Geology and coal potential of Somaliland

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Abstract: Geological field mapping along with available geological and drilling data suggest that Somaliland (Northwestern Somalia) has favourable stratigraphy and structure for coal deposits. Lignitic to sub-bituminous coal deposits with ages from Jurassic to Oligocene-Miocene occur in various locations across the country including Hed-Hed valley south of Onkhor, Guveneh hills north of Las Dureh and Daban Basin southeast of Berbera. However, the coal occurrence at Hed-Hed has both the greatest thickness and highest quality.

These deposits have the potential to provide an important alternative fuel resource which could alleviate the growing shortage of traditional fuels and assist in reducing the country's dependence on imported energy. However, further investigation, including drilling and laboratory analyses, still needs to be carried out, particularly on the Upper Cretaceous coal seams to evaluate the quality and resource potential of the deposits. [Received: October 4, 2008; Accepted: January 6, 2009]

Keywords: Somaliland; coal potential; bituminous coal; lignite; geology; Nubian (Yesomma) Sandstone; alternative fuel resource.

Reference to this paper should be made as follows: Ali, M.Y. (2009) 'Geology and coal potential of Somaliland', *Int. J. Oil, Gas and Coal Technology*, Vol. 2, No. 2, pp.168–185.

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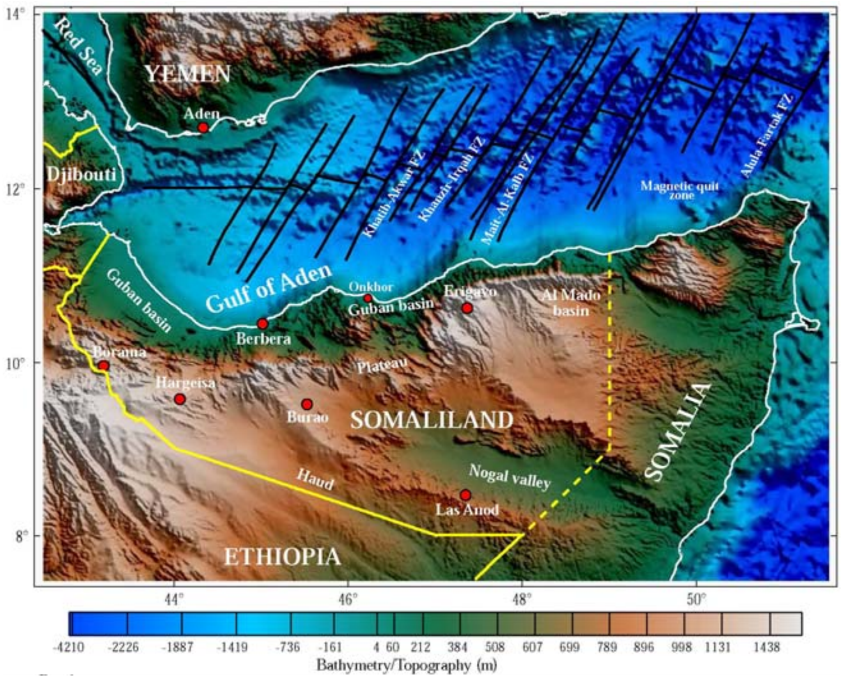
1 Introduction

Somaliland (Northwestern Somalia) is situated on the northern side of the Horn of Africa with the Gulf of Aden to the north, Ethiopia to the south and west and Djibouti to the northwest (Figure 1). The country is underlain mainly by Mesozoic and Tertiary continental-margin and marine sedimentary rocks deposited unconformably on Precambrian metamorphic and igneous rocks (Ali, 2006).

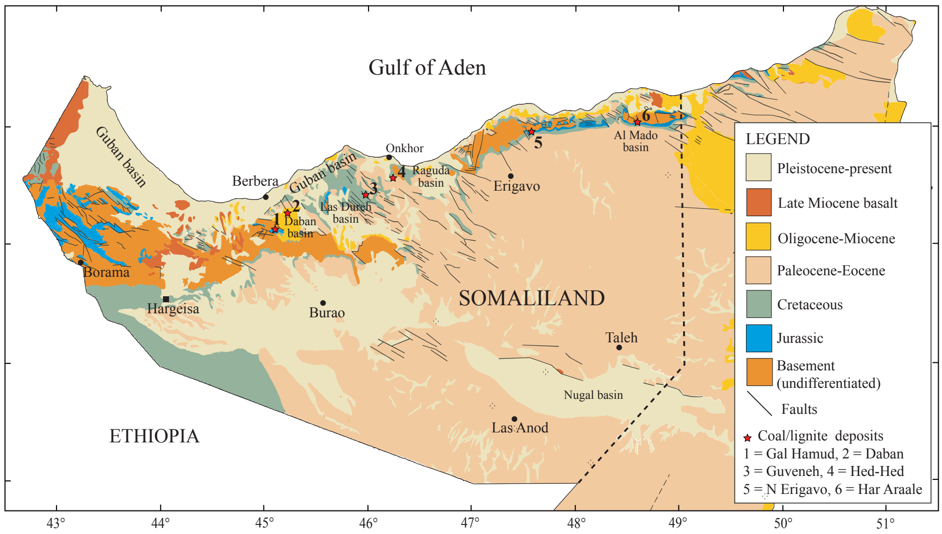
Figure 1 Map of Somaliland and surrounding regions showing plate boundaries and rift zone-transform faults of the Gulf of Aden and the Red Sea (see online version for colours)



