Geological characteristics and economic evaluation of oil shale deposits in Tigray, Ethiopia

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Abstract

The oil shale deposits in Tigray are widely distributed in the eastern and central part of the region. The oil shale deposits are of upper Paleozoic in age and are found as remnant of the Cretaceous erosion period underlain by tillite and overlain by sandstone. They are formed during the glacial retreat followed by marine deposition of shale in a basin which had been created by the enormous load of the glaciers. The deposits have an average mineable bed thickness of 55 meters, which on the upper part show interbeds and laminations of shaley limestone and cover an area extent of 30.38 km^2. The resource is estimated to be 3.89 × 10^9 tonnes. The shale shows regular closely spaced fracturing towards $N30^0W$ dipping 80^0E and $N70^0E$ dipping 75^0NW. Open cast mining of the oil shale is more preferable than in-situ retorting in Tigray. Ethiopia is a very poor country and is a net importer of fuel which expends a huge amount of hard-currency and contains no known petroleum reserves. Thus the exploitation of the Tigray oil shale deposits is an excellent alternative to fulfill the fuel and other petroleum product demand of the country.

Keywords: Oil shale, fracturing, open cast mining, Tigray.

Introduction

Ethiopia is a net importer of fuel and a very poor country which expends a huge amount of hard-currency to fulfill the fuel demand. In the last two months only (August and September 2006), spends about 160 million dollar. In this Ethiopian budget year the government has planned to import about 767,655 metric tonne of fuel with total expense of 1,031,107,670 US dollar (Reporter Sept. 2006), which is about 50 % of the total hard currency it gain. Ethiopia contains no known petroleum reserves. Thus the exploitation of the oil shale resources through out the country is an excellent alternative to save the country's currency for other urgent (development) needs.

The country has great potential of oil shale resources in most part of the provinces. The Tigray province is located in the north most part of the country. The oil shales in Tigray are generally of Upper Paleozoic-Mesozoic age, part of the Edaga Arbi Formation.

This study was based on the quick survey carried out at Bizet, Edaga Arbi, Nebelet, and Atebe areas, all in Tigray Region, to determine the resource potential and describe its geological characteristics (Figure 1).

Geology

The area is covered by the sedimentary succession of Upper Palaeozoic to Mesozoic age, and is exposed as erosion remnants of cliffs that found underlain unconformably by the basement Proterozoic Upper Complex metamorphic rocks.

The basement named Upper Complex have been folded but subjected to only the lowest grades of metamorphism mainly of greenschist facies. It includes the Tsaliet Group, the Tembien Group, the Didikama Formation, and the Matheos Formation (Beyth, 1971, Kazmin and Garland, 1973, and Garland 1980). The Tembien group, the Didikama Formations, and the Matheos Formation are metasediments, in contrast to the Tsaliet group which is mainly of metavolcanics (Garland 1980).

