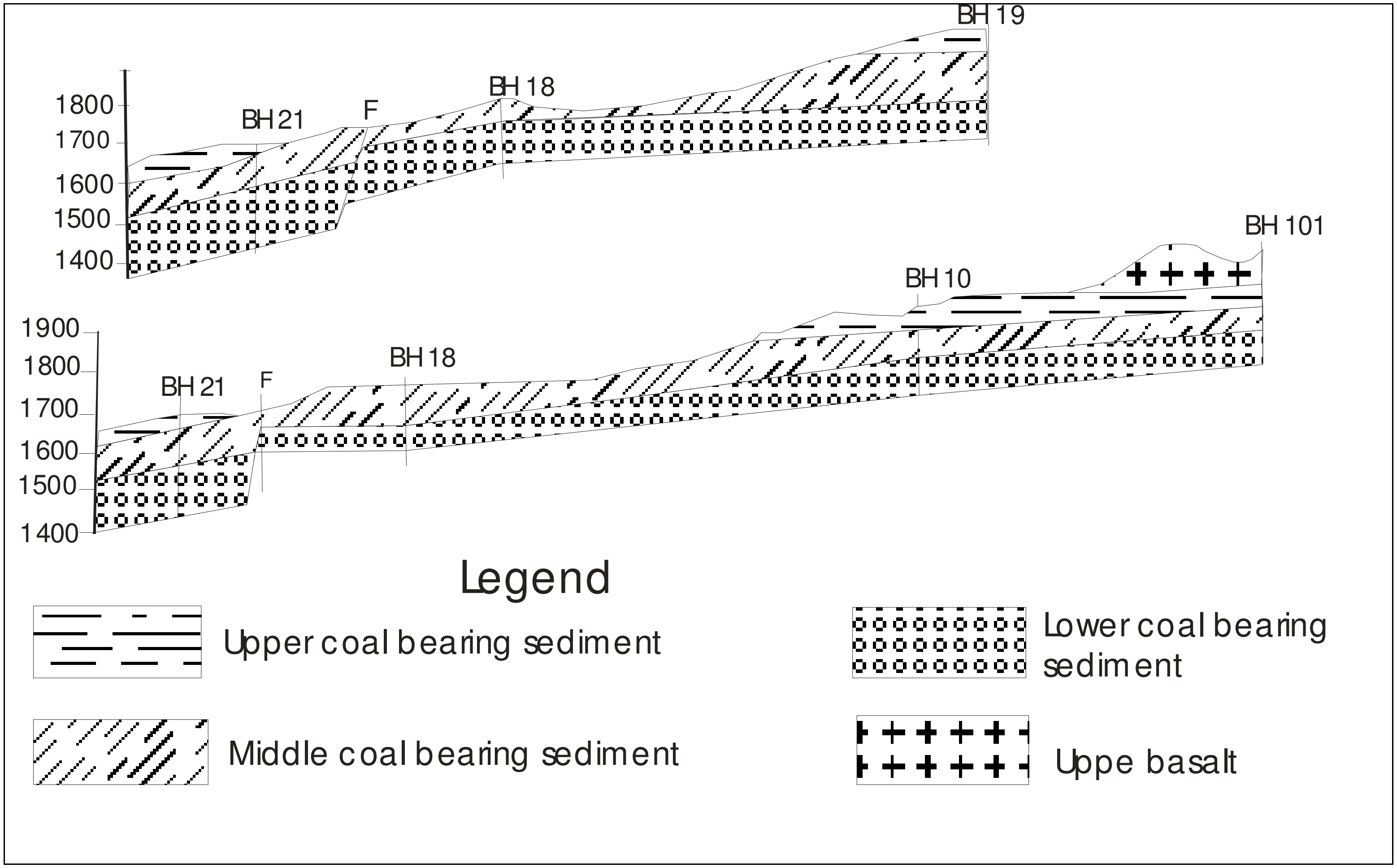


Fig. 3-3A Geological cross sections along boreholes in Moye Sub-Basin

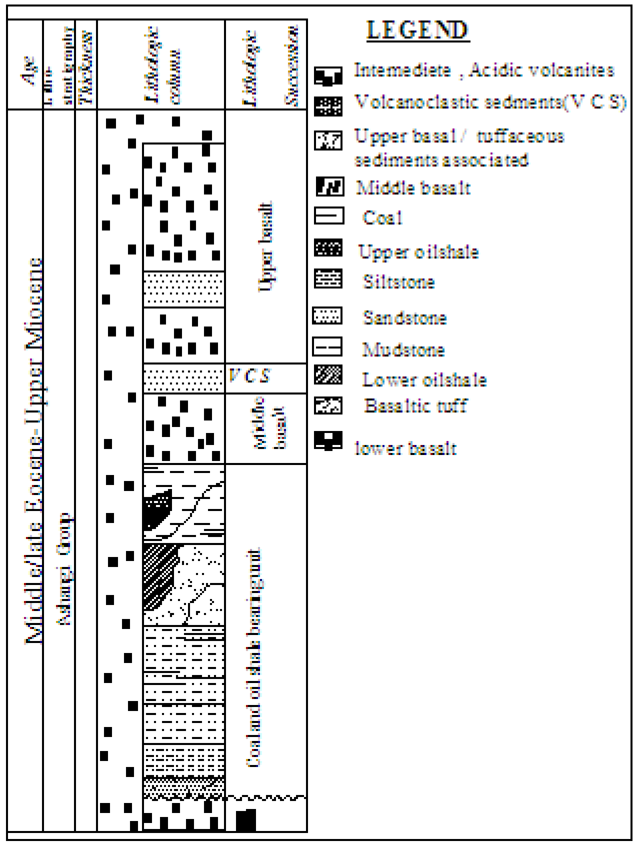


Fig. 3-4 Generalized stratigraphic column of Dilbi-Moye area (modified from Bae, 1991)

3.2.2 Tertiary Sediments

3.2.2.1 Sediment I (Coal-bearing Sediments)

Sedimentation in Dilbi-Moye Basin had been occurred together with active volcanic phase. The spores and pollens studies confirmed the age of the sediments, at Dilbi to be Oligocene-Miocene (Amoco, 1988). The coal-bearing sedimentary formation is deposited unconformably on a basaltic substratum; which is dated to be 31 Ma. This formation is characterized by five major sedimentary facies. These facies are the lower mudstone, lower oil shale, upper mudstone, upper oil shale, and coal-bearing sediments, and defining by three major sedimentary cycles (Bae et al., 1989; Wolela, 1991, 2004; Getahun et al., 1993).

This unit is generally named as coal and oil shale bearing unit, which is mainly composed of continental clastics of fluvio-lacustrine origin. It is exposed as erosional remnants on originally extensive volcanic substratum. In a very broad expression, the fluvio-lacustrine mainly consists of argilio-arenaceous rocks (mudstones, claystones, carbonaceous shales, siltstones, sandstones, etc), in which bands of coal and oil shale are inter-layered within the sequence. As observed from BH 4 of Dilbi Sub-Basin and BH 19 of Moye Sub-Basin, the thickness of the Sediment I vary between 33m and 228m respectively, with the thickest sections being confined to the western and eastern parts of the basin (Ketsela, 1990). They are generally, horizontal to sub-horizontal, but may locally dip gently to the northwest and southwest at angles of 10^0 to 25^0.

A typical basin fill sequence at Dilbi (Fig. 3-5) is subdivided into the lower mudstone, lower oil shale, upper mudstone, upper oil shale and the coal-bearing clastic units from bottom to top. Finer clastic sediments at Dilbi grade laterally into coarser clastics and the coal-bearing intervals at Moye (Wolela, 2004). A typical basin fill sequence at Moye (Fig. 3-6) is subdivided into lower mudstone, lower coal-bearing sediment, middle coal-bearing sediment and upper coal-bearing clastic sediment upwards. Within the coal-bearing units, both at Dilbi and Moye and the coal seams are contained in stratigraphic cluster (coal groups). Each coal group contained many coal seams and separated from other coal groups by thick sequences of sediments. The distribution of these coal seams, both laterally and vertically, is shown in Fig. 3-7, for Dilbi area, and Fig. 3-8 for Moye area.

3.2.2.2 Sediment II: (conglomeratic beds, tuffs and coals)

The top most part of the lithostratigraphic unit is unconformably overlain by medium to coarse-grained friable to compact tuffaceous material and coal seam. It is composed of lithic fragments with a heterogeneous composition. No distinct bedding characteristic is observed. However, the tuffs are associated with lateritic soils of red to various grey colours. Their thickness varies from 3 to 30m. While in places, recent sediments composed of conglomeratic beds consisting of rock pebbles with sandy sized particles are distinctly seen at the western part of the basin (Bae et al., 1989), (Fig. 3-8).

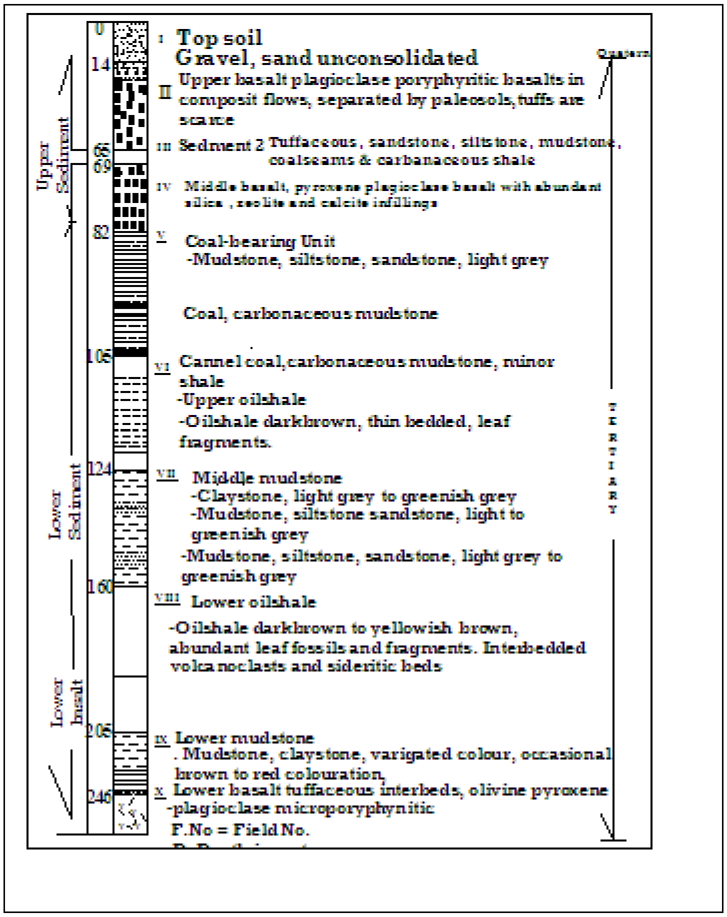


Fig. 3-5 Typical basin fill at Dilbi Sub-Basin (BH 1), (after Getahun et al., 1993)

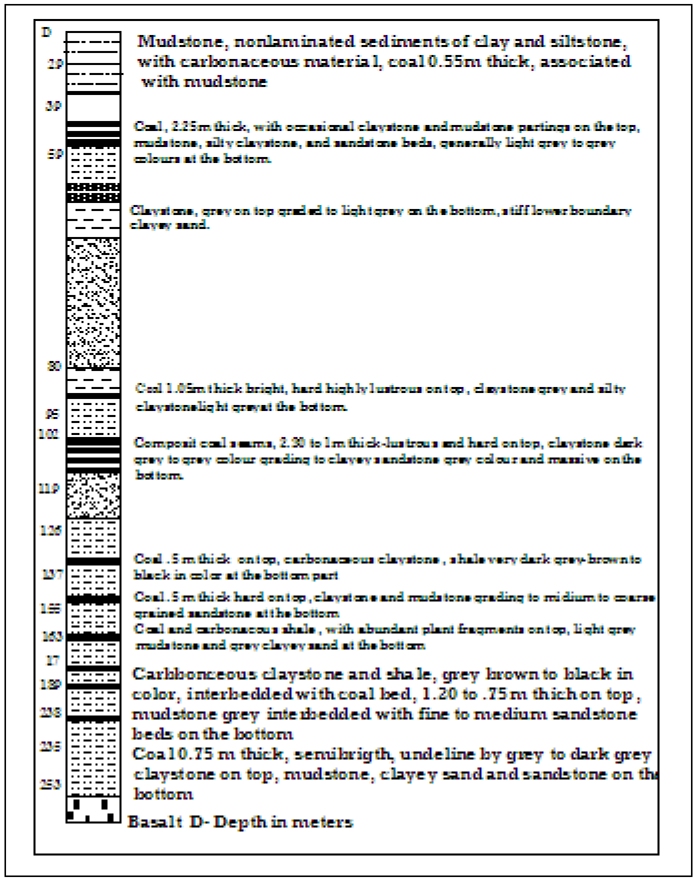


Fig. 3-6 Typical basin fill at Moye Sub-Basin (BH 19), (after Getahun et al., 1993)

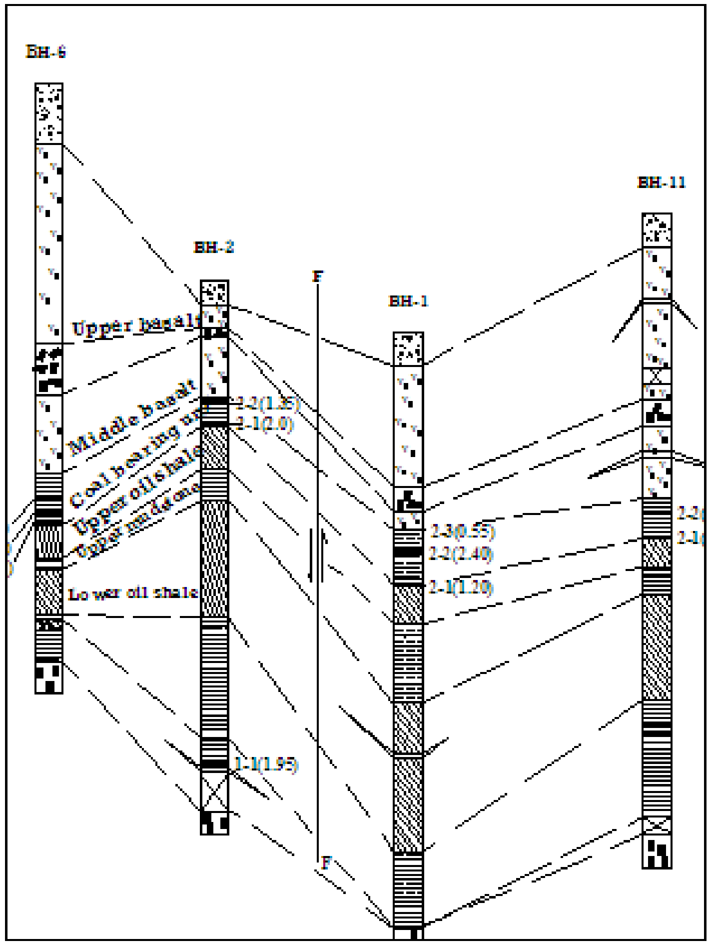


Fig. 3-7 **Geological cross-sections along BH 6, 2 and 1 and along BH 11 and 1, Dilbi area (after Getahun et al., 1993)**

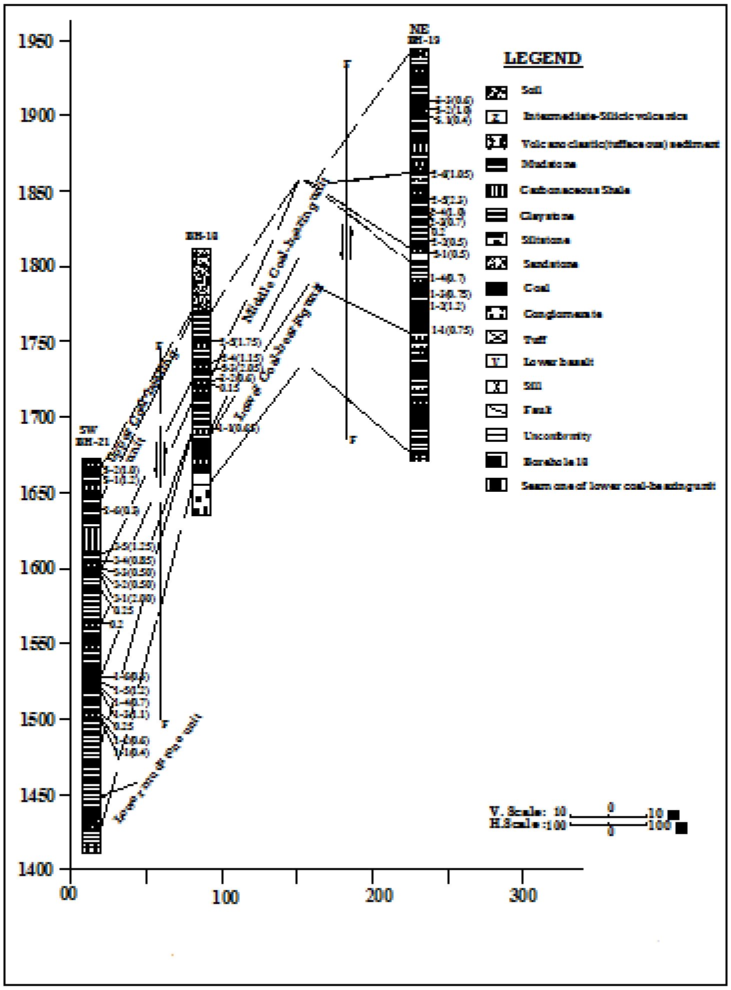


Fig. 3-8 Geological cross-section along BH 21, 18 and 19, Moye area (after Getahun et al., 1993)

3.2.3 Facies and Depositional Environments

The basin development evolution path and the tectonic configuration confirmed that the mode of occurrence of the coal-bearing formations of Dilbi-Moye Basin to be graben filling, characterized by facial variation and interfingering of units (Wolela, 2004). The sediments mostly, show an upward fining evolution from fluviatile to lacustrine facies; and defined by stable lacustrine, unstable lacustrine, fluviatile and swampy facies (Fig. 3-9).