Notes: Topography data is based on Shuttle Radar Topography Mission (SRTM) data. Bathymetry is based on satellite derived data (Smith and Sandwell, 1997). Also shown are cities mentioned in the text.

Three major plate boundaries meet in the Horn of Africa. They are the oceanic spreading ridges of the Red Sea and the Gulf of Aden and the continental East African Rift system (Figure 1). As a result, the structure of the country is dominated by the Gulf of Aden, Red Sea and East African trends (Figure 2). The opening of the Gulf of Aden has subjected the country to extensional tectonics, giving rise to a major system of E-W to ENE-WSW striking normal faults. These faults divide the country into two morphological regions, the down faulted Guban area and the relatively uplifted Somaliland plateau which exposed high grade Proterozoic migmatites, granitoides and pegmatites. Faults of the Red Sea have a trend of NW-SE to WNW-ESE direction whereas the East African faults trend almost due N-S. The East African faults are less frequent and they mainly affect the western part of the country. Field observations indicate that NW-SE faults are most dominant trends (Figure 2) and old basement structural trends exerted a controlling influence on younger fault trends. The movement of older faults appear to have taken place during the Mesozoic time and may be related to the early breaking up of Gondwanaland (SOEC, 1954; Bosellini, 1992). The Daban Basin (southeast of Berbera) is an example of an onshore basin that was formed as a result of the reactivation of the older NW-SE trending fault and subsequently filled with Oligocene-Miocene continental to marginal-marine sediments (Bott et al., 1992).

Figure 2 Simplified geological map of Somaliland showing locations of coal deposits (see online version for colours)



Source: Modified from Abbate et al. (1993b).

The exploration and exploitation of lignite and bituminous coal is important for developing countries such as Somaliland and can provide a vital, alternative fuel source for the country. In Somaliland, the traditional fuel supply is wood which has become severely depleted, while imports of petroleum products have become too expensive. However, extensive lignitic to sub-bituminous coal deposits of various ages from Jurassic to Oligocene-Miocene have been reported (e.g., Farquharson, 1924; MacFadyen, 1933; Grundstofftechnik, 1983). These deposits are known to exist in several localities in the country including Daban Basin southeast of Berbera, Hed-Hed valley south of Onkhor and various locations north of Erigavo. Although a number of geologic investigations were intermittently carried out since 1915, the quality of these deposits and the reserves has not been accurately determined.

In this paper, field mapping and available geological and drilling data have been used to review and document the occurrence of coal and carbonaceous shale in Somaliland. These observations provide the basis for future coal exploration, mining geology, feasibility studies and geological investigation in Somaliland.

2 Previous studies

Coal has been known to occur in Somaliland since it was first reported by Farquharson (1924) who described the analyses of coal samples collected from Hed-Hed in 1915. During British colonial occupation the geological investigation of the country increased, and as a result several more coal and lignite deposits have been discovered (e.g., MacFadyen, 1933; Hunt, 1951; Pallister, 1959; Gellatly, 1960; Hunt, 1960).

The few studies that have been carried out since independence include a United Nations Development Programme (UNDP) investigation in 1980 of the Tertiary coal and lignite occurrences in the Daban Basin, southeast of Berbera (Peeters, 1980). Further UNDP coal survey has been carried out in 1980/1981 to investigate Cretaceous outcrops north of Erigavo (Aden and Peeters, 1981). In 1983, the Bundesanstalt Fur Geowissenschaften und Rohstoffe (BGR) had carried out feasibility studies of the coal deposits of northern Somalia as part of a technical cooperation between the governments of Germany and Somalia. The fieldwork in Somalia was conducted by the consulting company of Grundstofftechnik (1983) on behalf of BGR. Grundstofftechnik (1983) conducted detailed geological and geochemical investigations on the Hed-Hed coal site. Five boreholes were drilled with maximum depth of 27 metres and trenches were excavated. Geologic investigations revealed the existence of four main coal units, designated as A, B, C and D. These units were traced over a strike length of 360 meters but probably extend over the entire Hodmo Basin, which occupies an area of 60–80 km^2.