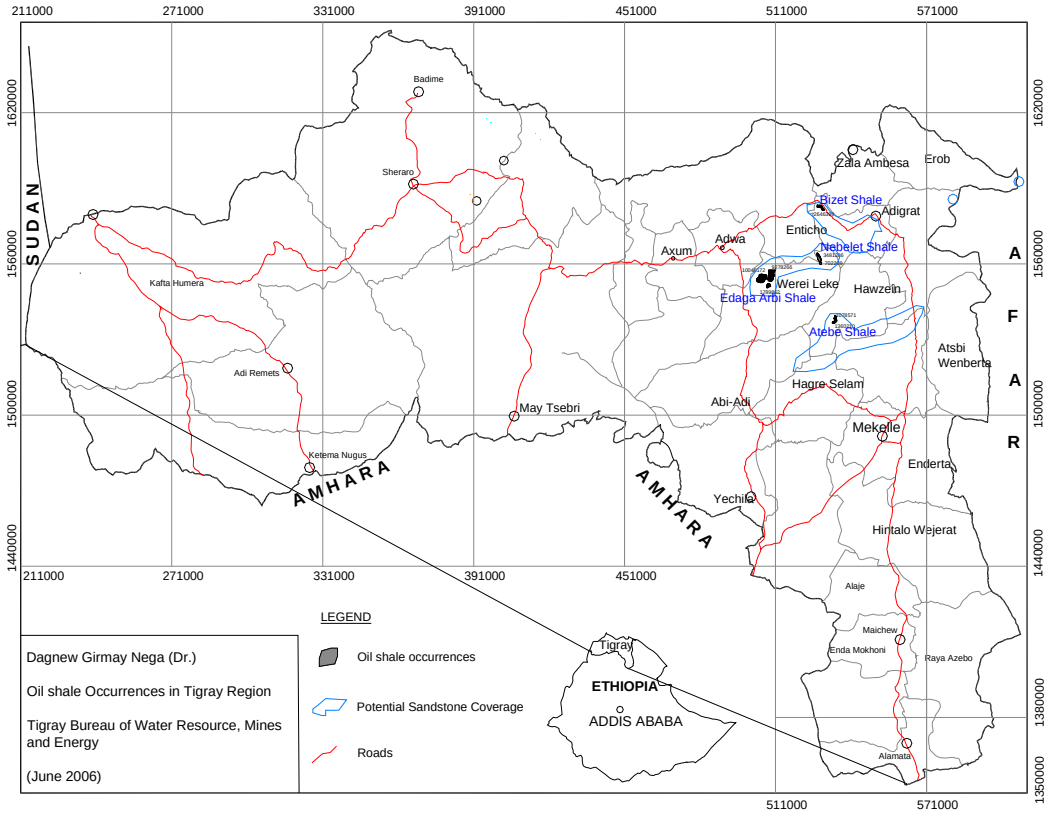

Figure 1 Location map and potential oil shale occurrences in Tigray

After the peneplanation of the continental land surface in the Lower-Middle Paleozoic, clastic deposition began, probably during the Upper Paleozoic (Garland 1980); and this whole succession is resting unconformably on the Precambrian rocks. This succession consists of three formations named Enticho Sandstone, Edaga Arbi Glacials, and Adigrat Sandstone (Blanford, 1870, Dow et al., 1971, and Garland 1980). The Enticho Sandstone and Edaga Arabi Glacials have been observed underlying the basements, however, if found together the Enticho sandstone is deposited earlier to the galcials.

The Enticho sandstone is a white medium grained quartzite without or coarse cross-bedding, which grades to siltstone and then to friable black shales of the Edaga Arbi Glacials. The Glacial unit consists of calcareous tillite which is poorly sorted fragments of quartz supported pebbles of metavolcanics, rounded granite, and boulders of gneissic rocks. This glacial grades to the deposition of friable shales which make up the greatest thickness of the glacials. This thick shale deposition is the potential oil shale resource in the Tigray region of Ethiopia. The probable sequence of events to the Edaga Arbi Glacials and the Enticho Sandstone is explained by Garland, 1980, as follows:

- Deposition of sandstone in continental fluviatile and subaerial environment;
- Glacial age begins: outwash from glaciers forms coarse sandstone channeled by migrating braided streams:
- After reduction of relief, a small rise in sea level and a change to warmer climate, deposition in very quite lacustrine or shallow marine conditions:
- Return of glacial conditions: deposition of moraine:
- Gradual retreat of glaciers with rising sea level; generally marine deposition of shale with some fresh water periods, forming thin limestones and varves.

The age of shales from the Edaga Arbi Glacials have been dated as Devonian or younger (Garland, 1980).

The uppermost unit of the clastic sequence, named Adigrat Sandstone, rests with undulating unconformity on the Edaga Arbi Glacials (shale) and on the Enticho Sandstone. The Adigrat sandstone is yellowish to pink fine to medium grained, non-calcareous

quartz sandstone with well sorted rounded grains; it is cross-bedded and current bedded (Garland, 1980) and is estimated to be deposited on Upper Triassic to Middle Jurassic (Mohr, 1963) (Table 1).

These clastic successions are observed grading to the Antalo Succession in the region, which consists of Antalo Limestone and Agula Shale. The Antalo limestone is conformable on the Adigrat sandstone and is estimated to be formed on Upper Jurassic which consists of limestone and marl sequences. The formation grades to Agula shale which include limestone, shale, gypsum, and dolomite; and the top units of the limestone appear more shaly and gypsiferous. These formations mainly cover the Mekelle basin and have been investigated for the probability of existence of petroleum resource.

Geological Characteristics of the Oil Shale

The oil shale deposits in Tigray is widespread under the Adigrat Sandstone, which covers a large portion of the region, and is found exposed covering a large area at Bizet, Edga Arbi, Nebelet, and Atebe. The current study is based on the shale outcrops in these areas, which is proportionally small compare to the occurrence coverage of the shale in the region (Figure 2).