There are five facies of sedimentary units recognized in the basin; namely, the lower mudstone, lower oil shale, upper mudstone, upper oil shale and coal-bearing sediments. Sedimentary structures within these facies include cross and horizontal laminations, graded and contorted bedding, concretions and nodules.

Facies analysis of the sediments indicates four major continental depositional settings ranging from alluvial fan and fluvial condition to marginal lacustrine, and open lacustrine environments (Miniye, 1992). The paleo-current movement confirmed that the shifting of the depocenter from Dilbi to north and northwestern part of the basin.

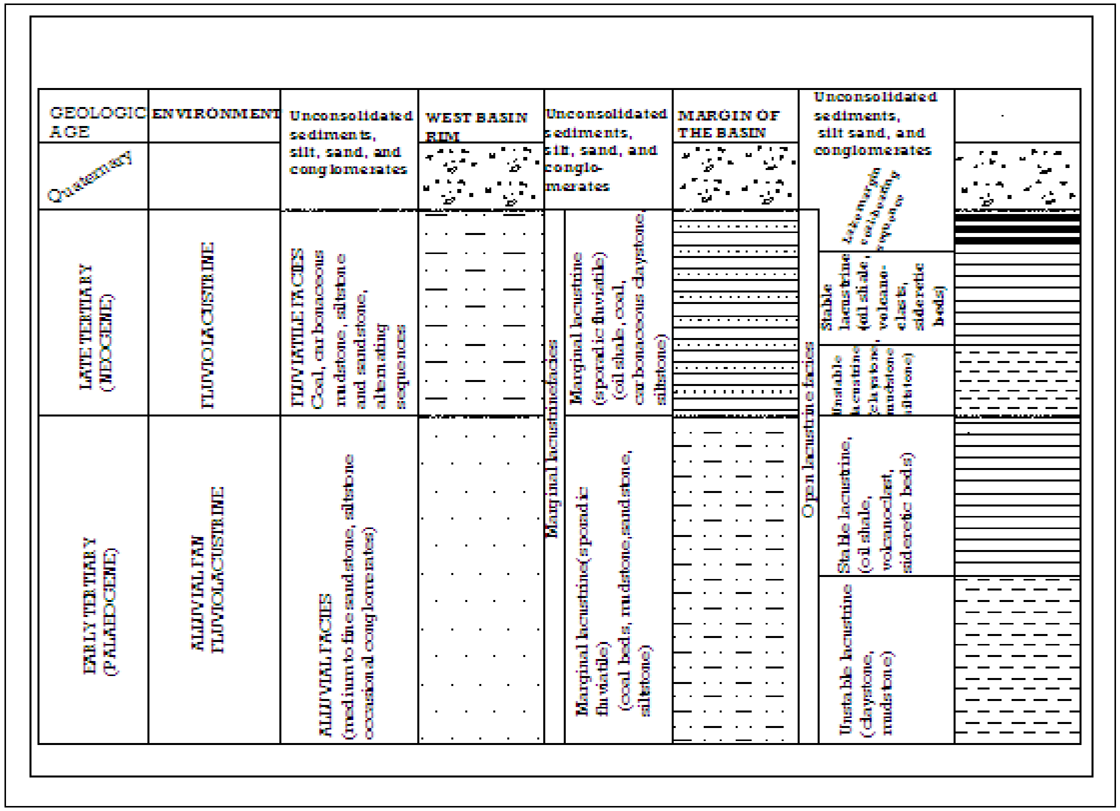


Fig. 3-9 Facies distribution and depositional environment in Dilbi-Moye Basin (after Miniye, 1992)

3.3 COAL GEOLOGY

Genetically, the coal seams of Dilbi-Moye Basin are grouped under sapropelic, humic, and mixed coal (sapropelic humic and humic sapropelic). Megascopically, the humic coal is characterized by vitrain, clarain, and minor amounts of macrolithotypes. The sapropelic coal is defined by boghead, cannel, boghead cannel, and cannel boghead lithotypes.

3.3.1 Dilbi Coals

The inter-Trappean fluvio-lacustrine coal and oil shale bearing sedimentary succession of Dilbi-Moye Basin is one of the best-studied coal and oil shale deposits in Ethiopia. The coal and oil shale bearing sediment is deposited on a basaltic substratum. The deposition took place within a large asymmetrical graben controlled by NNW-SSE direction fault system. The basin is found at altitudes between 2060-2240 meters. The sedimentary formation is characterized by two main cycles and defined by five major horizons (lower mudstone, lower oil shale, upper mudstone, upper oil shale and coal). The fluvio-lacustrine sedimentary formation is composed of mudstone, carbargillite silt, clay, sand, siltstone, sandstone, ash beds, sedritic concretion and nodules, coal (humic and sapropelic), organic shale, and pyroclastic sediment. The formation is composed of 45% by finer and 55% by coarser clasts (Wolela, 1992) and characterized by fluviatile, unstable lacustrine, stable lacustrine, and swampy facies. The sapropelic coal and the oil shale seams are concentrated at central part of Dilbi-Sub-Basin. The coal seams of Dilbi range in thickness from 0.4 to 2.4m. In the Dilbi area, the Geological Survey of Ethiopia sunk eighteen boreholes during the year of 1989-1990 within an area of 20 km^2.

3.3.2 Moye Coals

The fluvio-lacustrine coal-bearing formation of Moye deposited on a basaltic substratum, at elevation of 1500 to 2700m. Moye coal is one of the best studied coals in the country, and its detail drilling prospecting and final exploratory drilling prospecting has been carried out by the Geological Survey of Ethiopia in 1988-1990 and by Derba-East Africa Coal Mining PLC in the year 2007/2008 respectively.

The sedimentary formation is composed of, sandy breccio conglomerate, sandstone, mudstone, carbargillites, coal seams, and small amount of oil shale; and defined by 80% finer and 20% coarser clasts in volume, (Wolela, 1992). The sedimentary formation of Moye is characterized by unstable and stable lacustrine and fluviatile facies. Three humic coal-bearing cycles were registered at different levels of the sedimentary formation. The coal seams ranging in thickness (0.3 to 2.3m). The sedimentary formation as a whole show an attitude of bedding, horizontal to gentle dipping (up to 15^0), (plate 1). Eight and twenty boreholes were sunk by Geological Survey of Ethiopia and by Derba-East Africa Coal Mining PLC, 2008, respectively to evaluate the coal deposit at Moye. Genetically, the coal measures of Moye are classified under humic coal that is physically characterized by vitrain, clarain, and durain lithotypes.

The rock type associated with the Dilbi-Moye Basin coal is deposited in NNW-SSE trending graben. The basin fill consists of the lower basalt, lower sedimentary formation, middle basalt, upper sedimentary formation, upper basalt and acidic to intermediate volcanics. In a vertical section, the coal seams are distributed in the five major sedimentary facies of the sedimentary succession.

4. RESULT OF THE STUDY

Current field description and laboratory analysis results are presented in this section. In addition to this, to make the study complete and meaningful, other organization's chemical analyses results necessary for the completion of the thesis work are listed separately in this chapter.

4.1 DISTRIBUTION OF COALS OF DILBI-MOYE BASIN

The coal group is not designated differently from the previous one (Getahun et al., 1993). However, the distribution of the coal groups is extrapolated from the chemical analyses result of the Geological Survey of Ethiopia (Getahun et al., 1993, Table 4-1A and 4-2A) and the presently analyzed core coal samples (Table 4-1B and 4-2B) of Dilbi and Moye Sub-Basins. In addition, the geological cross sections of Dilbi (Fig. 3-7) and Moye (Fig. 3-8) Sub-Basins are used explicitly to define the distribution of coals of Dilbi-Moye Basin laterally.

Even though coal seams have rapid change laterally, an attempt was made to correlate between these sets. The Dilbi coals are distinguished into two (2) groups. Group one (1) is a single coal-bearing cycle designed as coal seam 1-1 encountered only in BH 2 with a thickness of 1.95m. Whereas, the occurrence of coal at Moye Sub-Basin is the three coal-bearing cycles (1^{st}, 2^{nd} and 3^{rd}) occurring in most drilled boreholes. Coal seams at Moye are well developed, more widespread, and much thicker than at Dilbi. Pinching out is also common phenomenon and splitting is rarely observed in the basin.

The coal seams in group one (1), represented in ranges from 1-1 to 1-6 at Moye Sub-Basin and as 1-1 at Dilbi BH 2 are seen to underlie thick mudstone succession.

The coal seams of group two (2), consisted of coal seams 2-1 to 2-6 at Moye area are interlaid within the middle coal-bearing unit. While at Dilbi Sub-Basin, the coal group is comprised of three coal seams 2-1 to 2-3 in BH 1 and 2 which is overlying the upper oil shale unit.

Coal group three (3) contains coal seams ranging from 3-1 to 3-4 limited to Moye Sub-Basin found within the upper coal-bearing unit.

4.2 PHYSICAL CHARACTERISTICS OF COALS OF DILBI-MOYE BASIN

In Dilbi area, of Laga Mese stream below the thick soil cover thin layer of clay is observed at the field. Below this outcrop, there is an exposed intermediate rock (andesite) overlying the shale unit. This shale unit is overlying the coal-bearing sediments.

In Moye Sub-Basin, coal seam is exposed in Yebba stream bed underlying an intermediate rock unit. There is an alternating layer of shale between the coal outcrop and an intermediate volcanic rock. Similarly, in Ramate stream 2m thick coal seam exposed at the bank of the stream course dipping up to 20^0. This coal outcrop is overlain by the mudstone unit. Its fresh colour is dark black and weathered colour is brownish.

The maximum thickness of total sediments reached up to 228m in which coal seams are situated with a maximum thickness of 2.2m. As observed in the field, the coal seams are characterized by brownish to black colour, brownish streaks, with thin shiny bands. Some of them show bedding while others are massive. Commonly, they appear to be denser, compacted to earthy appearance with conchoidal and prismatic fractures.

In the basin, weathering phenomenon occurs in the shallow parts. The weathered coal turns into grayish-brown or blackish-brown colour, loose and no luster.

Different coal outcrop photographs are taken from the basin. Plate 1, is a typical photograph taken from Moye Sub-Basin of Ramate Stream, which has a thickness of greater than 2m.

Plate 1   Coal outcrop of Ramate Stream in Moye Sub-Basin

4.3 LABORATORY ANALYSES RESULTS

4.3.1 Petrographic Description

During the field season, other than outcrop coal samples, twelve rock samples were collected from Dilbi-Moye Basin. Among the rock samples collected during the present field trip to the area, two rock samples one from acidic to intermediate and the other one is from the coal-bearing sediment were analyzed petrographically and described physically.

A volcanic rock sample collected from Laga Mese stream in Dilbi area above the sediments is described physically as dark gray in colour and medium to fine grained in texture. Petrographically, the mineral contents and their texture are identified as, plagioclase (46%) with anhedral, lath texture, pyroxene (32%) having anhedral texture, calcite (7%) with anhedral texture, olivine (5%) having texture of euhedral to anhedral and opaque or Fe-oxide (10%) have texture ranging from subhedral to anhedral. The rock name is designated as Olivine-Augite-Andesite.

The second rock sample is a carbonaceous mudstone taken from the base of a coal seam in Ramate stream of Moye Sub-Basin. In hand specimen, the rock is dark gray with brownish yellow tint, and fine grained in texture. Petrographically the rock sample has got siderite (37%) with sub-angular texture, clay (58%) having very fine texture, plagioclase (trace) with sub-angular texture, quartz (3%) of angular texture and opaque or Fe-oxide (2%) have angular texture. The rock name is designated as siderite mudstone (clay ironstone).

4.3.2 Chemical Analysis of the Coals

During this study, six (6) core coal samples and three (3) outcrop samples of Dilbi-Moye Basin are analyzed chemically to fill the data gap observed in the previously analyzed core coal samples by the Geological Survey of Ethiopia, to carryout the thesis work.

The chemical analysis results of seven boreholes: 1, 2, 6 and 11 (from Dilbi), 19, 18 and 21 (from Moye) carried out by the Geological Survey of Ethiopia, (Getahun et al., 1993) and the present analysis results of the author are going to be used in the coming chapters.

4.3.2.1 Proximate Analysis

Tables 4-1A to 4-2B, present some results of proximate analysis, calorific value, sulfur content and density of Dilbi-Moye Basin. Tables 4-1B of Dilbi and 4-2B of Moye are core and surfacial coal samples results recently analyzed by the author. In the Tables 4-1B and 4-2B, which is analyzed currently, the proximate analysis and sulfur content is given for the samples collected from surface and subsurface in the two sub-basins, as checking samples for the current research work.

The chemical analyses results of Dilbi Sub-Basin (Table 4-1A) and of Moye Sub-Basin (Table 4-2A), are obtained from the Geological Survey of Ethiopia (Getahun et al., 1993).

The chemical characteristics of the coals from Dilbi Sub-Basin on as received basis, show values ranging from 1.9 to 6.3% moisture, 19.3 to 37.9% volatile matter, 15.3 to 46.8% fixed carbon, 0.04 to 0.3% of very low sulfur, 13.1 to 59.4% ash content and 2,597.4 to 7,752 heating values in Btu/lb (Table 4-1A and 4-1B).

Results of chemical analyses of Dilbi coals indicate that fixed carbon contents ranging between 21.2% and 65.97% (d.m.m.f), and calorific values in the range of 4,322 Btu/lb to 13,054 Btu/lb (m.m.m.f).

On the other hand, the Moye coals on as received basis, have values of moisture content between 1.2 and 3.3%, fixed carbon between 20 and 60.2%, volatile matter between 11.5 and 26.7%, ash content between 16.9 and 60.6% and calorific value between 4,275 and 12,420 Btu/lb (Table 4-2A and 4-2B).

Chemical analyses results of Moye coals show that fixed carbon varies between 55.80 to 81.90% (d.m.m.f) and calorific values range from 11,937 to 15,625.60 Btu/lb on moist mineral matter free basis (m.m.m.f). The majority of Moye coals are average ash coals (16.9 to 48.9%).

Both fixed carbon and calorific value of the coals are higher at Moye area than Dilbi Sub-Basin. This difference might be emerged from the tectonic activity acted on the basin.

Generally, the Dilbi-Moye coals are of low sulfur coals; having sulfur values commonly <1%.

High volatile matter content of the coals may be account for the low rank of the coals (Van Krevalen, 1961), and has a relation with the yield of tar and gas when the coal is heated in the absence of oxygen.

Table 4-1A Representative proximate, calorific value, total sulfur and density analyses results of Dilbi coals (after Getahun et al., 1993)

On as received basis												d.m.m.f		m.m.m.f	Coal rank & coking Property	
Borehole & sample no.	'Coal group' & seam no.	Thickness of coal seam (m)	Depth (m)	Proximate analyses												
				M (%)	V.M (%)	A (%)	F.C (%)	C.V (Kcal/Kg)	C.V (btu/lb)	S (%)	Density gm/cm^3	F.C (%)	V.M (%)	C.V (btu/lb)	Rank	Coking property
1-4	2-2	2.4	92.45	2.8	36.5	13.1	41.73	1917	3450.6	0.3	1.32	57.26	42.74	6172.18	lig B	Non agglomerating
1-9	2-1	1.2	106.9	3.6	37.9	37	26.1	1443	2597.4	0.1	1.32	46.26	53.74	4322	lig B	"
2-1	2-2	1.35	51.85	4	26.3	47.1	22.7	3113	5060.3	0.1	1.32	50.32	49.68	11407	sub A	"
2-2	2-1	2	59.7	6.3	28.6	38	27.6	4221	7597.8	0.2	1.32	53.02	46.98	13054	hvBb	Commonly agglomerating
2-91	1-1	1.95	20.4	1.9	32.2	31.7	34.3	1697	3054.6	0.1	1.32	53.43	46.22	4641	lig B	Non agglomerating
6-2	2-3	0.5	168.2	4.8	26.8	22.4	46.8	4307	7752	0.2	1.32	65.97	34.03	10227.48	sub B	"
6-3	2-2	1.1	1751	2.9	21.8	54.6	15.8	1689	3040.2	0.1	1.32	41.46	58.54	7407	lig A	"
11-8	2-1	1.05	1347	6	19.3	59.4	15.5	2020	3636	2.4	1.32	21.2	78.79	10151	sub B	"

Abbreviations:

M: moisture content; V.M: volatile matter content; A: ash content; F.C.: fixed carbon content; C.V.: calorific value; S.: sulfur content; lig A: lignite A; lig B: lignite B; sub A: sub-bituminous A coal; Sub B: sub-bituminous B coal; hvBb: high volatile B bituminous coal; d.m.m.f.: dry mineral matter free; m.m.m.f.: moist mineral matter free.