3 Stratigraphy and depositional setting

3.1 Jurassic sequences

The Jurassic sequences of Somaliland have been investigated by several authors and a brief summary of Jurassic sedimentary rocks is given here. Detailed descriptions of Jurassic deposits can be found in MacFadyen (1933), SOEC (1954), Luger et al. (1990) and Bosellini (1992).

Jurassic sedimentary rocks of Somaliland consist of a thick sequence of conglomeratic continental deposits (basal Adigrat Sandstone) resting directly on the peneplain basement rocks and overlain by a succession of limestones (Bihendula Group), generally with some marl and shale intervals. Jurassic sediments were deposited in NW-SE trending grabens (e.g., Bihendula graben) that were formed as a result of tensional forces associated with the rifting of Africa from Madagascar-India-Seychelles (Bosellini, 1992; Bott et al., 1992). However, the Jurassic sequence is absent in the areas east of Hed-Hed and northeast of Erigavo due to either its non-deposition or Early Cretaceous erosion.

Jurassic strata outcrop in the following areas: the Borama-Zeila area of western Somaliland; the Bihendula area of north central Somaliland; and Al Mado region of northeastern Somaliland. However, the Jurassic outcrop at Bihendula, 35 kilometres south of Berbera, was the first to be recognised in the country and has since been the most extensively studied (e.g., MacFadyen, 1933; Luger et al., 1990; Bosellini, 1992). It is where the greatest thickness (more than 1,200 metres) of fossiliferous marine Jurassic beds is exposed in the country. The Adigrat Sandstone rests unconformably on Precambrian rocks and consists predominantly of medium to coarse grained quartz sandstone (Figure 4). The unit is transgressive from a lower fluvial facies to an upper littoral marine facies (Luger et al., 1990). The Adigrat Sandstone is overlain by marine sediments (Bihendula Group) containing various limestone and shale sequences of Middle and Upper Jurassic (MacFadyen, 1933; Bosellini, 1992).

3.2 Cretaceous sequences

A major crustal uplift and block faulting has affected the area prior to the Cretaceous sedimentation. This has been related to stress system imposed on eastern Africa due to the northward rifting of the adjacent Indian plate (Bosellini, 1986). As a result, the Cretaceous rocks of Somaliland unconformably overlie Jurassic or Precambrian rocks. Neocomian-Barremian interval is generally absent and Aptian sedimentation is characterised by lateral lithologic variability resulting from transgressing seas from the east interfingering with coarser terrigenous sands derived from the west. As a consequence, thick carbonate and shale sections were deposited in the eastern part of the basin and equally thick sequences of sandstones were deposited in the west. However, the Aptian transgression did not cover the entire country. For example, the Las Anod arch reminded exposed and transgressed by the sea during the Turonian (Bosellini, 1992).

The name 'Nubian sandstone' has been applied to describe the entire Cretaceous clastic sequences seen in outcrop (e.g., MacFadyen, 1933). However, the Cretaceous sequence has been divided into continental fluvial of Yesomma (also spelt Jesomma) Sandstone and marine Tisje carbonates (e.g., Bosellini, 1992). It is difficult to distinguish the different formations due to the transitional nature of the interfingering clastic and carbonate facies, although the area east of Erigavo is dominated by Tisje Formation. The best exposed section of Yesomma Sandstone in the country is at Bihendula with total thickness of 1,708 metres (MacFadyen, 1933). The succession consists of highly weathered course grain quartz rich sandstones. The contact with the underlying Upper Jurassic Gawan Limestone is unconformable and an angular unconformity has been documented at the base of the Yesomma succession (MacFadyen, 1933). In the Dagah Shabel area (south of Daban Basin), the base of the succession consist of a shaly facies, the Shabel beds, of about 300 metres thick suggesting a possible coastal plain or deltaic environment (SOEC, 1954).

3.3 Tertiary sequences

Tertiary rocks lie conformably over the Cretaceous formation and form most of the surface exposures of the country. The Tertiary sedimentary section can be divided into two parts (Figure 2).