Bizet Area

The Bizet area is about 135 km from Mekelle, the capital city of Tigray region, Ethiopia and is accessible by the Addis Ababa-Adwa main road. The shale lies over Enticho Sandstone and clearly under the tillites and Adigrat sandstone. It is black and marly shale. The characteristics of the shale vary from the Bizet city to the way Debre Damo. The exposed rock near the city is totally black marlstone and massive,

Table 1 Summarized stratigraphy of the area.

Age*	Rock units		Description	Physiography
Tertiary	Trap Series	Basalts, Trachyte, and Basanite	Lava flows horizontally underlying sandstone	Mountains, cliffs, hills
Middle Jurassic - Triassic	Adigrat Sandstone	Laterite	Weathering of sandstone rich in haematite	Steep cliffs, hill top plateau
		Sandstone	Medium grained, cross bedded pink-white sandstone	
Permian-Devenion	Edaga Arbi Glacials	Tillite	Composed of fragments of metvolcanic and boulders of granite and gneiss.	Bottom of cliffs
		Silty shale	Friable beds of silt and limestone	
		Shale	Black to grey, friable, with laminations of limestone	
Carboniferous-Devenion	Enticho Sandstone	Glacial Sandstone (conglomerate)	Fragments of granites cemented mostly by calcite	Low cliffs, low terrains
		Sandstone	Non or coarsely cross-bedded, with beds of shale, silt, and ferruginous bands	
Proterozoic	Precambrian basement rocks	Metavolcano-sedimentary rocks	Metaandesite, dolomite, crystalline limestone, schists, slate, marble, granitoids	Ridges, low land areas

*Based on the relative age estimation of Mohr (1963) and Garland (1980).

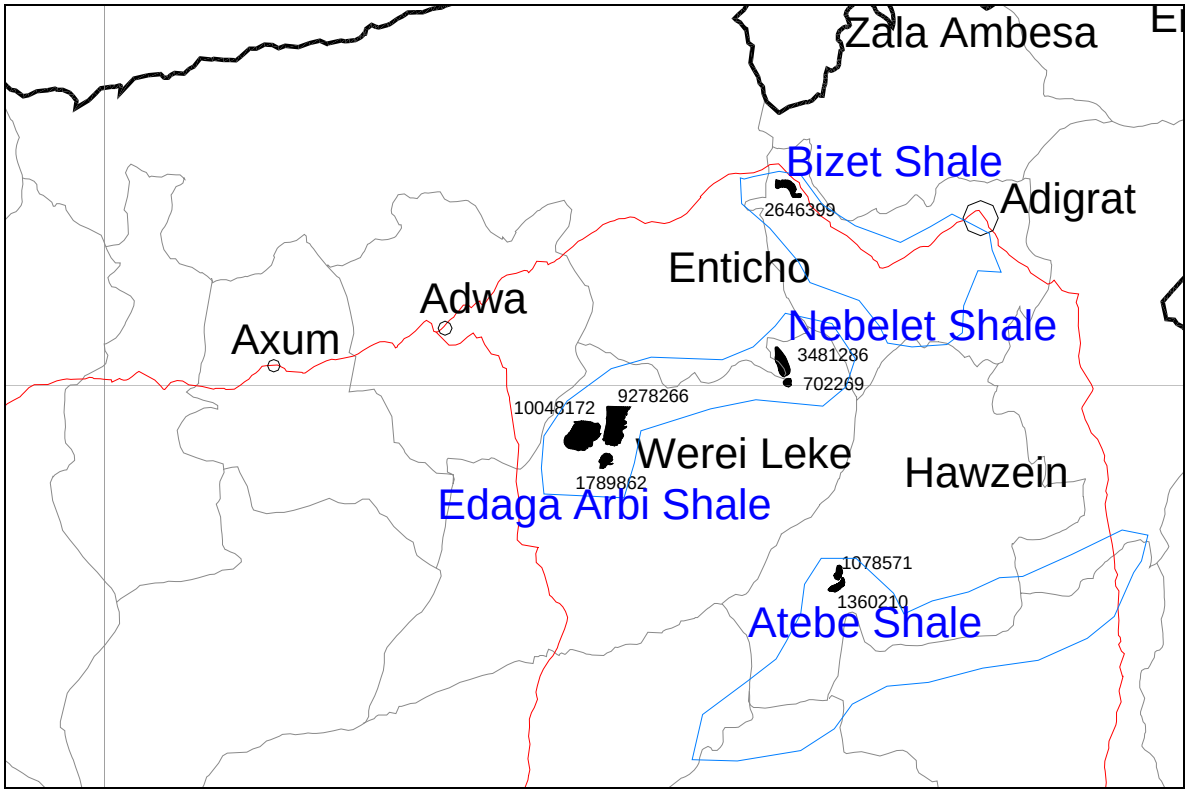

Figure 2 Location and area coverage estimates of the oil shale occurrences of Tigray

while the outcrops near the school on the way to Debre Damo is friable, black shale, and have brown streak (Figure 3).