Table 4-1B Representative proximate, calorific value, total sulfur and density analyses results of Dilbi coals

On as received basis												d.m.m.f		m.m.m.f	Coal rank & coking Property	
Borehole & sample no.	'Coal Group' & Seam No.	Thickness of coal seam (m)	Depth (m)	Proximate analyses												
				M (%)	V.M (%)	A (%)	F.C (%)	C.V (Kcal/Kg)	C.V (btu/lb)	S (%)	Density gm/cm^3	F.C (%)	V.M (%)	C.V (btu/lb)	Rank	Coking property
6-D-5	2-1	0.47	180	2.01	26.17	51.49	20.32	2908.69	5235.6	0.02	1.61	47.95	52.05	11,794.95	hvCb	Commonly agglomerating
11-D-6	2-3	0.4	12.25	2.68	25.73	56.28	15.3	2006.1	3611	0.02	1.8	41.88	58.12	9,207.54	sub C	Non agglomerating
D-4	Surfacial	Laga Mese stream		7.62	26.16	45.5	20.71	2917.79	5252	0.04	1.82	47.91	52.09	10,326.92	sub B	Non agglomerating

Abbreviations:

M: moisture content; V.M: volatile matter content; A: ash content; F.C.: fixed carbon content; C.V.: calorific value; S.: sulfur content; Sub B: sub-bituminous B coal; Sub C: sub-bituminous C coal; hvCb: high volatile C bituminous coal; d.m.m.f.: dry mineral matter free; m.m.m.f.: moist mineral matter free.

Table 4-2A Representative proximate, calorific value, total sulfur and density analyses results of Moye coals (after Getahun et al., 1993)

On as received													d.m.m.f		m.m.m.f	Coal rank& coking Property	
Borehole & sample no.	'Coal group' & seam no.	Thickness of coal seam (m)	Depth (m)	Proximate analyses				C.V (Kcal/Kg)	C.V (btu/lb)	S (%)	Density gm/cm^3		F.C (%)	V.M (%)	C.V (btu/lb)	Rank	Coking property
				M (%)	V.M (%)	A (%)	F.C (%)										
18-4	2-5	1.75	60	1.5	21.9	35.6	42.4	5222	9399.6	0.9	1.32		70.99	29.03	15321.1	mvb	Commonly agglomerating
18-6	2-4	1.85	71.4	1.5	26.7	16.9	56.9	6900	12420	2.1	1.32		71.8	28.46	15280	mvb	"
18-7	2-3	2.05	72.5	2	17.8	56.1	26.2	3000	5400	1.4	1.32		67.26	32.71	13,793.33	hvBb	"
18-10	2-1	0.65	83	1.5	22.2	28.5	49.3	5730	10314	1.3	1.32		73.08	26.92	14,961	mvb	"
19-5	3-2	1.1	40	2.7	26.3	35.6	38.2	5040	9072	0.4	1.32		65.05	34.95	14,789	hvAb	"
19-10	2-6	1.05	82	3	24.9	42	33.2	4343	98174	0.3	1.32		64.4	35.69	14,322.90	hvAb	"
19-12	2-4	1.1	102	3.2	20	52.8	24.5	5780	10404	0.4	1.32		66.54	38.82	14,726.57	hvAb	"
19-13	2-2	0.7	105	2.4	21.1	48.9	29	3652	6573.6	0.4	1.32		69.67	33.46	14,570	hvAb	"
19-16	1-3	0.75	165	2.1	17.7	57.8	25	3110	5598	0.03	1.32		81.9	12.1	11937	lvb	"
19-20	1-1	0.75	190	3.3	11.5	52.9	32.4	2850	5130	0.03	1.32		81.9	12.1	11937	lvb	"
21-12	2-4	0.85	67.35	2.9	16	60.6	20.5	2375	4275	0.2	1.32		64.7	35.3	12,349.61	hvCb	"
21-13	2-3	0.5	69.1	3	20.4	56.6	20	2705	4869	0.4	1.32		55.8	44.02	12,545	hvCb	"
21-20	1-5	1.2	141.1	1.2	21.5	18.3	60.2	6900	12420	1.3	1.32		77	23	15,537	mvb	Commonly agglomerating
21-21	1-3	1.1	149.18	1.5	21.4	24.4	54.2	6276	11297	1.3	1.32		75.6	24.4	15,400	mvb	"
21-23	1-2	0.6	162.18	1.3	20.7	20.5	58.8	6743	12137	0.8	1.32		77.09	22.9	15,625.60	mvb	"

Abbreviations:

M: moisture content; V.M: volatile matter content; A: ash content; F.C.: fixed carbon content; C.V.: calorific value; S.: sulfur content; lvb: low volatile bituminous coal; mvb: medium volatile bituminous coal; hvAb: high volatile A bituminous coal; hvBb: high volatile B bituminous coal; hvCb: high volatile C bituminous coal; d.m.m.f.: dry mineral matter free; m.m.m.f.: moist mineral matter free.

Table 4-2B Representative proximate, calorific value, total sulfur and density analyses results of Moye coals

On as received basis												d.m.m.f		m.m.m.f	Coal rank& coking Property	
Borehole & Sample no.	'Coal group' & seam no.	Thickness of coal seam (m)	Depth (m)	Proximate analyses				C.V (Kcal/Kg)	C.V (btu/lb)	S (%)	Density gm/cm^3	F.C (%)	V.M (%)	C.V (btu/lb)	Rank	Coking property
				M (%)	V.M (%)	A (%)	F.C (%)									
19-M-5	2-3	0.2	85	1.71	11.48	86.75	0.05	<24	<43.2	0.01	1.5					
21-M-6	1-1	0.4	163	2.86	14.6	76.51	6.07	<24	<43.2	0.02	1.75					
21-M-7	2-1	2	73	1.7	19.15	77.25	1.9	<24	<43.2	0.01	2.24					
21-M-8	3-1	1.2	9	1.52	19.26	55.7	23.52	3028.41	5451.1	0.02	1.93	61.38	38.62	13,682.37	hvBb	Commonly agglomerating
M-1	Surfacial	Yeba stream		1.61	16.05	78.35	3.99	<24	<43.2	<0.01	1.93					
M-3	Surfacial	Ramate stream		2.97	28.54	20.01	48.47	6018.64	10834	0.04	1.49	64.28	35.72	13,822.14	hvBb	Commonly agglomerating

Abbreviations:

M: moisture content; V.M: volatile matter content; A: ash content; F.C.: fixed carbon content; C.V.: calorific value; S.: sulfur content; hvBb: high volatile B bituminous coal; d.m.m.f.: dry mineral matter free; m.m.m.f.: moist mineral matter free.

4.3.2.2 Coal Rank

In accordance with ASTM, 1989 scheme of classification, the coals of Dilbi Sub-Basin are classified as lignite B to high volatile B bituminous coal and the coals of Moye Sub-Basin are classified as high volatile C bituminous coals to low volatile bituminous coals. Calorific values are related to maceral composition and properties. They are greatest for liptinitic maceral bearing sapropelic coals than vitrinite and inertinite bearing macerals (Miniye, 1992).

Results of proximate analysis of Dilbi coals indicate fixed carbon contents ranging between 21.2% and 65.97% (d.m.m.f) and calorific values in the range of 4,322 Btu/lb and 13054 Btu/lb suggesting lignite B to high volatile B bituminous coal rank. Most of the coals of Dilbi Sub-Basin are of sub-bituminous type having little or no coking capacity.

Proximate analysis results of Moye coals (Table 4-2A and 4-2B) show the fixed carbon values between 55.80% to 81.90% (d.m.m.f) and calorific values range from 11,937 Btu/lb to 15,625.60 Btu/lb on moist mineral matter free basis (m.m.m.f).

The rank determination of the Dilbi coals, hence, may be considered to range from lignite B to high volatile B bituminous coals. The majority of the coal seams in this area exhibit lower ranks relative to Moye Sub-Basin coals.

The rank determination of the Moye Sub-Basin coals range from high volatile C bituminous coal to low volatile bituminous coal. The majority of the coal seams in the area exhibit higher ranks due to the proximity of volcanic extrusion and the supper incumbent volcanics. The ranks of the coals in the basin are generally considered to be controlled largely by the level of temperature under confining pressure reached by the organic matter, and partly by the time within which these effects were maintained.

4.3.2.3 Interrelation of the Chemical Characteristics of the Coals within the Dilbi-Moye Basin

From the study, different types of diagrams and analyses are used to evaluate, compare, and establish the interrelationships of proximate and heating value data. The interrelationship is analyzed by using scatter plots with regression lines of paired proximate variables and calorific value results from the analyzed coal samples results shown on tables 5-1 to 5-6. These results are computed on figures 5-1A, 5-2A, 5-3A, 5-4A, 5-5A and 5-6A. The scatter plot is used to compute the interrelation of the chemical characteristics of the coals within the basin.

The very low negative correlation in Fig. 5-1A, within the Dilbi-Moye Basin illustrates more or less the inverse relationship of ash with calorific value that is as the ash content increases, the rank (heating value) of the coal slightly decreases. The high positive correlation in Fig. 5-2A, within the basin shows that the fixed carbon also varies directly with calorific value of the coals. The very high negative correlation in Fig. 5-3A, within the Dilbi-Moye Basin illustrates that the inverse relationship of volatile matter with calorific value, that is as the volatile matter increases the heating value of the coals decreases. However, the low negative correlation in Fig. 5-4A, within the basin shows that the inverse relationships of ash and fixed carbon contents in a given rank, that is coals with high ash content tend to have low fixed carbon content. The low positive correlation in Fig. 5-5A, within the Dilbi-Moye Basin shows that the ash content varies directly with volatile matter content of the coals. The trend displayed by the low negative correlation in Fig. 5-6A, illustrates that the higher moisture content tend to have lower calorific value.

From these analyses, two significant factors can be distinguished. The first factor is explained by fixed carbon, heating value, and ash. It shows that, coals with high fixed carbon have accompanying high heating value and relatively low ash and vice versa. The second factor is explained by volatile matter and ash, and shows that coals with high volatile matter are accompanied by low ash.

4.3.2.4 Spatial Variation of the Chemical Characteristics of the Coals across the Dilbi-Moye Basin

The spatial variation is computed across the Dilbi-Moye Basin from northeast to southwest by using the clustered column diagrams, keeping the borehole-coal seam constant. The analyzed coal samples results shown on tables 5-1 to 5-6 are computed on figures 5-1B, 5-2B, 5-3B, 5-4B, 5-5B and 5-6B for spatial variation.

Keeping the borehole-coal seams of Dilbi-Moye Basin from northeast to southwest (1-2-2 to 21-1-2) constant, the ash content across the Dilbi-Moye Basin in relation to the calorific value (Fig. 5-1B) has both inverse and direct relationship, which shows the inconsistency of both type of organic matter and inclusion of inorganic materials. The correlation in Fig. 5-2B, illustrates the direct relationship of calorific value with fixed carbon content. This means, as the calorific value of the coal increases, so does the fixed carbon content from northeast to southwest of the basin. The correlation of heating value with volatile matter content in Fig. 5-3B shows no definite pattern of relationship. However, the correlation shown in Fig. 5-4B illustrates the inverse relationships of ash and fixed carbon contents that are coals with higher fixed carbon content (higher rank) tend to have lower ash content across the basin. The trend displayed in Fig. 5-5B also is that the coals with higher volatile matter contents are found at Dilbi than at Moye Sub-Basin. From the graph of moisture content and calorific value (Fig. 5-6B), one can understand that for low moisture content there is high calorific value across the basin from northeast to southwest.

5. THERMAL CHARACTERISTICS OF DILBI-MOYE COALS

The energy value of coal, or the fuel content, is the amount of potential energy in coal that can be converted into actual heating ability. The value can be calculated and compared with different grades of coal. Coal of different grades will produce differing heat values.

To carryout the vertical and lateral thermal variations analyses of the coals in Dilbi-Moye Basin, boreholes BH 1, BH 2, BH 6, and BH 11 from Dilbi and boreholes BH 18, BH 19 and BH 21 from Moye Sub-Basins were selected to show the possible thermal variations of the coals in the basin.

5.1 VERTICAL THERMAL VARIATIONS

To analyze the vertical thermal variations of each well, it is necessary to know the vertical thermal difference of each borehole. Therefore, using the necessary drilled borehole's data is the most crucial condition, to analyze the thermal variations of each borehole from bottom to top or vice versa.

In Dilbi Sub-Basin, comparing the ash and calorific value (Table 5-1 and Fig. 5-1B) vs borehole-coal seam for BH 1 shows the inverse proportion of ash and calorific value; as calorific value increases, the ash content decreases. The analysis of depth (coal seam) vs calorific value for BH 1, shows that the calorific value increases upwards. Even though, the calorific value shows an increment from bottom to top, the rank of the two samples of the well falls in the range of lignite B and is non-agglomerating (Table 4-1A).

From the three samples analyzed, the ash and calorific value (Table 5-1 and Fig. 5-1B) vs borehole-coal seam for BH 2 is different from BH 1. The ash content of BH 2 increases from bottom to top. However, the calorific value for two samples from bottom to top increases as ash content increases and decreases for the other sample at the top. In other words, the analysis of depth (borehole-coal seam) vs calorific value for BH 2 shows the increment of calorific value for two samples (coal seam 1-1 and 2-2) from bottom to top. However, comparing the calorific value of 2-1 and 2-2, the calorific value for coal seam 2-2 is relatively decreases upwards. The rank vs calorific value for BH 2 increases from lignite B to high volatile B bituminous coal then decreases to sub-bituminous A coal as the calorific value of the coal changes (Table 4-1A). In other words from non-agglomerating to commonly agglomerating then decreased to non-agglomerating.

The ash and calorific value vs borehole-coal seam (Table 5-1 and Fig. 5-1B) for BH 6 shows that the calorific value decreases from bottom, coal seam 2-1 to 2-2 and then increases from coal seam 2-2 to 2-3 top for the three analyzed samples. Whereas, the ash content increases for the first two samples and then decreases for the third sample drastically. The rank vs calorific value for BH 6 decreases from high volatile C bituminous coal to lignite A then shows slight increase from lignite A to sub-bituminous B coal (Table 4-1A & B); from commonly agglomerating to non-agglomerating coking property from bottom to top (coal seam 2-1 to 2-3).

The ash and calorific value vs borehole-coal seam (Table 5-1 and Fig. 5-1B) for BH 11 shows the direct proportion of ash and calorific value; as calorific value decreases, the ash content also decreases from bottom to top, from coal seam 2-1 to 2-3. The rank vs calorific value of this well shows that as the calorific value decreases upward, the rank of the coal also decreases from sub-bituminous B coal to sub-bituminous C coal (Table 4-1A & B). However, the coking property for both coal seams is non-agglomerating.

In the Moye Sub-Basin of BH 19, comparing the ash and calorific value vs borehole-coal seam (Table 5-1 and Fig. 5-1B) shows more or less the increment of calorific value from bottom to top with variable ash content. The ash content is relatively decreasing for the top two seams. There is no direct or inverse relationship between calorific value and ash content of the coal samples. The rank vs calorific value is evaluated as that the calorific value increases upwards; the ranks of the coal seams decrease from low volatile bituminous (for the two bottom coal seams) to high volatile A bituminous coal for the rest of the analyzed coal seams (Table 4-2A). However, the coking property of the whole analyzed coal seams is the same; commonly agglomerating.

The ash and calorific value vs borehole-coal seam of BH 18 (Table 5-1 and Fig. 5-1B) shows more or less the increment of calorific value from bottom to top; but the ash content varies. Particularly, at coal seam 2-3, as the ash content increases and the calorific value decreases. There is no direct or inverse relationship between calorific value and ash content of the coal samples. The rank vs calorific value indicates that as the calorific value shows a slight decrease from 14,961 Btu/lb to 13,793.33 Btu/lb the rank of the coal also decreases from medium volatile bituminous coal to high volatile B bituminous coal (Table 4-2A). Upward in borehole, the rank of the coal again decreased to medium volatile bituminous coal. However, the coking property of all coal seams remains the same: commonly agglomerating.

The ash and calorific value vs borehole-coal seam (Table 5-1 and Fig. 5-1B) for BH 21 shows the increment of ash content and decreasing of the calorific value from bottom to top of the borehole. The rank vs calorific value of BH 21 shows that for the three lower coal seams with higher calorific values, the rank is medium volatile bituminous coal and for the middle two coal seams, the rank is decreased to high volatile C bituminous coal (Table 4-2A). Then, since the calorific value shows a slight increment at the upper coal seam (coal seam 3-1), the rank of the coal increases from high volatile C bituminous coal to high volatile B bituminous coal (Table 4-2A & B). However, all samples analyzed in BH 21 have the same coking property; commonly agglomerating.

5.2 LATERAL THERMAL VARIATIONS

The analyses results of the seven selected boreholes are used by correlating the equivalent coal seams occurring in similar or correlate-able coal-bearing sediments across the Dilbi-Moye Basin. This means coal seam 1-1 at Moye correlated with coal seam 1-1 at Dilbi; coal seam 1-3 of boreholes 19 and 21 at Moye correlated with each other; since there are no equivalent coal seams at Dilbi area. However, coal seams 2-1, 2-2 and 2-3 (Table 5-1 and Fig. 5-1B) of Moye are correlated with similar coal seams of Dilbi Sub-Basin and coal seam 2-4 is correlated among boreholes 19, 18, and 21 of Moye Sub-Basin, so that there is no similar coal seam at Dilbi Sub-Basin. However, coal seam 2-5 of borehole 18 and 2-6 of borehole 19 of Moye Sub-Basin were compared side by side in the area; since there is no another analyzed coal sample at Moye Sub-Basin, among the selected boreholes and no correlate-able coal seam occurrence at Dilbi Sub-Basin. In addition to these, coal seams 3-1 and 3-2 of boreholes 21 and 19 of upper coal-bearing unit of the Moye area were compared side by side to one another within the sub-basin respectively; since there is no analyzed coal sample among the boreholes selected for this evaluation and equivalent coal seams occurrence at Dilbi area.