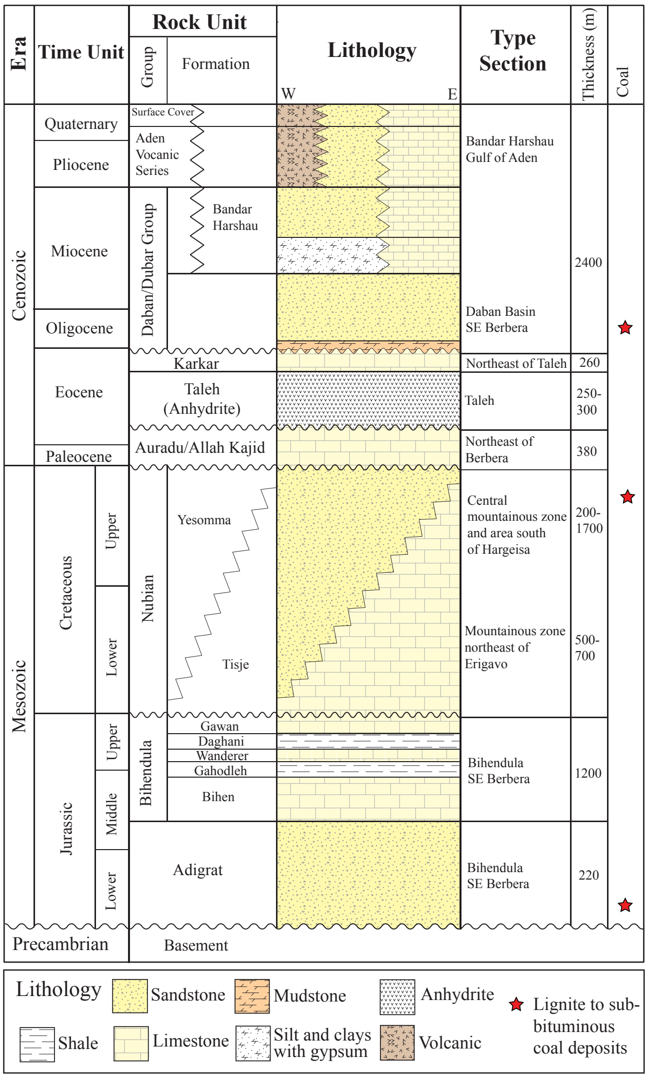
3.3.1 Eocene sequences

Eocene deposits of Somaliland consist of massive limestones of Auradu and Karkar Formations separated by massive to banded gypsum and anhydrites of the Taleh Formation. This is the result of Eocene seas transgressing from the east depositing Auradu limestones. Periodic regression in the Middle Eocene resulted in evaporatic conditions, which led to the deposition of the Taleh Formation (Anhydrite Series). Further transgression in the Upper Eocene caused the deposition of marine cherty limestone of the Karkar Formation (SOEC, 1954).

3.3.2 Oligocene-Miocene rift sequences

Oligocene and Miocene sediments are mostly restricted to narrow and isolated sub-basins along the coastal belt bordering the Gulf of Aden, occasionally extending inland in low lying regions. They were deposited in localised grabens caused by the rifting of the Gulf of Aden and consist of a thick (up to 2,700 metres) syn-rift sequence of red-brown, green sand, siltstone and gypsiferous sandstone (Bosellini, 1992; Abbate et al., 1993a). These sedimentary rocks are almost entirely terrigenous and were deposited in lagoon, delta and alluvial environments (MacFadyen, 1933; Sagri et al., 1989; Abbate et al., 1993a). The best outcrops of Oligocene-Miocene sediments occur in the Daban Basin (southeast of Berbera) bordering the Somaliland plateau (Figure 2). The sediments were deposited in fast subsiding faulted rotated block during rifting and opening of the Gulf of Aden (Bosellini, 1992; Abbate et al., 1993a). The basin is bounded to the south by the Dagah Shabel fault and to the north and east by Eocene strata of the Taleh Formation in which the Daban Group rests conformably. The Daban sequence has an east-west strike and dip gently to the south. However, close to the Dagah Shabel fault, a local syncline is recognised (Bruni et al., 1987). The sequence is overlain unconformably by alluvial conglomerates (boulder beds) of Pliocene age which is related to the uplift of the Somaliland plateau (MacFadyen, 1933; Abbate et al., 1993a).

Figure 3 General stratigraphic column of Somaliland showing stratigraphic occurrences of lignite and coal deposits (see online version for colours)



A summary of the stratigraphy of Somaliland is given in Figure 3. The figure shows the major formations, general thicknesses and known occurrences of coal in these rocks.

4 Potential coal areas

Coal deposits have been reported in many sites in Somaliland. The following occurrences have been visited on two separate fieldtrips in the country (July 2006 and July 2007). Locations of study area are shown in Figure 2.

4.1 Jurassic deposits

Location: Gal Hamud, north of Bihendula (45°09.885′E; 10°09.713′N)

In the area of Gal Hamud, eight kilometres north of Bihendula, coal stringers showing branches and trunks are deposited in the Lower Jurassic sandstones and conglomeratic beds of the Adigrat Formation which underlie the Bihen Limestone (Figure 4). The coal is contained in 5–8 centimetres thick lenses of sandstone (Figure 5). Analyses of the coal samples reported by Grundstofftechnik (1983) suggest that the coal is sub-bituminous type with low ash contents (8.1%), volatile matter content of 27.6% and relatively high calorific values (6,251 kcal kg^{-1}).