Edaga Arbi Area

The area is about 125 km from Mekelle and is accessible along the all-weather road Mekelle-Wikro-Hauzien-Nebelet-Edaga Arbi. The oil shale is exposed all around the Edaga Arbi city and is observed overlain by the Adigrat Sandstone and sometime by tillites with horizontal bedding. It has about 55 meter thickness of exposed part, and may still continue to depth (Figure 4). The shale is totally friable, black to dark brown in color, and shows brown streak. It is observed showing lamination of limestone increasing in frequency as you rise up to the top. This shows time gap frequent deposition of shales in varying environment. The shale show regular N30^{0}W dip-

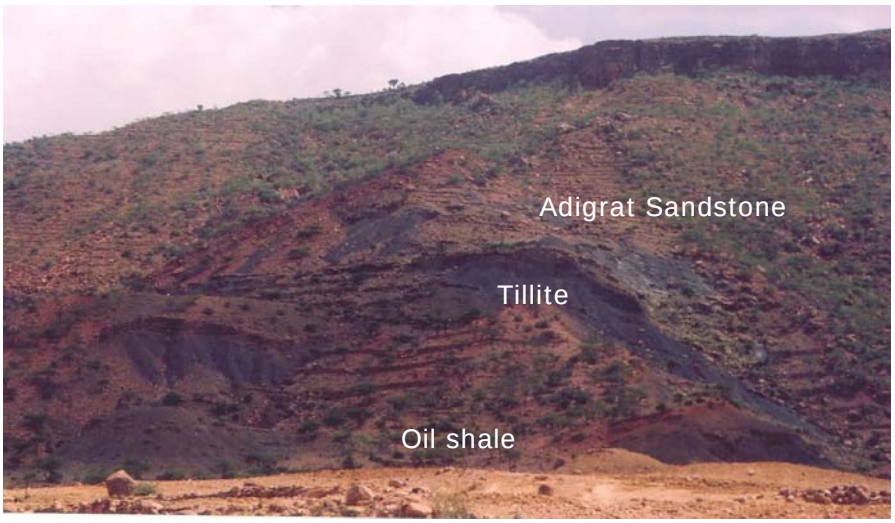

Figure 3 The oil shale at Bizet lies over Enticho sandstone and under Adigrat Sandstone.

Figure 4 The Edaga Arbi shale exposures showing overlain by Adigrat Sandstone and showing laminations of shaly Limestone (increasing its frequency towards the top).

ping 80^{0}E and N70^{0}E dipping 75^{0}NW trending fractures (Figure 5), which makes it a good aquifer beside the sandstone. There is a spring which flows from this shale and used by the local people as holy-water for traditional medication purpose.

Nebelet Area

The shale is found exposed on northern part of the small village, Nebelet, around

Figure 5 Regular fractures trending N30^{0}W dipping 80^{0}E and N70^{0}E dipping 75^{0}NW on the Edaga Arbi shale.

95 km from Mekelle. The shale shows horizontal bedding underlain by erosion remnant of Adigrat sandstone, which forms plugs of sediment in the area. The thickness of the shale is difficult to estimate, because can not be detected its bottom contact, however, has about 45 meter exposed thickness. The shale is black, friable, and shows laminations of shaly limestone, which its frequency increases to the top of the layer (Figure 6).

Atebe Area

Atebe is found about 13 km south of Hauzien along the Hauzien-Abi Adi road. The shale is exposed along the main Atebe River and also on the slope of the ridges covered by Adigrat Sandstone. The shale on the river is an under thrown part of the main shale by tectonic fault, it is underlain directly by the basement metamorphic rocks. The shale is black, friable, and has shown an intensive lamination of limestone increasing its frequency towards top of the layer. It is intruded by sub-volcanic dykes striking the same as the trend of the fault, which is N30^{0}W (Figure 7).