Keeping the borehole-coal seam constant across the basin from northeast to southwest, the ash vs calorific value (Table 5-1 and Fig. 5-1B) of coal seam 1-1 in borehole 2 of Dilbi (31.7%) and borehole 19 of Moye (52.9%) show that there is low ash content coal at Dilbi than of Moye Sub-Basin. However, the calorific value of Moye coals (11,937 Btu/lb) is very high by far than the calorific values of coals at Dilbi area (4,641 Btu/lb). Comparing the coal seam 1-3 (Table 5-1 and Fig. 5-1B) of boreholes 19 and 21 of Moye area within the Sub-Basin itself, from northeast to southwest (BH 19 to BH 21) direction, the ash content decreases drastically from 57.8% to 24.4% and the calorific value increases from 11,937 Btu/lb to 15,400 Btu/lb in the same manner. This means, as the calorific value increases, the ash content decreases from northeast towards the southwest in case of this particular Coal seam.

In Dilbi Sub-Basin, coal group two (2) which is deposited between the upper oil shale unit and middle basalt and interlaid in the coal-bearing unit correlates with similar coal group of Moye Sub-Basin, which is deposited within the middle coal-bearing unit.

The ash content of coal seam 2-1 (Table 5-1 and Fig. 5-1B) of Dilbi Sub-Basin, from SE to NW direction increases from 37.0% BH 1 to 59.4% BH 11 and calorific value increases from 4,322.00 Btu/lb BH 1 to 13,054.00 Btu/lb BH 2 drastically. And then, dropped to 10,151.00 Btu/lb at BH 11 of which the ash content in BH 11 is relatively seen to be very high (59.4%). But at Moye Sub-Basin, of BH 18 the ash content decreases significantly (28.5%) and calorific value is found to be 14,961.00 Btu/lb.

The ash content of coal seam 2-2 (Table 5-1 and Fig. 5-1B) from SE to NW direction, in Dilbi Sub-Basin increases from 13.10 to 54.6%. At Moye Sub-Basin of BH 19 (from NE to SW) from Dilbi, the ash content shows a decreasing value (48.9%); whereas the calorific value increases from 6,172.18 Btu/lb at Dilbi BH 1 to 11,407.00 Btu/lb, then dropped to 7,407 Btu/lb at BH 6. Finally, the maximum value (14,570.00 Btu/lb) is attained for this coal seam at BH 19 of Moye Sub-Basin.

The ash content of coal seam 2-3 (Table 5-1 and Fig. 5-1B) at BH 6 of Dilbi Sub-Basin is very low (22.4%) and increases to 56.60 at BH 21. The calorific value of coal seam 2-3 increases from 10,227.48 to 13,793.33 Btu/lb and 12,545.00 Btu/lb in the same manner.

The ash content of coal seam 2-4 (Table 5-1 and Fig. 5-1B) decreases from 52.8 (BH 19) to 16.90% (BH 18) and suddenly increases to 60.6% at BH 21; whereas the calorific value increases from 14,726.57 to 15,280.00 Btu/lb and decreases to 12,349.61 Btu/lb from northeast to southwest direction in Moye Sub-Basin respectively.

In Moye Sub-Basin of BH 19 (coal seam 2-6) and BH 18 (coal seam 2-5) (Table 5-1 and Fig. 5-1B) are analyzed to yield ash contents 42.0 and 35.6%; though they are not in the same coal seam number. Their calorific value increases from 14,322.90 (coal 2-6) to 15,321.10 Btu/lb (coal seam 2-5).

In the same manner, even though, they are not in the same coal seam in Moye Sub-Basin of BH 19 (coal seam 3-2) and BH 21 (coal seam 3-1) (Table 5-1 and Fig. 5-1B) are analyzed to yield an increase in ash contents from 35.6 (coal seam 3-2) to 55.7% (coal seam 3-1). Though they are not correlate-able laterally, simply to see the trend side by side, their calorific value decreases from 14,789 (coal seam 3-2) to 13,682.37 Btu/lb (coal seam 3-1).

Generally, from (Table 5-1 and Fig. 5-1B), the calorific value increases from Dilbi Sub-Basin to Moye Sub-Basin (NE to SW direction). On the contrary, concerning the ash content of the coals, maximum ash percentage is recorded at Moye Sub-Basin, BH 21 of coal seam 2-4 (60.6%) and Dilbi Sub-Basin, BH 11 of coal seam 2-1 (59.4%). However, the lowest ash content is at Dilbi Sub-Basin, BH 1 of coal seam 2-2 (13%) and Moye Sub-Basin, BH 18 of coal seam 2-4 (16.9%). Conclusively, the ash content increases from Dilbi area to Moye Sub-Basin except the very low records of ash content at BH 18 of coal seam 2-4 and the lower coal seams (coal group one) of BH 21 at the SW extreme of the basin.

Table 5-1 Ash content and calorific value of Dilbi-Moye Basin

Dilbi (BH: 1, 2, 11, 6) and Moye (BH: 19, 18, 21)

Borehole no.	Depth (m)	Borehole-coal seam no.	Ash content (%)	Calorific value (Btu/lb)	
1	92.45	1-2-2	13.1	6172.18	Dilbi Sub-Basin
1	106.9	1-2-1	37	4322	
2	51.85	2-2-2	47.1	11407	
2	59.7	2-2-1	38	13054	
2	220.4	2-1-1	31.7	4641	
6	168.2	6-2-3	22.4	10227.48	
6	175.1	6-2-2	54.6	7407	
6	180	6-2-1	51.49	11794.95	
11	12.25	11-2-3	56.28	9207.54	
11	13.47	11-2-1	59.4	10151	
19	40	19-3-2	35.6	14789	Moye Sub-Basin
19	82	19-2-6	42	14322.9	
19	102	19-2-4	52.8	14726.57	
19	105	19-2-2	48.9	14570	
19	165	19-1-3	57.8	11937	
19	190	19-1-1	52.9	11937	
18	60	18-2-5	35.6	15321.1	
18	71.4	18-2-4	16.9	15280	
18	72.5	18-2-3	56.1	13793.33	
18	83	18-2-1	28.5	14961	
21	9	21-3-1	55.7	13682.37	
21	67.35	21-2-4	60.6	12349.61	
21	69.1	21-2-3	56.6	12545	
21	141.1	21-1-5	18.3	15537	
21	149.18	21-1-3	24.4	15400	
21	162.18	21-1-2	20.5	15625.6	

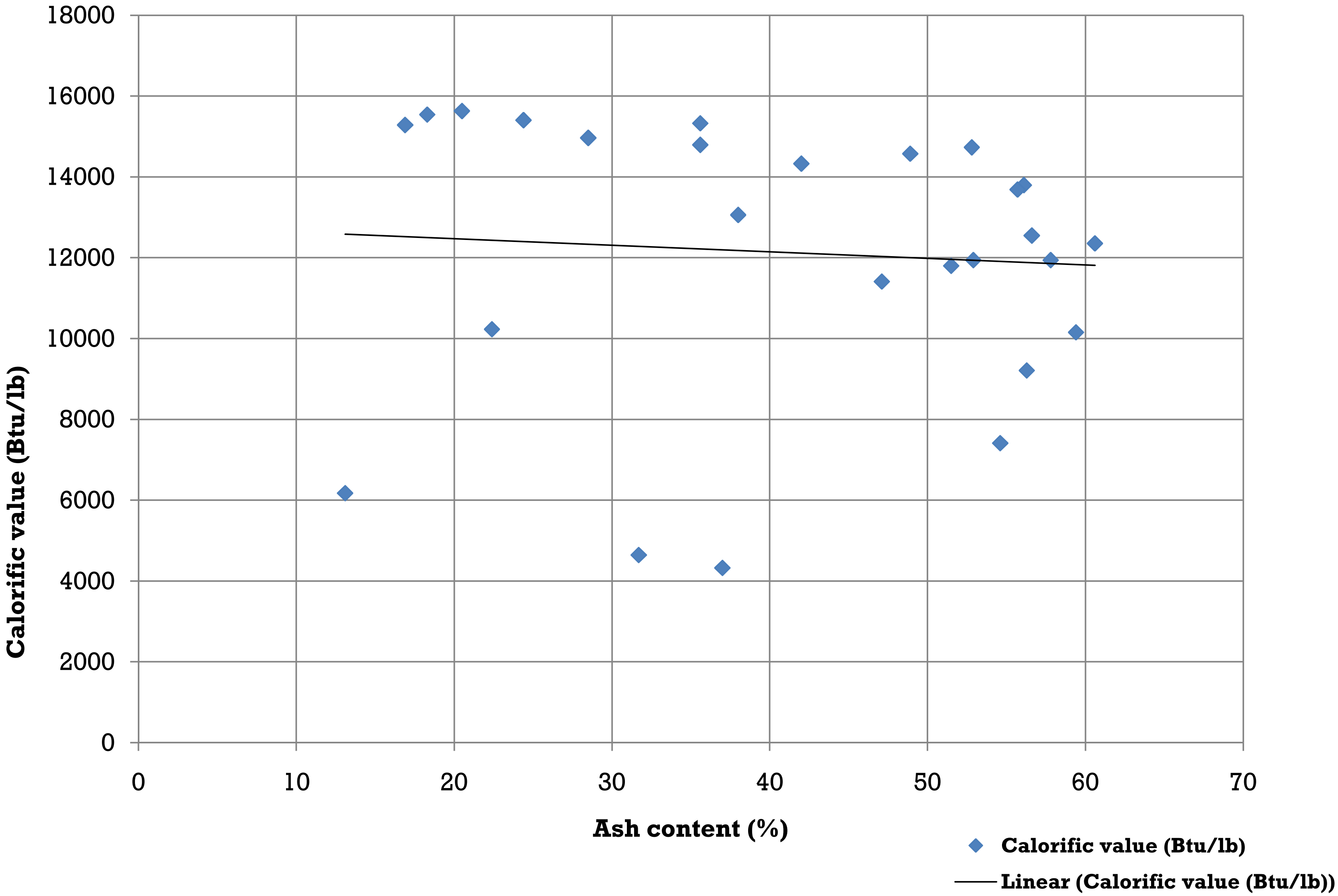


Fig. 5-1A Interrelation of ash content vs calorific value within the basin

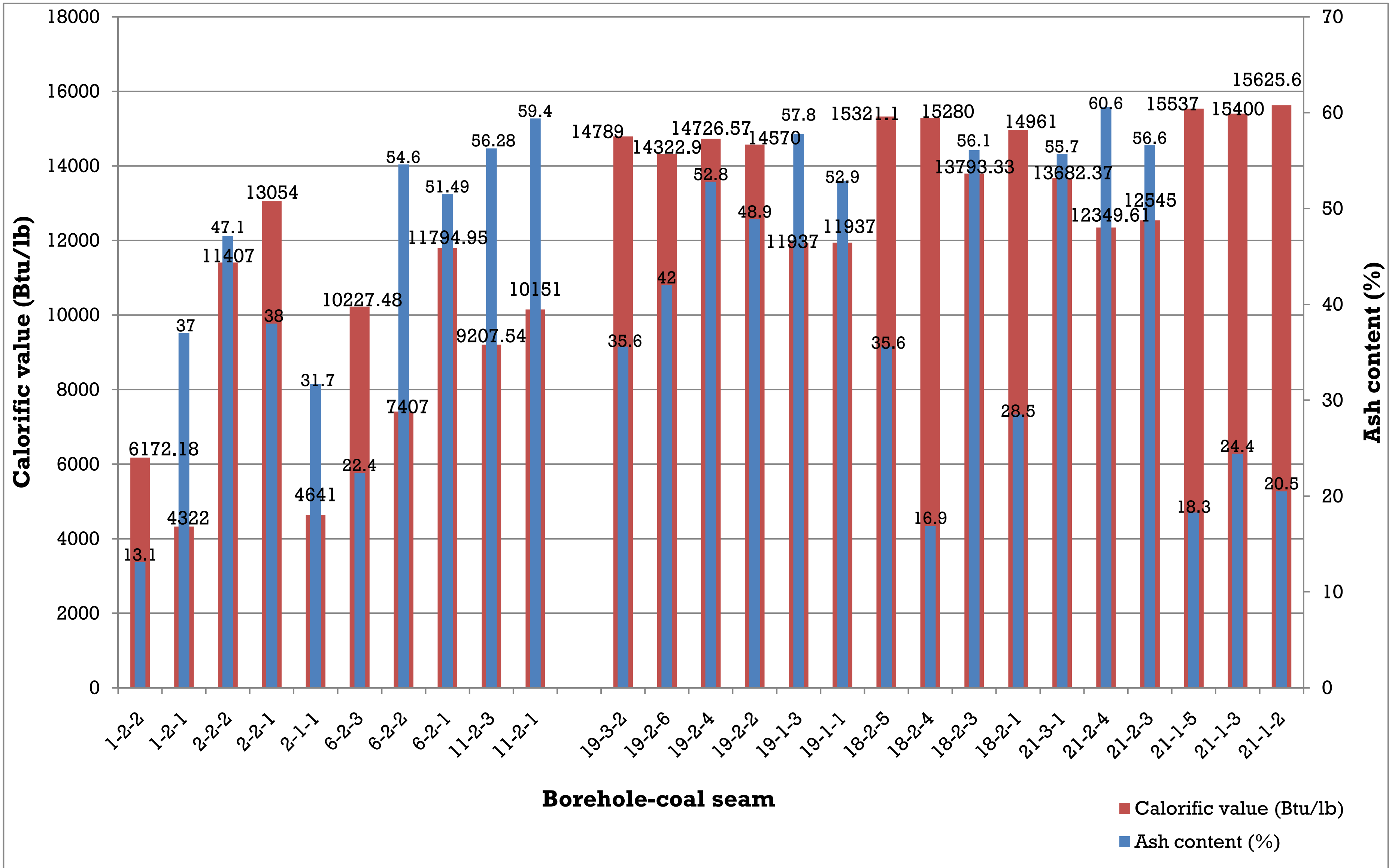


Fig. 5-1B Borehole-coal seam vs ash content and calorific value across the basin (from NE to SW)

Table 5-2 Fixed carbon content and calorific value of Dilbi-Moye Basin

Dilbi (BH: 1, 2, 11, 6) and Moye (BH: 19, 18, 21)

Borehole no.	Depth (m)	Borehole-coal seam no.	Fixed Carbon Content (%)	Calorific value (Btu/lb)	
1	92.45	1-2-2	57.26	6172.18	Dilbi Sub-Basin
1	106.9	1-2-1	46.26	4322	
2	51.85	2-2-2	50.32	11407	
2	59.7	2-2-1	53.02	13054	
2	220.4	2-1-1	53.43	4641	
6	168.2	6-2-3	65.97	10227.48	
6	175.1	6-2-2	41.46	7407	
6	180	6-2-1	47.95	11794.95	
11	12.25	11-2-3	41.88	9207.54	
11	13.47	11-2-1	21.2	10151	
19	40	19-3-2	65.05	14789	Moye Sub-Basin
19	82	19-2-6	64.4	14322.9	
19	102	19-2-4	66.54	14726.57	
19	105	19-2-2	69.67	14570	
19	165	19-1-3	81.9	11937	
19	190	19-1-1	81.9	11937	
18	60	18-2-5	70.99	15321.1	
18	71.4	18-2-4	71.8	15280	
18	72.5	18-2-3	67.26	13793.33	
18	83	18-2-1	73.08	14961	
21	9	21-3-1	61.38	13682.37	
21	67.35	21-2-4	64.7	12349.61	
21	69.1	21-2-3	55.8	12545	
21	141.1	21-1-5	77	15537	
21	149.18	21-1-3	75.6	15400	
21	162.18	21-1-2	77.09	15625.6	

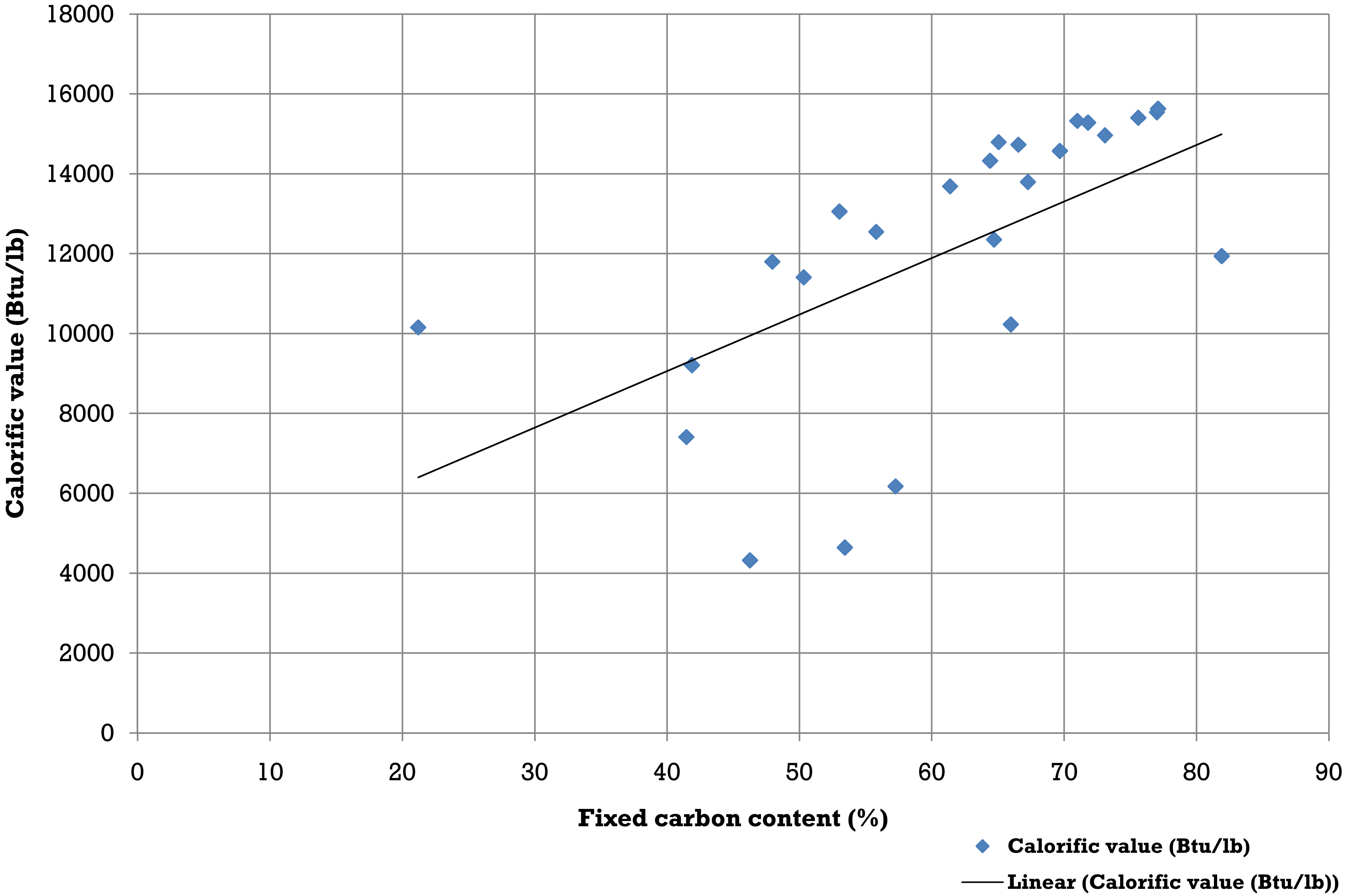


Fig. 5-2A Interrelation of fixed carbon content vs calorific value within the basin