Figure 4 Basal clastics of Adigrat Sandstone showing conglomerate consisting of detrital quartz, Bihendula area, south of Berbera (see online version for colours)

Figure 5 A thin seam in Adigrat Sandstone, Gal Hamud, south of Berbera (see online version for colours)

Note: The coal is contained in 5–8 centimetres thick lenses of sandstone.

4.2 Cretaceous deposits

Location: Hed-Hed, south of Onkhor (46°14.484′E; 10°33.802′N)

Hed-Hed is located about 25 kilometres south of the coastal village of Onkhor. The coal deposits occur approximately 4 kilometres upstream in the Hed-Hed gorge from its junction with the Hodmo ravine. The main outcrop occurs on the bottom of the eastern side of the gorge. The coal occurrences at Hed-Hed were the first to be recognised in the country and have since been the most extensively studied. Hed-Hed has the greatest thickness and highest quality of coal so far exposed in the country. The coal-bearing sedimentary strata dip 5° to the south and occur in the upper part of the Cretaceous within the Yesomma Sandstone, which is overlain by massive Eocene Auradu limestone (Figures 6 and 7).

Farquharson (1924) has documented the coal-bearing that outcrop in the area and recent fieldwork has also confirmed the occurrence of seams that are exposed at the base of the Hed-Hed gorge. Two further seams were discovered during the drilling campaign carried out by Grundstofftechnik (1983), making a total of four coal seams to have been recognised in the area within a 20 metres Upper Cretaceous sequence and a horizontal extent of at least 500 metres in a north-south direction. The thickness of the coal seams varies considerably over the distance with some of the seams extending much further laterally. The stratigraphy of the coal bearing sections drilled in the Hed-Hed area is shown in Figure 8. The seams consist of multiple layers of carbonaceous material interbedded with clay, shale, marlstone and sandstone. In general, the coal is black, hard and compact with a conchoidal fracture. The seams are designated from top to bottom as shown in Table 1.

Table 1 Description of the coal seams in Hed-Hed

Seams	*Comments*
A	The seam is up to 0.4 metre thick and is overlain by a sandy unit and 25 metre thick grey shales
B	The seam is up to 1.1 metres thick with minimum horizontal exposure of about 500 metres. The seam thins in a northerly direction and is overlain by a mixture of sand and clay
C	The seam has a maximum thickness of 0.5 metre with increasing thickness to the south and is composed of carbonaceous shale and clayey coal
D	The seam is about 2.8 metres thick. The lower part comprises coaly clays and clay-rich sandstones which are underlain by massive sandstones. The upper part is predominantly coaly with the coal becoming more shaly from north to south

Figure 6 Hed-Hed gorge, south of Onkhor, showing gently dipping seams occurring in the upper part of the Cretaceous within Yesomma (Nubian) Sandstone (see online version for colours)

Notes: The coal is overlain by a 20 metres thick sandstone unit which is in turn overlain by massive Eocene Auradu Limestone. The massive conglomerate on the top is a recent channel deposit.

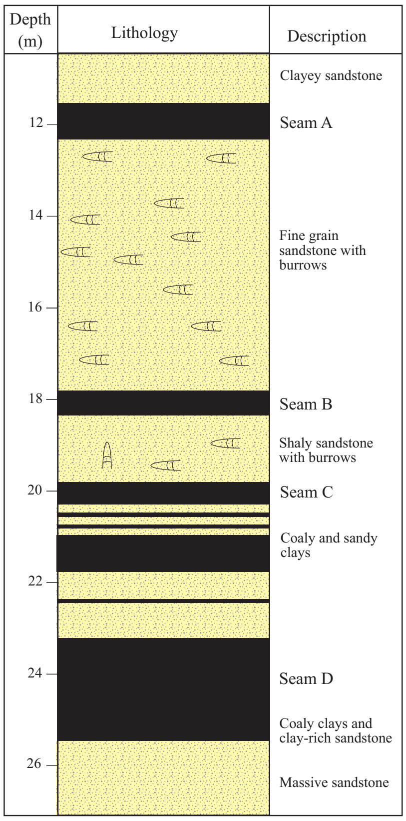
Figure 7 (a, b) Hed-Hed gorge showing gently dipping seam (see online version for colours)

(a)

(b)

Note: The coal is black, hard and compacted with a conchoidal fracture.

Figure 8 Stratigraphy of the seams in Hed-Hed gorge (see online version for colours)



Notes: Four seams have been recognised. Each seam consists of multiple layers of carbonaceous material interbedded with clay, shale, marl and sandstone.

Source: Modified from Grundsofftechnik (1983).

The coal was sampled and analysed by Farquharson (1924), Aden and Peeters (1981) and Grundstofftechnik (1983). The results of the analyses are presented in Table 2. It is not known whether the variations observed in the results reflect the petrological differences in the coal seams, differences in sample collection procedure, chemical and physical changes which occurred after the samples were taken or may be due to differing analytical procedures. For example, the moisture ranges from 8% when analysed by Grundstofftechnik (1983), to 13.24% and 17.4% when analysed by Farquharson (1924) and Aden and Peeters (1981) respectively. The calorific values show values ranging between 4,712 kcal kg^{-1} and 5,550 kcal kg^{-1}, with high ash content from 8.2% to 11.78%, and high volatile matter content at 33.9% to 38.1%. As a result, the coal is classified as being between sub-bituminous and lignite (Unsworth et al., 1991).

Samples from the drilled wells at Hed-Hed were examined geochemically and by means of coal petrography and palynology. Mineral matter from all seams shows a predominance of quartz and kaolinite (Ganz, 1990). This corresponds to the largely terrestrially derived palynomorph assemblages. Furthermore, the intercalations of clastics (quartz sandstones and siltstones) between the seams indicate stages of higher energy potential, probably related to fluvial inundations (Hidalgo et al., 2002).

Table 2 Coal analyses of Hed-Hed, Daban, Guveneh and Gal Hamud

	Hed-Hed (F)	*Hed-Hed (G)*	*Hed-Hed (A&P)*	*Daban (F)*	*Daban (G)*	*Gal Hamud (G)*	*Guveneh (G)*
Moisture (%)	13.24	8.0	17.4	9.68	7.24	5.5	8.2
Ash (%)	11.78	11.3	8.2	9.32	43.80	8.1	49.7
Volatile matter (%)	36.87	38.1	33.9	46.51	-	37.6	-
Fixed carbon (%)	38.11	-	40.5	34.49	-	-	22.8
Sulphur (%)	0.65	-	0.55	6.86	17.94	-	-
Caloric value (kcal/kg)	5,404	4,712	5,550	5,733	3,915	6,251	2,521

Notes: Letters represent sources of analyses F = Farquharson (1924); G = Grundstofftechnik (1983); seam B and A&P = Aden and Peters (1981). Samples of Hed-Hed and Daban by Farquharson (1924) were taken from about 0.5 metre from the exposed surface. Therefore, fresh unweathered seams may contain higher calorific value and lower ash and sulphur content at depth. Guveneh sample was clayey coal.

The maceral and total organic carbon (TOC) analyses of samples are highly variable (Table 3). The analyses indicate that Liptinite (18%–90%) and Huminite (10%–73%) are the dominant macerals assembles (Ganz, 1990). Inertinite contents are very low (< 10%) indicating that the seams were possibly deposited in a large shallow basin which was rarely subaerially exposed, thus the conditions favourable to formation of inertitine macerals, like oxidation and forest fires, were uncommon during peat accumulation (Taylor et al., 1998). In addition, the palynological analyses of core samples from shallow boreholes in the Hed-Hed area yielded predominately terrestrial microfloras (Schrank, 1990). This suggests that the coals have developed under humid conditions in tropical lowland with rivers, fresh lakes and swamps. Moreover, low sulphur (0.65%) content of the Hed-Hed coal indicates depositional conditions without marine influence possibly deposits of upper delta plain. This is because high sulphur content in coal is generally explained by the proximity of the peat to sea waters that can provide an abundant source of sulphur during deposition (Cohen et al., 1984; Given and Miller, 1985).

Table 3 Maceral composition and reflectance and TOC measurements of Hed-Hed coal

Seam (depth in metre)	*Maceral composition*				*R_o (%)*	*TOC*
	Liptinite (%)	*Inertinite (%)*	*Huminite (%)*	*Min. matter (%)*		
A (11.81)	18	9	73	52	0.39	30.30
B (18.37)	90	0	10	60	0.38	1.48
C (21.55)	90	0	10	48	0.40	15.97
D (24.10)	56	8	36	38	0.44	25.16

Source: The measurements are taken from Ganz (1990).

The analyses also indicate that the coal in Hed-Hed gorge falls into the rank of sub-bituminous with vitrinite reflectance (%R_o) ranging from 0.38 to 0.44. The vitrinite reflectance values also generally increase with depth (Table 3). However, tectonic events during the formation of the coal seams that caused horsts and grabens (Bosellini, 1992) and rapid differential compaction of peat and sand-dominated sedimentary sequences on the delta plain may have differentiated the area into various smaller basins separated by local highs (Grundstofftechnik, 1983).