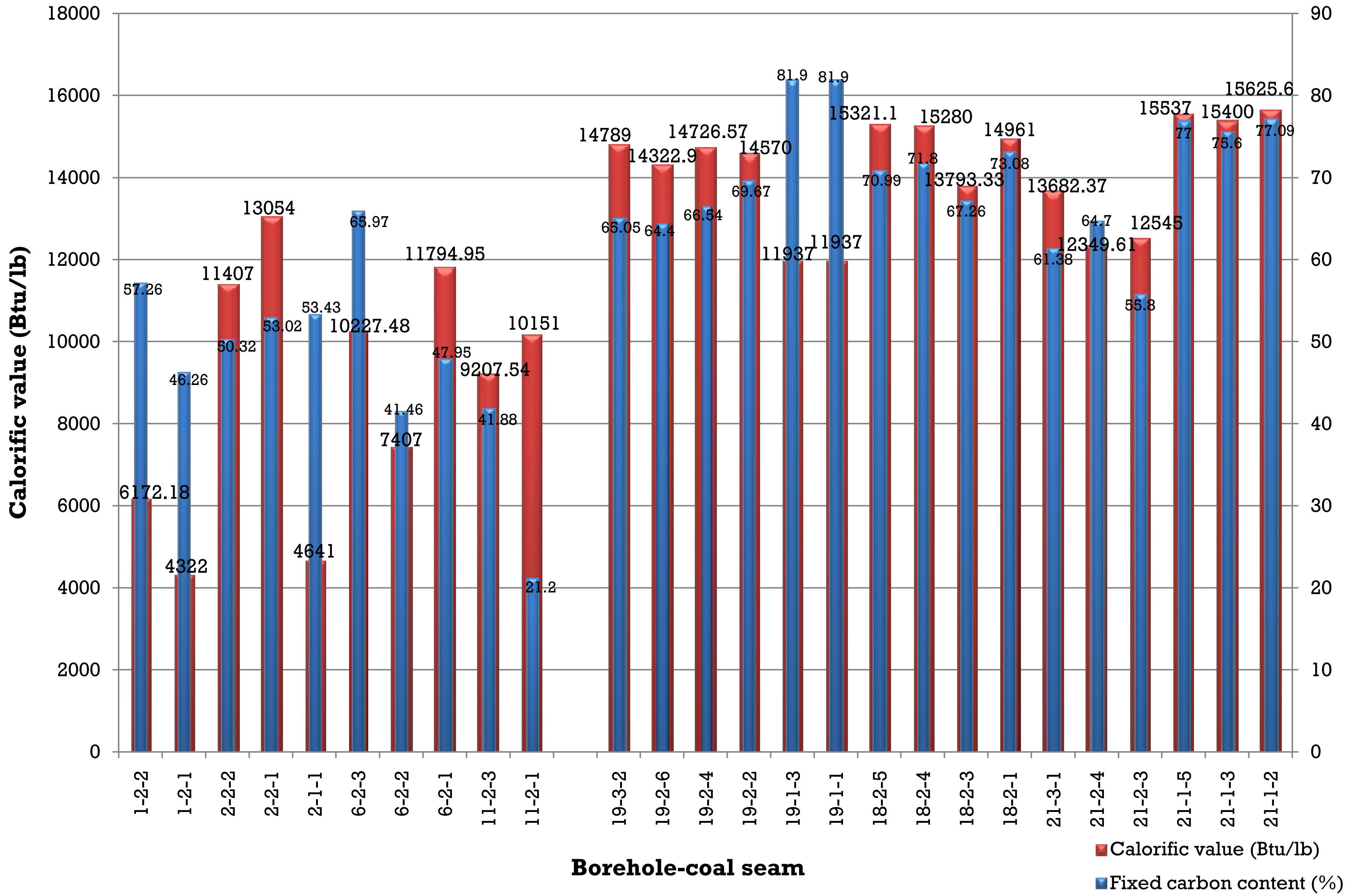


Fig. 5-2B Borehole-coal seam vs fixed carbon and calorific value across the basin (from NE to SW)

Table 5-3 Volatile matter content and calorific value of Dilbi-Moye Basin

Dilbi (BH: 1, 2, 11, 6) and Moye (BH: 19, 18, 21)

Borehole no.	Depth (m)	Borehole-coal seam no.	Volatile Matter Content (%)	Calorific value (Btu/lb)	
1	92.45	1-2-2	42.74	6172.18	Dilbi Sub-Basin
1	106.9	1-2-1	53.74	4322	
2	51.85	2-2-2	49.68	11407	
2	59.7	2-2-1	46.98	13054	
2	220.4	2-1-1	46.22	4641	
6	168.2	6-2-3	34.03	10227.48	
6	175.1	6-2-2	58.54	7407	
6	180	6-2-1	52.05	11794.95	
11	12.25	11-2-3	58.12	9207.54	
11	13.47	11-2-1	78.79	10151	
19	40	19-3-2	34.95	14789	Moye Sub-Basin
19	82	19-2-6	35.69	14322.9	
19	102	19-2-4	38.82	14726.57	
19	105	19-2-2	33.46	14570	
19	165	19-1-3	12.1	11937	
19	190	19-1-1	12.1	11937	
18	60	18-2-5	29.03	15321.1	
18	71.4	18-2-4	28.46	15280	
18	72.5	18-2-3	32.71	13793.33	
18	83	18-2-1	26.92	14961	
21	9	21-3-1	38.62	13682.37	
21	67.35	21-2-4	35.3	12349.61	
21	69.1	21-2-3	44.02	12545	
21	141.1	21-1-5	23	15537	
21	149.18	21-1-3	24.4	15400	
21	162.18	21-1-2	22.9	15625.6	

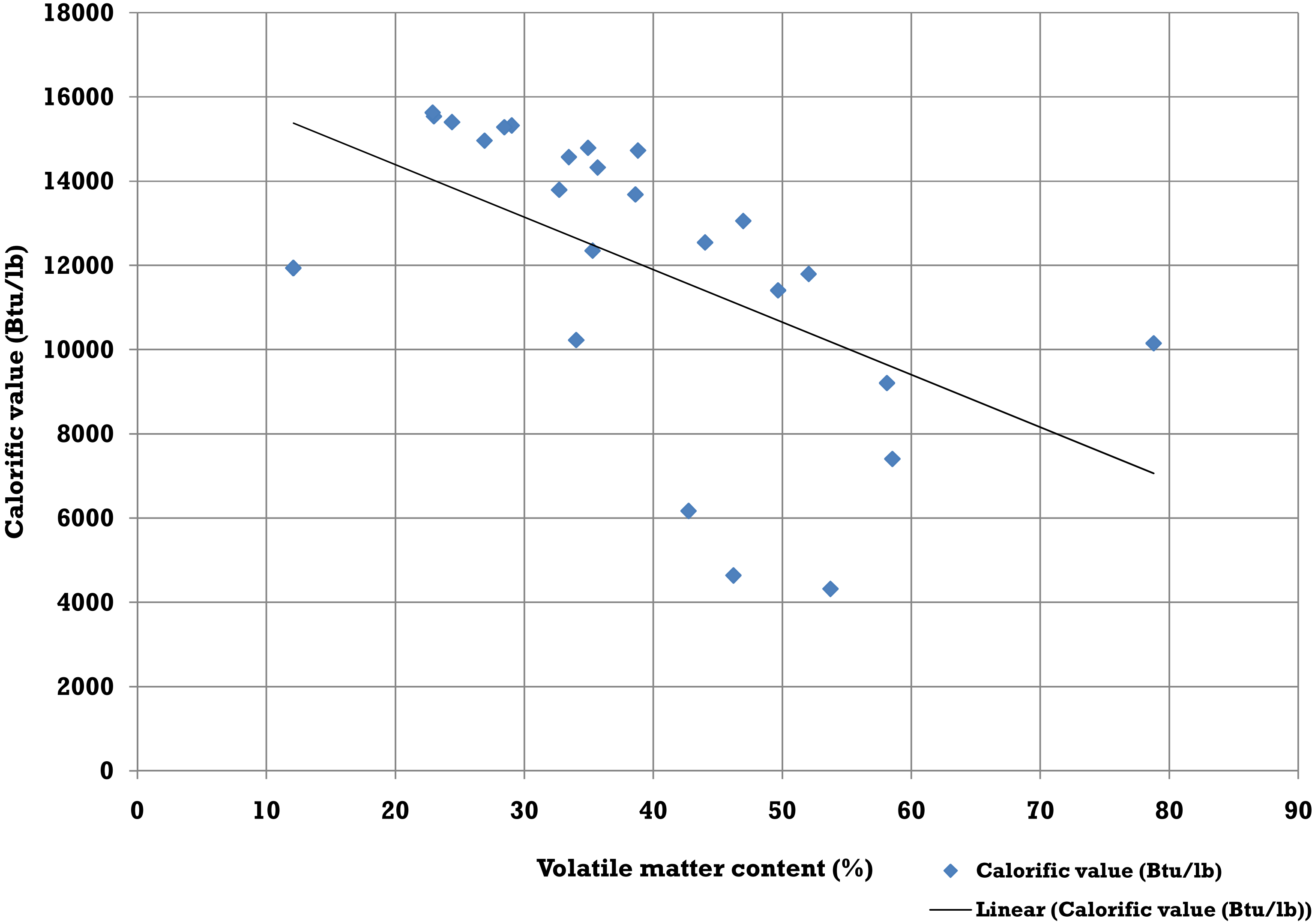


Fig. 5-3A Interrelation of volatile matter vs calorific value within the basin

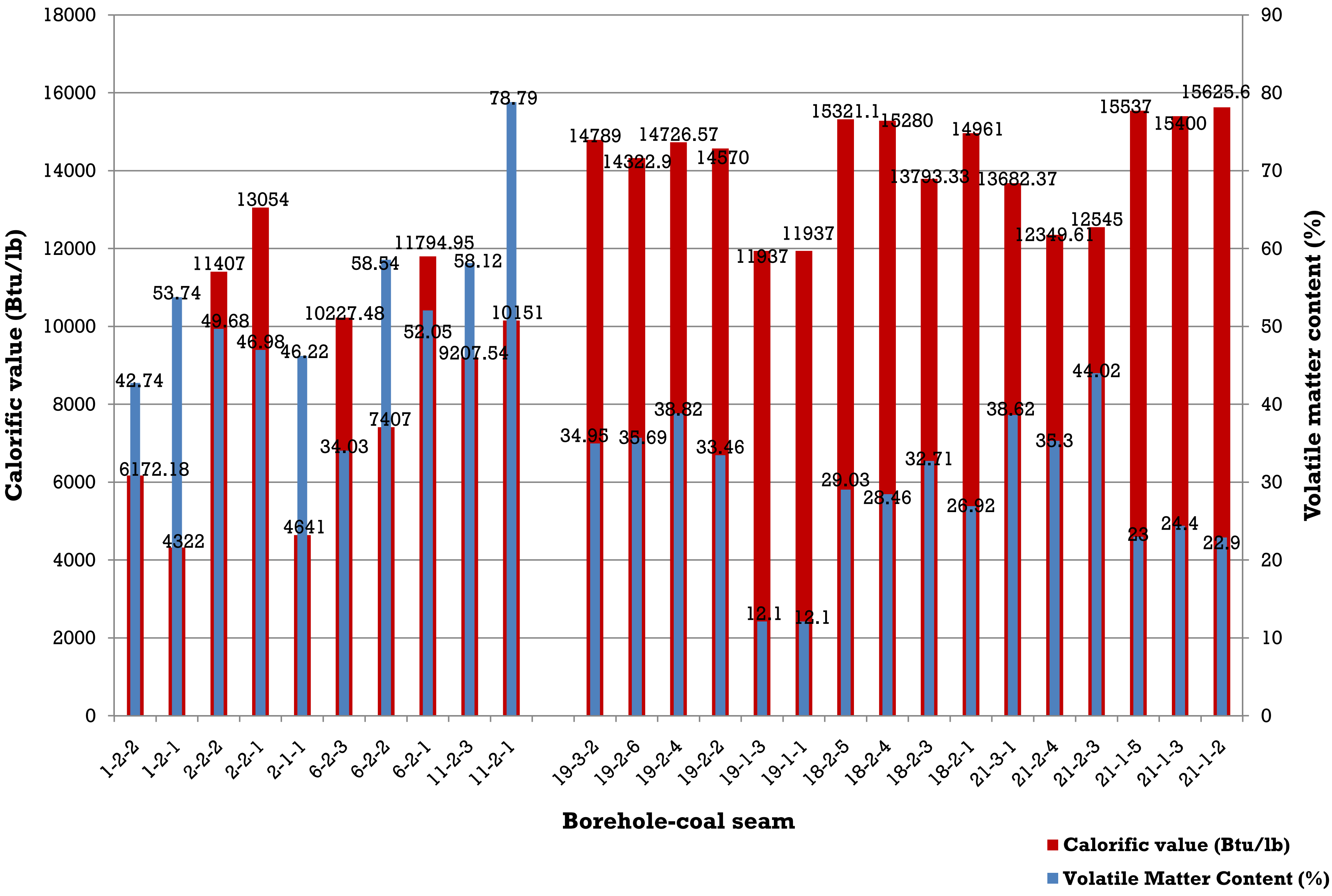


Fig. 5-3B Borehole-coal seam vs volatile matter and calorific value across the basin (from NE to SW)

Table 5-4 Ash content and fixed carbon content of Dilbi-Moye Basin

Dilbi (BH: 1, 2, 11, 6) and Moye (BH: 19, 18, 21)

Borehole no.	Depth (m)	Borehole-coal seam no.	Ash content (%)	Fixed carbon content (%)	
1	92.45	1-2-2	13.1	57.26	Dilbi Sub-Basin
1	106.9	1-2-1	37	46.26	
2	51.85	2-2-2	47.1	50.32	
2	59.7	2-2-1	38	53.02	
2	220.4	2-1-1	31.7	53.43	
6	168.2	6-2-3	22.4	65.97	
6	175.1	6-2-2	54.6	41.46	
6	180	6-2-1	51.49	47.95	
11	12.25	11-2-3	56.28	41.88	
11	13.47	11-2-1	59.4	21.2	
19	40	19-3-2	35.6	65.05	Moye Sub-Basin
19	82	19-2-6	42	64.4	
19	102	19-2-4	52.8	66.54	
19	105	19-2-2	48.9	69.67	
19	165	19-1-3	57.8	81.9	
19	190	19-1-1	52.9	81.9	
18	60	18-2-5	35.6	70.99	
18	71.4	18-2-4	16.9	71.8	
18	72.5	18-2-3	56.1	67.26	
18	83	18-2-1	28.5	73.08	
21	9	21-3-1	55.7	61.38	
21	67.35	21-2-4	60.6	64.7	
21	69.1	21-2-3	56.6	55.8	
21	141.1	21-1-5	18.3	77	
21	149.18	21-1-3	24.4	75.6	
21	162.18	21-1-2	20.5	77.09	