Location: Guveneh Range (46°01.020′E; 10°27.010′N)

Guveneh hills are located about 32 kilometres north of Las Dureh and 30 kilometres southwest of Hed-Hed. Gellatly (1960) visited the area and recognised a seam that is exposed within the Yesomma sandstone near Haro gorge on the western margin of the Guveneh hills. The seam is 30 centimetres thick and consists of laminated coal associated with carbonaceous shale. Grundstofftechnik (1983) revisited the area and reported three gently dipping coal-bearing horizons that are exposed in the area. They are located in the uppermost part of the Cretaceous succession, with a similar stratigraphic setting as the coal seams of Hed-Hed.

In July 2007, the author visited the Guveneh area and recognised that seam 1 consists mainly of 10 centimetres thick beds of coal fragments within a sandy matrix. Seams 2 and 3 are situated about 50 metres below seam 1 and consist of black carbonaceous shale. The lowermost bed of horizon 2 is up to 17 centimetres thick and consists of a soft clayey coal. The three seams can be followed to at least 3 kilometres to the south and show almost unaltered composition. Samples collected and analysed by Grundstofftechnik, (1983) suggest that the coal is of generally low quality with high ash contents (49.7%) and low calorific values (2,521 kcal kg^{-1}) (Table 2).

The plant fossils in the coal bearing horizons reported by Grundstofftechnik (1983) indicate that peat was deposited in swamps where the vegetation was not dense enough to develop clean coal beds. Similar depositional environments are suggested for other Upper Cretaceous coal layers such as the Hed-Hed seams.

Other coal seams of varying thicknesses have been reported at various locations in the country (Aden and Peeters, 1981; Grundstofftechnik, 1983) including several Cretaceous deposits along the escarpment approximately north and east of Erigavo (e.g., Har Araale and Ham-Ham). In addition, Fantozzi and Ali-Kassim (2002) have reported two lignite horizons within continental arenaceous formation of Yesomma Sandstone in Dhurbo area, northeast of Somalia. All of these deposits have been formed in Upper Cretaceous strata but none can be regarded as being sufficiently enough to warrant commercial development.

4.3 Oligocene-Miocene deposits

Location: Daban basin, southeast Berbera (45°12.825′E 10°20.858′N)

Oligocene-Miocene lignite deposits have been found on the southern slopes of Al Wein Range of Biyo Gure gorge about 25 kilometres southeast of Berbera (Daban Basin). The seams have been reported by Farquharson (1924) and Hunt (1960). Abbate et al. (1987) and Abbate et al. (1993a) have also recognised thin lignite horizons within the basin. On a recent visit to the area the author observed two seams at the bottom of the gorge in two separate locations about three kilometres apart. The maximum thickness of each seam is about 30 centimetres and the horizontal outcrop distances are about 30 metres, although the seams probably extend over a wider area within the Daban Basin. However, in weathered surfaces correlation between coal seams becomes impossible.

The seams crop out within the lower Daban Group, which consists of shales, clays and sandstones. The Daban succession shows a variation from shallow marine at the base to continental sediments at the top (MacFadyen, 1933; Sagri et al., 1989; Abbate et al., 1993a). The lower Daban Group has a very high content of shallow marine fossils, such as nautiloids, nummulites, ostracods and gastropods (MacFadyen, 1933; Sagri et al., 1989; Abbate, et al., 1993a). In contrast, the upper part of the sequence contains few fossils such as Cichlids (fresh-water fishes) (Abbate et al., 1993a) and silicified trees (MacFadyen, 1933). The coal bearing sections are overlain by gypsum-dominated unit. The coal deposits consist mainly of lignite (dull-bright coal) with numerous cleats, breaks and conchoidal fractures.

Figure 9 A seam in the lower Daban Series which consists of shales, clays and sandstones, Daban Basin, southeast of Berbera (see online version for colours)

The coal was sampled and analysed by Farquharson (1924), the results of which are presented in Table 2. The analysis suggests that the deposits are of high quality with low ash (9.32%) content and relatively high calorific values (5,733 kcal kg^{-1}), corresponding to a rank of hard lignite to sub-bituminous coal. However, analysis of samples taken by Grundstofftechnik (1983) suggests that the coal is of relatively poor quality with high percentages of ash (43.80%) and sulphur (17.94%) and low calorific value (3,915 kcal kg^{-1}). The vitrinite reflectance (R_o) for the coal samples ranges between 0.48 and 0.54 (Grundstofftechnik, 1983), which is considered high for lignite. This deposit has the potential to be used as an energy source for the cement factory in Berbera, which is located less than 8 kilometres from the deposit and as feedstock for a power station.