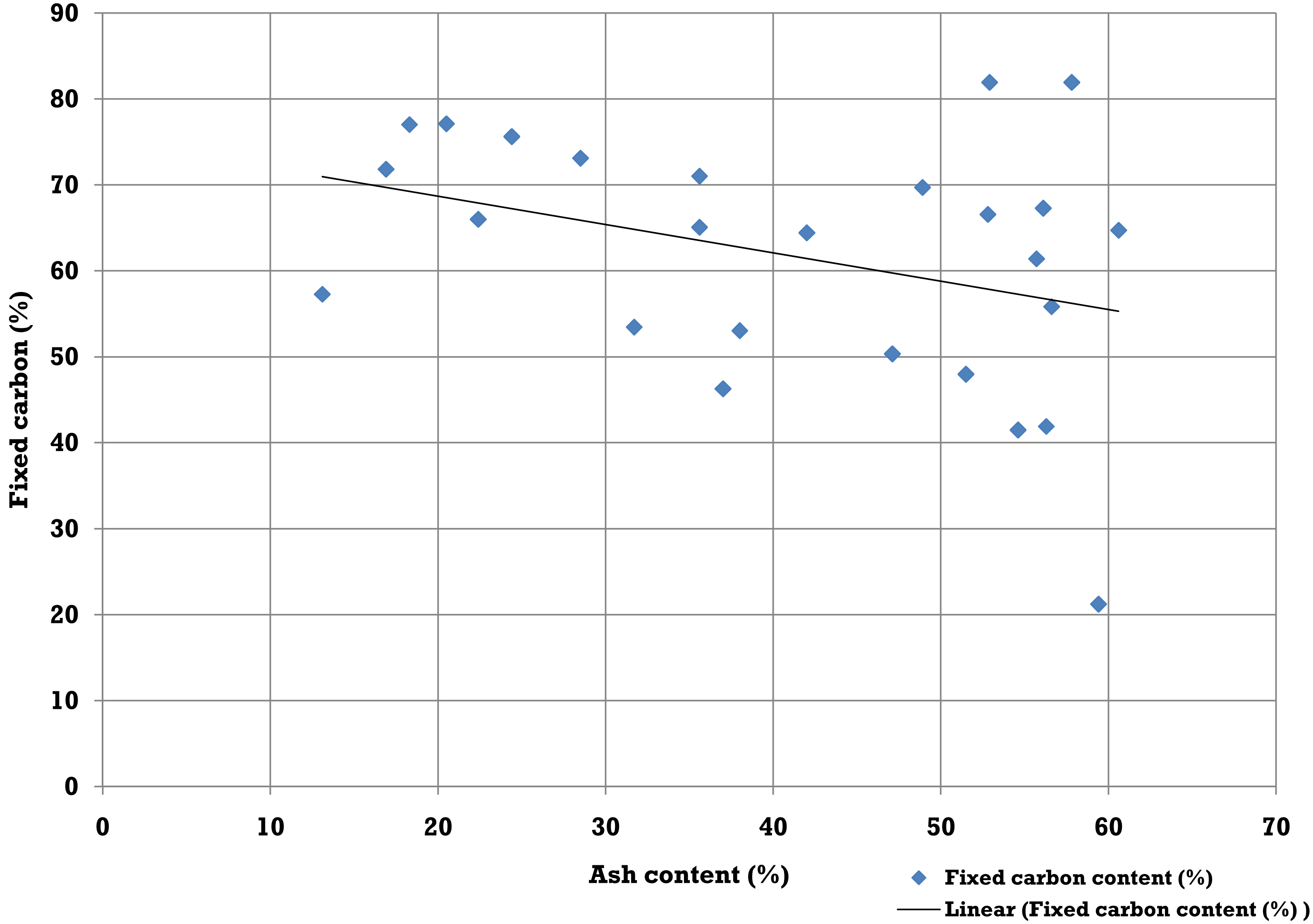


Fig. 5-4A Interrelation of ash content vs fixed carbon within the basin

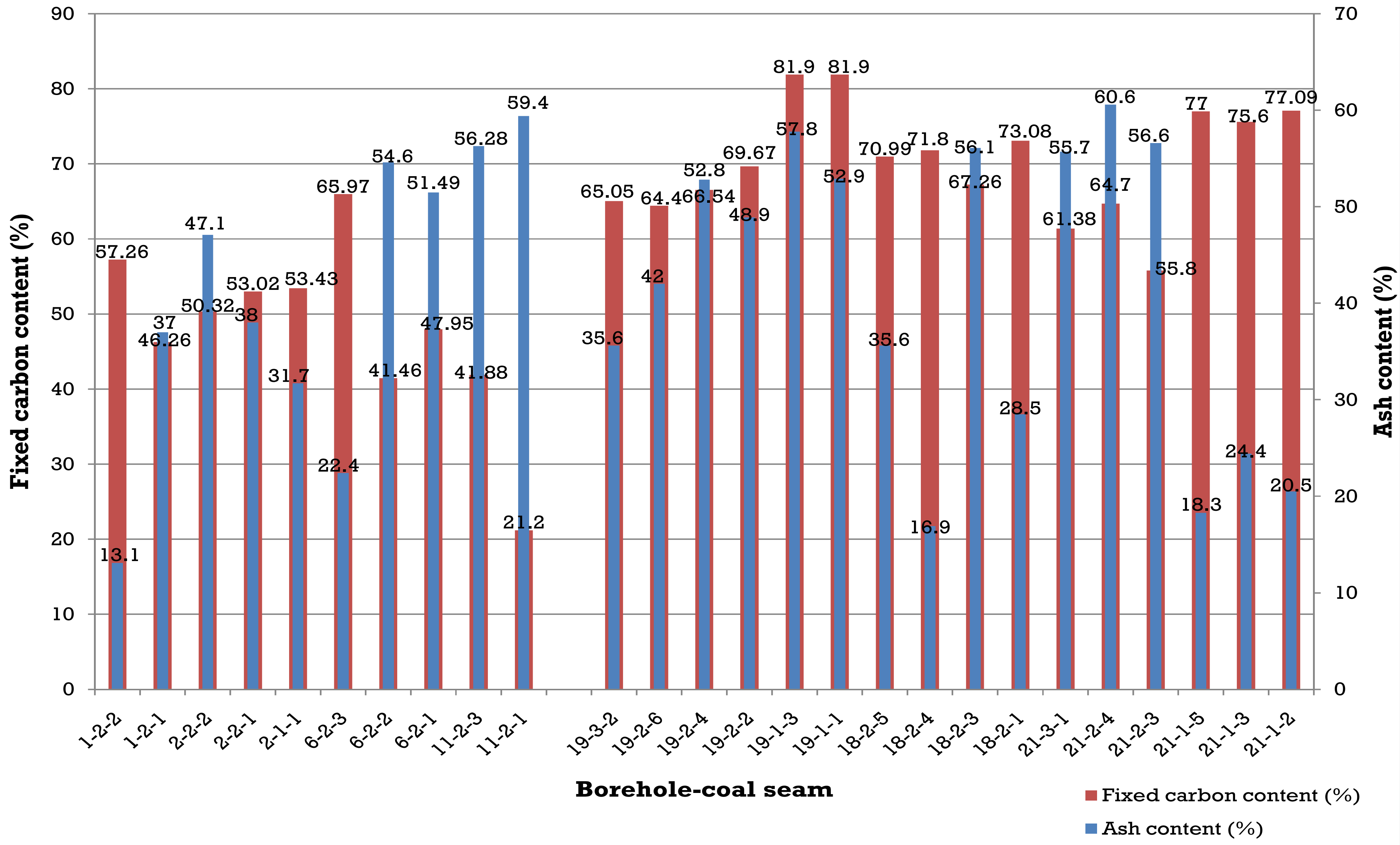


Fig. 5-4B Borehole-coal seam vs ash content and fixed carbon content across the basin (from NE to SW)

Table 5-5 Ash content and volatile matter content of Dilbi-Moye Basin

Dilbi (BH: 1, 2, 11, 6) and Moye (BH: 19, 18, 21)

Borehole no.	Depth (m)	Borehole-coal seam no.	Ash content (%)	Volatile matter content (%)	
1	92.45	1-2-2	13.1	42.74	
1	106.9	1-2-1	37	53.74	
2	51.85	2-2-2	47.1	49.68	
2	59.7	2-2-1	38	46.98	
2	220.4	2-1-1	31.7	46.22	Dilbi Sub-Basin
6	168.2	6-2-3	22.4	34.03	
6	175.1	6-2-2	54.6	58.54	
6	180	6-2-1	51.49	52.05	
11	12.25	11-2-3	56.28	58.12	
11	13.47	11-2-1	59.4	78.79	
19	40	19-3-2	35.6	34.95	
19	82	19-2-6	42	35.69	
19	102	19-2-4	52.8	38.82	
19	105	19-2-2	48.9	33.46	
19	165	19-1-3	57.8	12.1	
19	190	19-1-1	52.9	12.1	
18	60	18-2-5	35.6	29.03	
18	71.4	18-2-4	16.9	28.46	Moye Sub-Basin
18	72.5	18-2-3	56.1	32.71	
18	83	18-2-1	28.5	26.92	
21	9	21-3-1	55.7	38.62	
21	67.35	21-2-4	60.6	35.3	
21	69.1	21-2-3	56.6	44.02	
21	141.1	21-1-5	18.3	23	
21	149.18	21-1-3	24.4	24.4	
21	162.18	21-1-2	20.5	22.9	

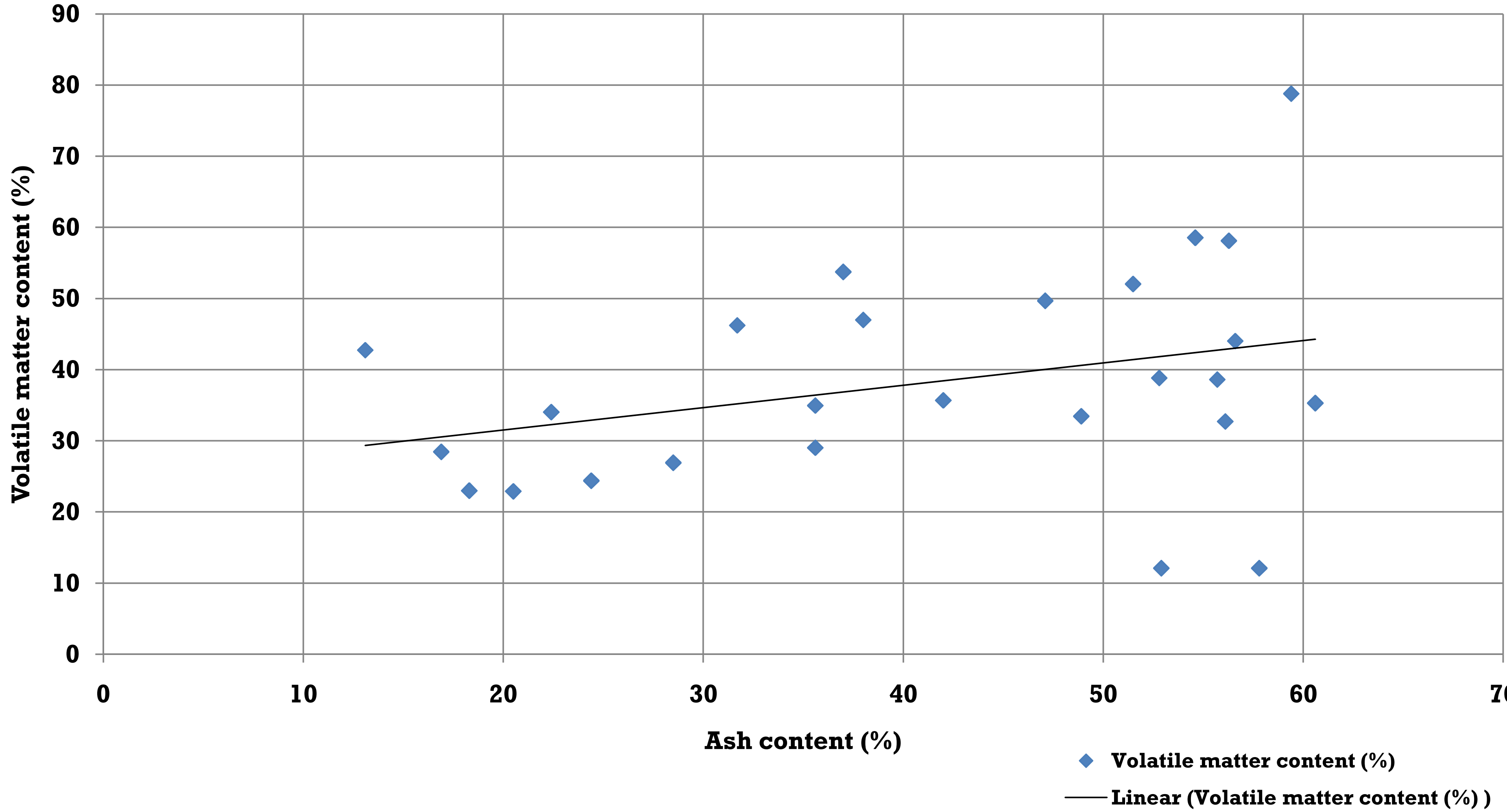


Fig. 5-5A Interrelation of ash content vs volatile matter content within the basin

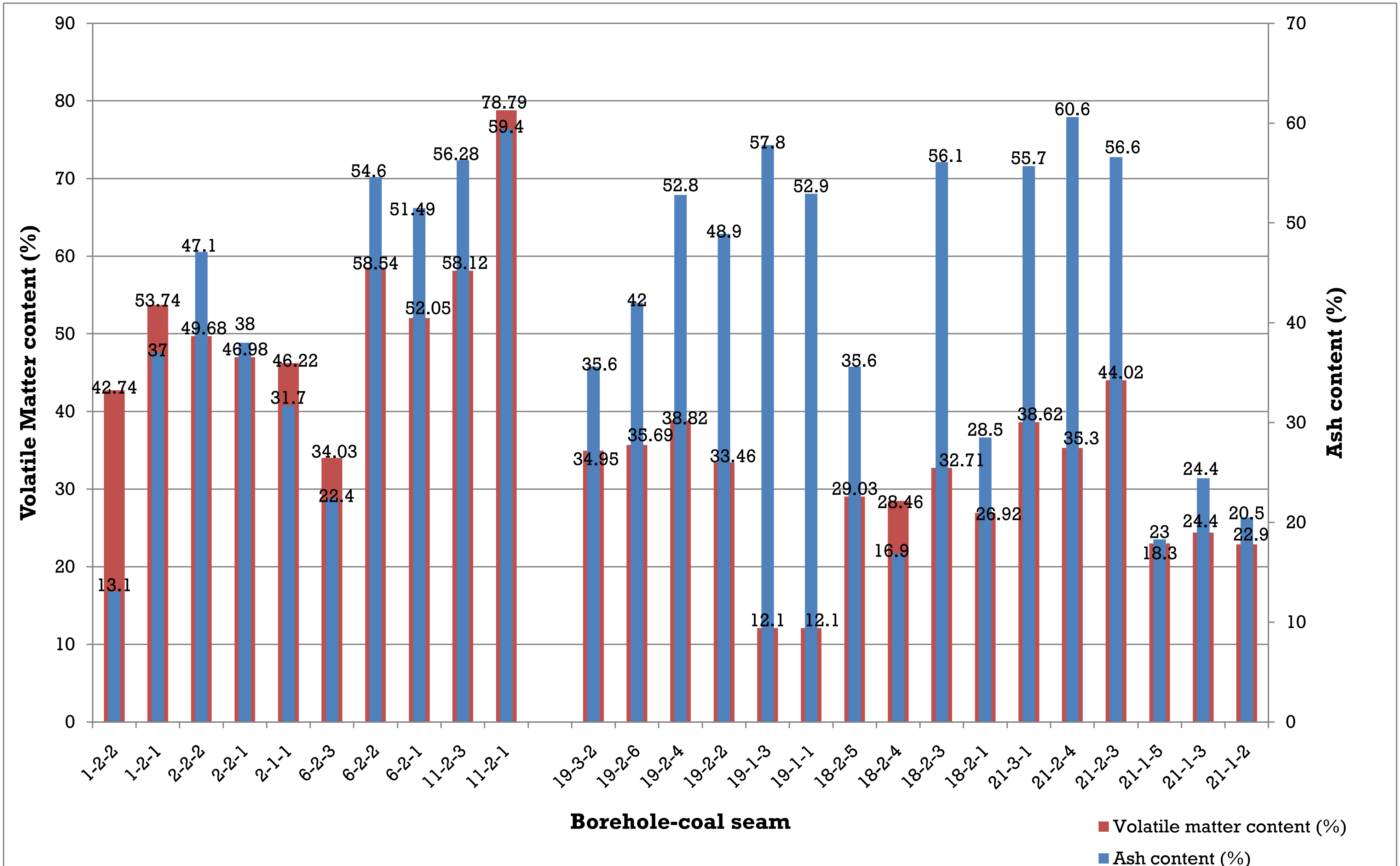


Fig. 5-5B Borehole-coal seam vs ash content and volatile matter across the basin (from NE to SW)

Table 5-6 Moisture content and calorific value of Dilbi-Moye Basin

Dilbi (BH: 1, 2, 11, 6) and Moye (BH: 19, 18, 21)

Borehole no.	Depth (m)	Borehole-coal seam no.	Moisture content (%)	Calorific value (Btu/lb)	
1	92.45	1-2-2	2.8	6172.18	Dilbi Sub-Basin
1	106.9	1-2-1	3.6	4322	
2	51.85	2-2-2	4	11407	
2	59.7	2-2-1	6.3	13054	
2	220.4	2-1-1	1.9	4641	
6	168.2	6-2-3	4.8	10227.48	
6	175.1	6-2-2	2.9	7407	
6	180	6-2-1	2.01	11794.95	
11	12.25	11-2-3	2.68	9207.54	
11	13.47	11-2-1	6	10151	
19	40	19-3-2	2.7	14789	Moye Sub-Basin
19	82	19-2-6	3	14322.9	
19	102	19-2-4	3.2	14726.57	
19	105	19-2-2	2.4	14570	
19	165	19-1-3	2.1	11937	
19	190	19-1-1	3.3	11937	
18	60	18-2-5	1.5	15321.1	
18	71.4	18-2-4	1.5	15280	
18	72.5	18-2-3	2	13793.33	
18	83	18-2-1	1.5	14961	
21	9	21-3-1	1.52	13682.37	
21	67.35	21-2-4	2.9	12349.61	
21	69.1	21-2-3	3	12545	
21	141.1	21-1-5	1.2	15537	
21	149.18	21-1-3	1.5	15400	
21	162.18	21-1-2	1.3	15625.6	

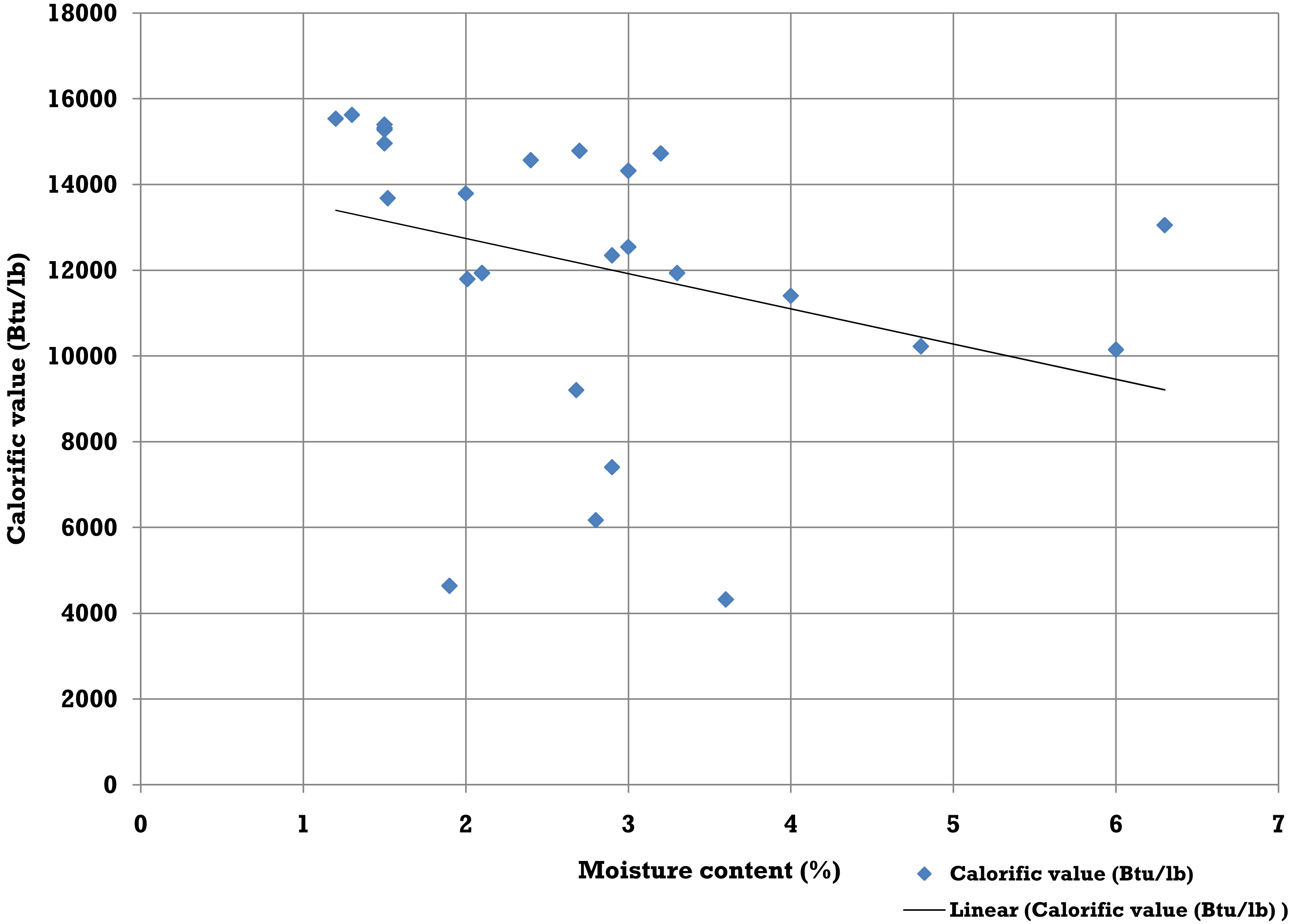


Fig. 5-6A Moisture content vs calorific value within the basin

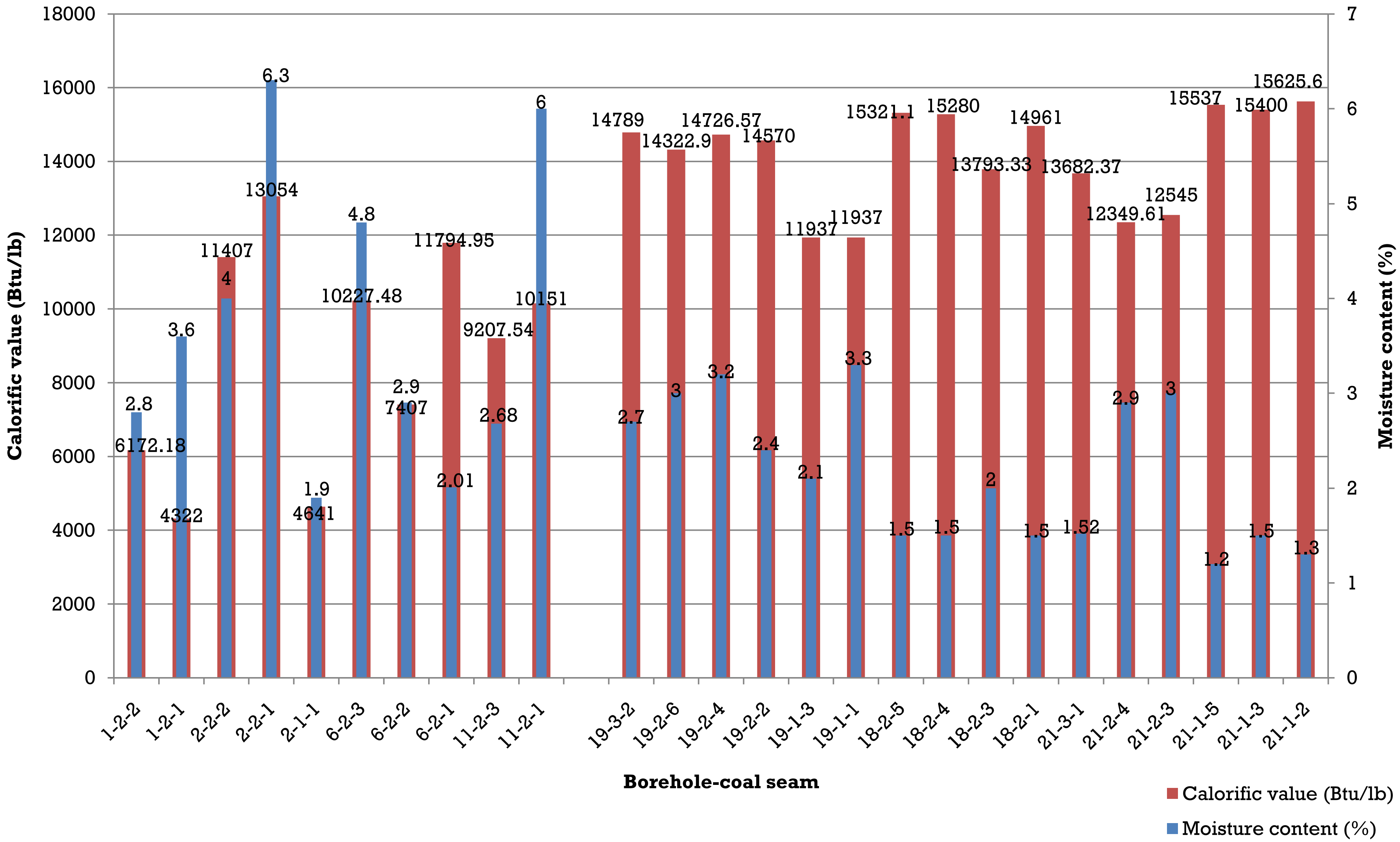


Fig. 5-6B Borehole-coal seam vs moisture content and calorific value across the basin (from NE to SW)

5.3 THE POSSIBLE CAUSES OF THERMAL VARIATIONS OF THE BASIN

The geochemical analyses results of Dilbi-Moye samples of many researchers (Bae et al., 1989; Miniye, 1992; Wolela, 2007) have been shown that the Dilbi coal is humic to sapropelic (boghead and cannel) in nature; whereas the Moye area coal is humic in type. The type of Dilbi Sub-Basin coal is a thermal coal and of Moye Sub-Basin is both thermal and coking coal.

Thermal variation can be caused by several reasons; among these suggested reasons: the ash content or inclusions of inorganic minerals, environment of deposition and/or genesis of the coal material are the most important ones.

Ash is the inorganic matter of the coal and is directly proportional to the density of the coal. If the graph of the heat energy (calorific value) vs ash content is normal (as ash increases heat energy decreases), the reason of thermal variation would be the inorganic content of the ash; otherwise, if as ash increases heat energy also increases, the reason might be type of the organic matter, environment of deposition and inclusion of the inorganic material.

The Dilbi-Moye Basin coal has comprised of varied vertical and lateral thermal conditions. Even though, there is no uniform increment of ash or calorific value across the basin, towards the east and northeast direction of the basin there is decreasing of both calorific value and ash content; whereas towards the west and southwest there is an increase of calorific value and ash content. In principle, if the ash content percentage vs calorific value (Btu/lb) shows inverse relationship, the possible causes of the thermal variation of the basin could be most probably the inclusion of inorganic materials (elements) into the coal. Since their relationship is not uniformly inverse, the possible causes of the thermal variations of the coals seem to be most likely due to type and preservation of the organic matter and partially the inclusion of inorganic material into the coal.

The reason for the observed variability in the inorganic composition of the coals resides in the variation in the geochemistry under which the coals (peats) accumulated. The mineral composition ash varies systematically on both a regional and a local basis reflecting the variation in the geochemistry of the depositional basin in which the peat accumulated (Renton, 1979).

The western part of the basin, Moye area coals, is with high calorific value and ash content relative to Dilbi area coals. This may signifies that the Moye area to be more marginal part of the basin than Dilbi. In those coals, formed along the margins of the basins where the peat would have been subjected to the over bank materials during the time of flood and in the immediate vicinity of crevasse splays or other catastrophic influxes, detrital materials could definitely be dominant components. However, most of the mineral matter in the coal would not be detrital but rather would arise from inorganic materials originally contained within the plants (Renton and Blaine, 1979). Since the origin of the Moye coals, were woody tissues of plants (Miniye, 1992), in principle, it should contain the least ash (Renton and Blaine, 1979). However, reversely it is of high ash content, which leads to conclude this ash is fully, or partially because of the inorganic content inherently contained in the plant or due to the detrital material engulfed in the peat.

The relatively high calorific value of the coal of Moye area with respect to Dilbi Sub-Basin might be due to the preservation of the organic material or the type (genesis) of the organic matter itself.

The calorific value of the upper coal seams in some boreholes is greater than the lower one; the most possible cause for this result could be the upward increment of the rank (organic metamorphism) due to the near-by volcanics. In other words, the fact that the calorific value of the coals show a generally an upward increment may be explained by cooking effect of acidic intrusions; because the temperature gradient of this intrusion is very low (decreases downward) to penetrate down where the lower coal seam layers are existing.

6. DISCUSSION AND INTERPRETATION

Under this topic the geochemical analysis results of the previously and recently analyzed coal samples issues and the possible causes of the vertical and lateral thermal variations analyses results are raised, discussed and a brief interpretation will be forwarded accordingly.

The analysis of thermal variation of Dilbi-Moye coals is mainly accomplished by studying the chemical analysis results of the chemical characteristics of the coals encountered in seven boreholes, `sunk by the Geological Survey of Ethiopia.

Presently, six core coal samples and three surface coal samples were submitted for proximate, calorific value, total sulfur content, and density analyses and two rock samples for petrographic descriptions, which were carried out in the Central Geological Laboratory of the Geological Survey of Ethiopia. From these samples three core and one surfacial (outcrop), samples were analyzed and their results seem misleading. Because their ash content is generally ranges from 76.51 to 86.75% and their calorific value falls below twenty-four (24) cal/gm (Table 4-1B and 4-2B). Therefore, it is recommended that not to be used in the process of the whole work of this thesis research.

From the presently analyzed and accepted and previously analyzed core coal samples results it is clearly seen that the moisture content of the basin varies from 1.2 (BH 21) to 6.3% (BH 2). The minimum moisture content (1.2%) is recorded at Moye Sub-Basin of borehole 21, coal seam 1-5. The maximum moisture content (6.3%) is registered at Dilbi Sub-Basin of Borehole 2 of coal seam 2-1. The general trend of moisture content in the basin is increasing from southwest extreme (Moye area) to northeast (Dilbi area).

The moisture content of Moye Sub-Basin varies between 1.2 to 3.3%; whereas in Dilbi area, the moisture content of the coals varies between 1.9 and 6.3%. From this result, the moisture content of the coal of the basin decreases from northeast (Dilbi area) to the southwest (Moye Sub-Basin).

The representative core coal samples analyses result of the seven boreholes show that the volatile matter of coals in Moye Sub-Basin ranges from 11.5 to 26.7%; whereas the volatile matter of Dilbi Sub-Basin ranges from 19.3 to 37.9%. The general trend of the volatile matter of the basin is increasing from southwest (Moye area) to northeast (Dilbi area).

The fixed carbon content of the Dilbi Sub-Basin ranges between 15.3 to 46.8%; whereas the fixed carbon of Moye Sub-Basin varies between 20 and 60.2%. The general trend of the fixed carbon of the basin is increasing from Dilbi to Moye area of borehole 21 (southwestern margin of the basin). From Fig. 5-4B, the trend of the ash content is more or less very low for coal seams, which have high fixed carbon in both sub-basins.

The low positive correlation in Fig. 6-1, within the Dilbi-Moye Basin shows that the sulfur content varies directly with calorific value of the coals. This means as the sulfur content increases, the calorific value of the coals increases more or less in the same manner. This might show that the well preservation of organic matter and non-oxic conditions which leads to more deposition of sulfur and increment of calorific value.

From Table 6 and Fig. 6-1, 6-2, and 6-3 the sulfur content of the Dilbi area varies between 0.02 to 0.3%. However, there is one extraordinary (erratic) result recorded at borehole 11, coal seam 2-1 (2.4%) relative to other results in the sub-basin. The sulfur content of Moye Sub-Basin ranges from 0.02 to 2.1%.

Generally, the sulfur content of the basin increases from Dilbi area to Moye except the result recorded at borehole 11, which is the highest sulfur content record for the basin, which might indicate the deposition of the seam, might be under good reducing environment. In other words, the organic matter preservation is better at Moye than Dilbi Sub-Basin, since sulfur is deposited at reducing environment, under non-oxic condition in Moye Sub-Basin.

Conclusively, from the proximate, calorific value and total sulfur analyses the coalification pattern and organic matter preservation increases from Dilbi to Moye with high ash content of the coals in the later.

The coals in the study area are diverse in lithologic association, and composition. Their organic matter is also derived from a variety of sources, which include precursors of terrestrial and lacustrine origins. All these needed, indication of definitive genetic relationships in which the detailed environmental interpretations in conjunction with other disciplines would contribute greatly to the knowledge of the coal and oil shale genesis, as well as, a base for their genetic classifications (Miniye, 1992).

Owing to the fact that heat energy of coals is retained by their organic matter components (Renton, 1979); the release of that energy is by way of direct oxidation or conversion to intermediate liquid or gaseous products. The high heat values in the Moye Sub-Basin may suggest well-preserved organic matter in this part of the basin. In addition, calorific value of coals may also vary with their rank. However, the observed variation of heat value in the Dilbi-Moye Basin does not imply any significant trend of lateral rank variation.

There is high ash content and high calorific value at Moye Sub-Basin and relatively low calorific value and high ash content in Dilbi Sub-Basin. The abundance of ash in a peat layer is a function of the amount of plant debris accumulated and the rate of degradation (Renton and Blaine, 1979). A low rate of degradation (acid conditions) would result in a low ash, kaolinite rich peat; the amount of plant debris accumulation would determine whether the layer would be thick or thin. The high rate of degradation of organic matter also could be a reason for the high ash content of the Dilbi-Moye Basin. Because a high rate of degradation (alkaline conditions) would result in a high ash content (Renton and Blaine, 1979) with the abundance of illite equal to or dominating over that for kaolinite.

The thickness of coals of Dilbi-Moye Basin ranges between 0.3 to 2.4m. Specially, coals of Moye Sub-Basin, comprised of more than 16 coal seams of most of them are very thin. Since coals of the basin have thin layers, they could be categorized as high rate of organic degradation. Thick coals imply low rates of organic degradation; high ash content implies a high rate of organic degradation (Renton and Blaine, 1979). Thin coals, on the other hand could accumulate under a variety of conditions ranging from small amounts of plant debris accumulating under ideal conditions of slow degradation to large amounts of plant debris accumulation under conditions of non-ideal rapid organic degradation. Both situations would produce a thin coal; the difference would be that the former would result in a thin-low ash coal while the latter would form a thin-high ash coal (Renton and Blaine, 1979). Therefore, the later one could be applied to the basin under study.

In Moye Sub-Basin vitrinite, maceral dominates over inertinite and liptinite macerals (Miniye, 1992). Vitrinite is generally considered to be derived from plant cell walls and fusinite and semifusinite are generally believed to be coalified products of partially carbonized (oxidized) cell wall material. The carbonization process causes a decrease in the amount of organic matter and a resultant increase in the concentration of mineral matter (Blaine et al., 1979).

Therefore, the maceral type also could be the possible cause of the thermal variation of the basin.

From the chemical analysis results, the Dilbi-Moye coals are of high ash and low sulfur contents. Given acid conditions with intermittent sub-aerial exposure, resulting carbonization (oxidation?) would tend to concentrate mineral matter with a corresponding increase in certain inertinite macerals. Sulfur fixation and bacterial activity is inhibited. Such conditions would give rise to a low sulfur, high ash coal (Blaine et al., 1979).