Preservation of fossils (e.g., gastropod shells) in the coal seams suggests that water acidity was probably very low (Pickford, 1986). In addition, gypsum dominated unit overlying the coal seams indicates that the sulphate content in waters was probably raised as a result of evaporation under dry conditions. Both low acidity and high sulphate content in water heavily enhances sulphur content. These observations suggest that the coal seams were deposited in an estuarine environment that was subjected to marine transgressions, which increased the sulphur content of the peat. In addition, high ash contents indicate inadequate isolation of peat forming environments from clastic influx (Koukouzas and Koukouzas, 1995). This interpretation is consistent with sedimentological studies of Abbate et al. (1993a) which suggested that the lower Daban Group is deposited on restricted lagoon to deltaic environment.

5 Reserve estimates

The investigation indicates that the most important coal bearing sequences are found within the Upper Cretaceous formation of Yesomma Sandstone. The Jurassic aged coal deposits are very thin while the Tertiary deposits are poor in quality.

The available data on the coal deposits of the Upper Cretaceous is currently inadequate for definitive evaluation of either the quantitative or qualitative factors of the resource. The potentially coal-bearing sequences in the upper part of the Cretaceous sequence are often not exposed for regional investigation due to the thick coverage of Auradu limestone. Both in Hed-Hed and the Guveneh areas the coal deposits occur 40–50 meters below the base of the Auradu limestone which is highly resistant to erosion and weathering. As a result, the outcrops of coal-bearing beds are only exposed over small distances making it difficult to adequately evaluate their quality and reserves.

Furthermore, open cast mining will probably not be economically feasible due to the high stripping ratio (>10) and thick and hard overburden rocks (Auradu limestone) which will require considerable drilling and blasting prior to excavation. Another major problem for future development of this resource is that the deposits are located hundreds of kilometres from the major cities of the country (such as Hargeisa, Burao and Berbera) and there is currently no road access to any of the deposits. To reach the Guveneh deposit it currently takes at least a day of off-road driving and trekking on foot from the Las Dureh village. Therefore, all of the coal deposits which have been investigated are not presently recognised as being a resource or reserve due to their relatively low calorific value, poor quality, high ash and sulphur contents, and difficulties in accessing the deposits. The deposits may still have the potential to provide an important alternative fuel resource in the future. However, further investigation of the coal deposits of Somaliland, including drilling and laboratory analyses particularly of the Upper Cretaceous coal seams, is required to effectively evaluate the quality and resource potential of these deposits.

6 Conclusions

The outcrops and available geological and drilling data show that Somaliland has high potential for coal deposits. In summary this study found that:

- Lignitic to sub-bituminous coal deposits of various ages from Jurassic to Oligocene-Miocene have been formed at various locations across the country, including Hed-Hed valley south of Onkhor, Guveneh north of Las Dureh and Daban Basin southeast of Berbera.
- The Jurassic coal of Gal Hamud has the highest quality with low ash content and high calorific values. However, the coal bearing horizon is very thin.
- Four seams of varying thickness are recognised in the Hed-Hed area within the Upper Cretaceous Yesomma (Nubian) Sandstone. These seams are lignite to sub-bituminous in rank with calorific value of 4,712 kcal/kg to 5,550 kcal/kg, moisture content of 8% to 17.4%, volatile matter of 33.9% to 38.1%, sulphur content of 0.55% to 0.65% and vitrinite reflectance (%R_o) ranging from 0.38 to 0.44.
- The depositional environment for the formation of the Hed-Hed and Guveneh coal seams was upper delta plain with peat swamps that were not dense enough to develop clean coal beds. Both in Hed-Hed and Guveneh the peat accumulations were not isolated from clastic influx and, as a result, high ash content of impure coals developed.
- Oligocene-Miocene coal deposits of the Daban Basin have lower quality compared to the other deposits. The coal has a high percentage of ash and a relatively low calorific value. The depositional environment for the formation of the seams was that of an estuarine with low acidity and high sulphate content.
- Available geological and drilling data of the coal seams are inadequate to accurately estimate reserves of the deposits. The coal bearing sequences of Upper Cretaceous are unexposed in many parts of the country and therefore inaccessible for regional investigation.
- Coal deposits preserved in the country have the potential to alleviate the growing shortage of traditional fuels and assist in reducing dependence on imported energy. However, more exploration work and in particular sub-surface drilling is needed, especially in the Cretaceous basins to determine the lateral extent, thickness and quality of the deposits.

Acknowledgements

I am grateful to Suleiman Weirah, Suleiman Mohamed Ali and Sahal Adan Mohamed for assisting my fieldwork in Somaliland. I thank Ahmed Behi, Ahmed Ali and James Small for many valuable discussions. Two anonymous reviewers greatly improved the manuscript.

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