Table 6 Sulfur content and calorific value variations of Dilbi-Moye Basin

Dilbi (BH: 1, 2, 11, 6) and Moye (BH: 19, 18, 21)

Borehole no.	Depth (m)	Borehole-coal seam no.	Sulfur content (%)	Calorific value (Btu/lb)	
1	92.45	1-2-2	0.3	6172.18	Dilbi Sub-Basin
1	106.9	1-2-1	0.1	4322	
2	51.85	2-2-2	0.1	11407	
2	59.7	2-2-1	0.2	13054	
2	220.4	2-1-1	0.1	4641	
6	168.2	6-2-3	0.2	10227.48	
6	175.1	6-2-2	0.1	7407	
6	180	6-2-1	0.02	11794.95	
11	12.25	11-2-3	0.02	9207.54	
11	13.47	11-2-1	2.4	10151	
19	40	19-3-2	0.4	14789	Moye Sub-Basin
19	82	19-2-6	0.3	14322.9	
19	102	19-2-4	0.4	14726.57	
19	105	19-2-2	0.4	14570	
19	165	19-1-3	0.03	11937	
19	190	19-1-1	0.03	11937	
18	60	18-2-5	0.9	15321.1	
18	71.4	18-2-4	2.1	15280	
18	72.5	18-2-3	1.4	13793.33	
18	83	18-2-1	1.3	14961	
21	9	21-3-1	0.02	13682.37	
21	67.35	21-2-4	0.2	12349.61	
21	69.1	21-2-3	0.4	12545	
21	141.1	21-1-5	1.3	15537	
21	149.18	21-1-3	1.3	15400	
21	162.18	21-1-2	0.8	15625.6	

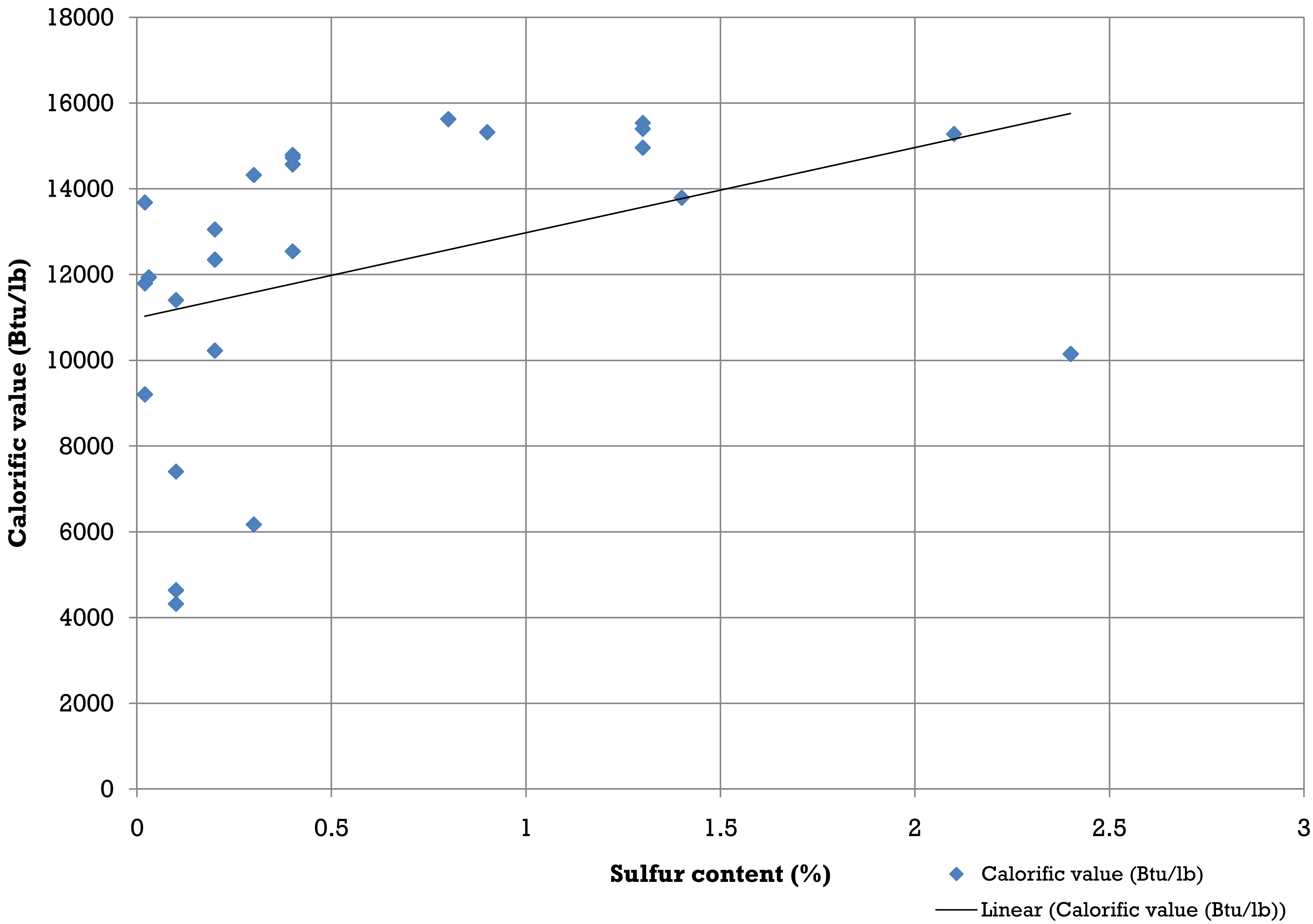


Fig. 6-1 Sulfur content vs calorific value within the basin

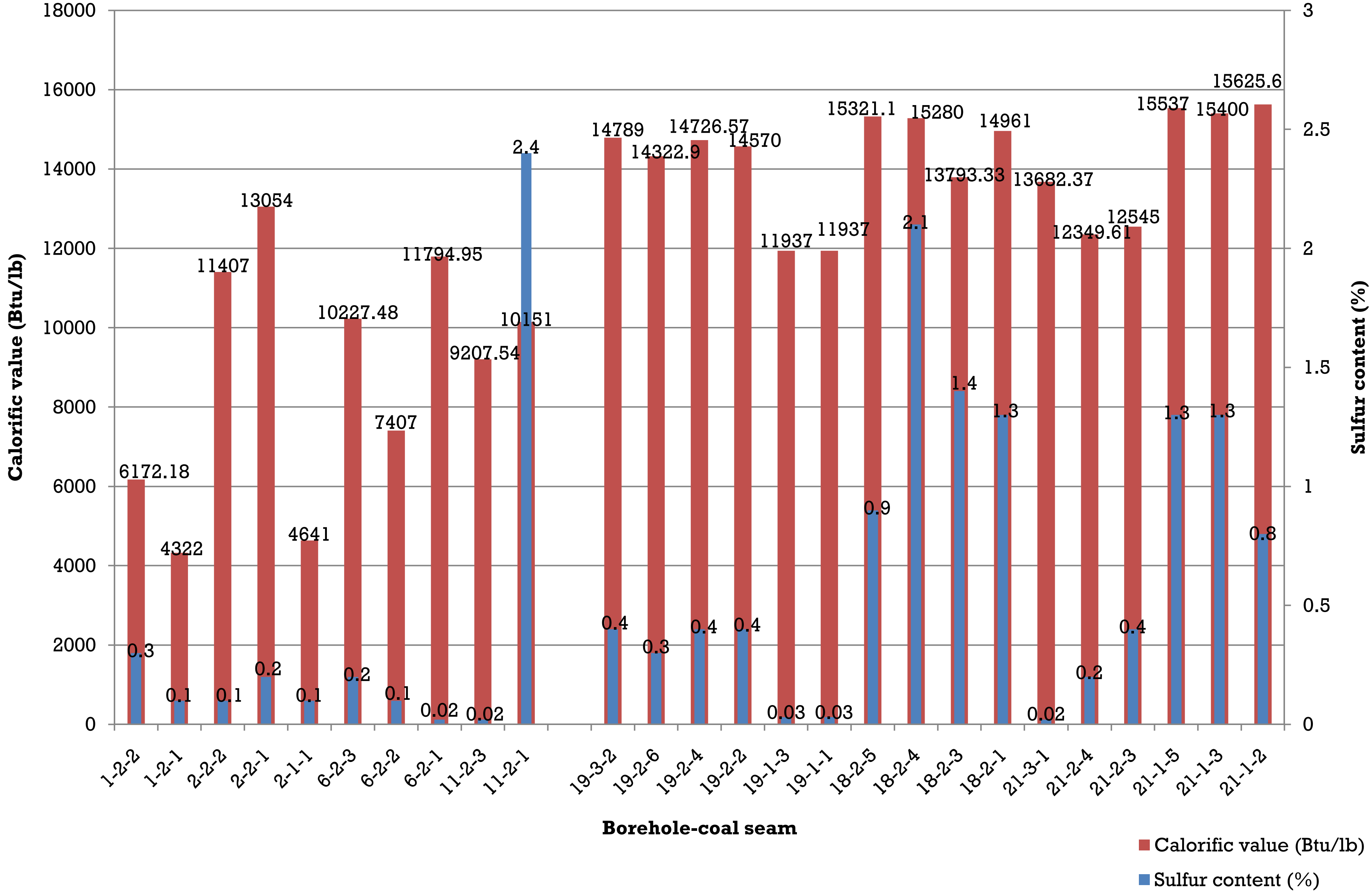
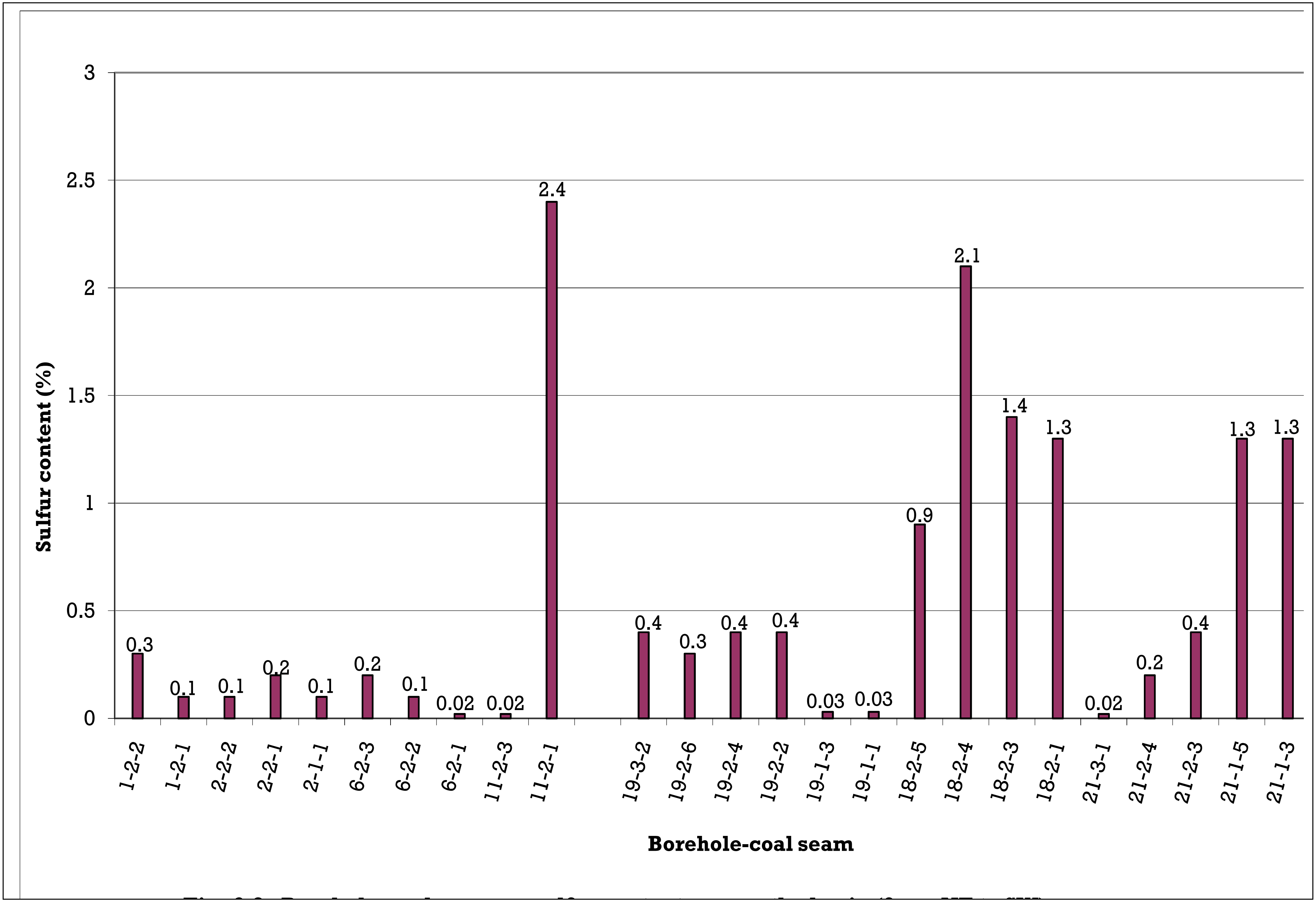


Fig. 6-2 Borehole-coal seam vs sulfur content and calorific value across the basin (from NE to SW)


Sulfur content (%)
3
2.5
2
1.5
1
0.5
0
0.3
0.1
0.1
0.2
0.1
0.2
0.1
0.02
0.02
2.4
0.4
0.3
0.4
0.4
0.03
0.03
0.9
2.1
1.4
1.3
0.02
0.2
0.4
1.3
1.3
1-2-2
1-2-1
2-2-2
2-2-1
2-1-1
6-2-3
6-2-2
6-2-1
11-2-3
11-2-1
19-3-2
19-2-6
19-2-4
19-2-2
19-1-3
19-1-1
18-2-5
18-2-4
18-2-3
18-2-1
21-3-1
21-2-4
21-2-3
21-1-5
21-1-3
Borehole-coal seam

7. CONCLUSION

The Dilbi-Moye Basin is one of the basins in the southwestern Ethiopian Plateau, which is the ubiquitous sedimentary intercalation within the plateau volcanics. The tectono-volcanic systems active during Middle Tertiary in the western and southwestern parts of Ethiopia are assumed to have controlled the arrangements and orientations of the coal-bearing basin.

The Dilbi-Moye Basin coal-bearing sediments are deposited in NNW-SSE trending basin that may have evolved locally, from contemporaneous regional tectonic episodes, as a minor associated feature. Their depositional environment ranges from fluviatile to lacustrine.

The results of proximate, calorific value, and sulfur content analyses show that the coals of Dilbi-Moye Basin have nearly similar properties. However, that of the Moye Sub-Basin coals appears to be relatively of higher quality. From the chemical analysis result, the fixed carbon of Moye area coals fall below 81.9% (d.m.m.f basis), with the calorific value ranging between 11,570 and 15,625.60 Btu/lb (m.m.m.f).

In a general consideration, the Moye Sub-Basin coals are fairly suitable for thermal and coking purposes; whereas the Dilbi Sub-Basin coals are useful for thermal heating. The modal heating value of Dilbi-Moye Basin, which ranges between 4,322 and 15,625.60 Btu/lb, may allow these coals to be used for local thermal power generation.

The coals in Dilbi-Moye Basin display significant vertical and lateral thermal variations. Even though, there is no uniform increment/decreasing of ash or calorific value across the basin, in general terms, towards the east and northeast direction of the basin there is decreasing of both calorific value and ash content. Towards the west and southwest, there is a clear increment of calorific value and ash content.

Similarly, there is no uniform vertical increment/decreasing of ash content or calorific value in Dilbi and Moye areas. In most of the boreholes, there is inverse proportion of ash contents and calorific values; whereas, in some boreholes there is direct relationship of ash contents and calorific values. At a few boreholes, the calorific values and/or ash contents of the top coal seams are higher than the lower ones and vice versa.

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APPENDICES

Appendix A Classification of Coals by Rank (From ASTM., 1989)

Class	Group	Fixed carbon limits, % (Dry, mineral matter- free- basis)		Volatile matter limits, % (Dry, mineral matter- free- basis)		Calorific value limits, Btu/lb (Moist, mineral matter- free- basis)		Agglomerating Character
		Equal or greater than	**Less than**	**Greater than**	**Equal or less than**	**Equal or greater than**	**Less than**	
I. Anthracite	Meta-anthracite	98	-	-	2	-	-	Non-agglomerating
	Anthracite	92	98	2	8	-	-	
	Semi-anthracite	86	92	8	14	-	-	
II. Bituminous	Low volatile bituminous coal	78	-	14	22	-	-	Commonly Agglomerating
	Medium volatile bituminous coal	69	-	22	31	-	-	
	High volatile A bituminous coal	-	-	31	-	14,000	-	
	High volatile B bituminous coal	-	-	-	-	13,000	14,000	
	High volatile C bituminous coal	-	-	-	-	11,500	13,000	
		-	-	-	-	10,500	11,500	Agglomerating
III. Sub-bituminous	Sub-bituminous A coal	-	-	-	-	10,500	11,500	Non-agglomerating
	Sub-bituminous B coal	-	-	-	-	9,500	10,500	
	Sub-bituminous C coal	-	-	-	-	6,500	9,500	
IV. Lignite	Lignite A	-	-	-	-	6,300	6,300	
	Lignite B	-	-	-	-	-	6,300	

APPENDIX B: Analytical procedure

All coal samples were chemically analyzed at the Central Geological Laboratory of Geological Survey Ethiopia. In all cases, the laboratory follows the ASTM analytical procedures.

Proximate Analysis:

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

Volatile matter: Coal heated at 950 ± 25^{0}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^{0}C, an dheld 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 oxidation of the coal at 800^{0}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.

Density

The density of the Dilbi-Moye Basin coal is determined based on the loss of weight when samples are immersed in a methanol.

DECLARATION

I, the undersigned, declare that this is my work and that all sources of materials used in the Thesis are dully acknowledged.

Addisu Geleta

Signature --

Addis Ababa, July 2009

This Thesis has been submitted for examination with my approval as research advisor.

Dr. Wolela Ahmed

Signature --