Economic Evaluation of the Oil Shale

The oil shale occurrences in Ethiopia have been known since the mid 1950th and investigation have been done at Wollo province in the northern part of Ethiopia. The laboratory result of samples during that time have proved that the shale contain at least 6 per cent of petroleum volatiles (Astrup, 1956). However, due to the high mining cost, the projects were not feasible and have been ceased since then. The Ethiopian Geological Survey (EGS) has also conducted many exploration projects for coal and shale discovery in different part of Ethiopia. The projects were successful in identifying many occurrences and some of them have given a kerogen value of 120 litre/ton (personal communication with Gashawbeza Mengistu, Regional Department, EGS).

Ethiopia is sole importer of fuel and fuel products, and estimates about half of its hard currency spent to fulfill the country's fuel demand. As all know, Ethiopia is the poorest country on which each cent counts in its economic development. The country is dependent on agricultural and livestock products to earn hard currency and almost all spent on fuel, weapon, and few for fertilizer expenses, never used in any economic development projects of the country. Such policy is hard to be changed, except there is a total change of better government. However, the only way to support this country is to search an alternative ways of reducing hard currency expenses on items imported except weapons. The most possible alternative is to reduce expenses on fuel by developing and producing the oil shale resource in the country.

Figure 6 Shale is observed overlain by Adigrat sandstone and partly covered by landslide debris of sandstone.

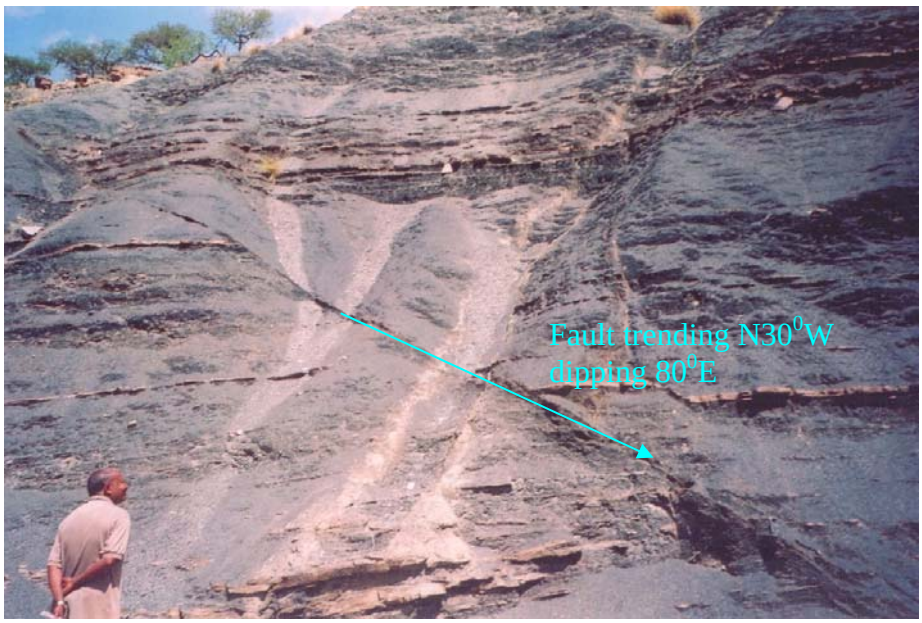

Figure 7 Shale exposed on the bank of Atebe River and showing bed-mark of fault which trends N30^{0}W and dipping 80^{0}E.

Ethiopia has no any well known conventional petroleum resources, however, is blessed with extensive oil shale occurrences all over the country. The government has to give attention and commence an exploration to discover oil shale deposits with out any delay to support its need of hard currency.

The quick survey done to discover oil shale in Tigray has found very vast area coverage of shale overlain by Adigrat Sandstone on the region. Most of the shale are covered by weathered floats of debris of sandstone, though, have been observed exposed at Bizet, Edaga Arbi, Nebelet, and Atebe. These are the sites observed by the team; there may be still many other undiscovered exposures in the region.

The resource estimation was calculated based on the section exposed on surface and its area coverage on the area coverage of the overlying sandstone. Although the shale have horizontal bedding and is unconformably overlain by Adigrat Sandstone, at places it disappears or have thin beds (up to 10 meters) like in the Adigrat area, where thick succession of sandstone occurs. Such disappearance occurs on places of highlands and the shale thickness increases on the rims of Werri glacial basin. The Werri glacial basin is surrounded by rims of peaks of sedimentary ridges and currently is covered by exposed basement rocks due to erosion. The shale is found exposed on the slope of these rims of sedimentary ridges.

Thus to calculate the real potential of these shale requires a detail exploration works, because the area coverage of the sandstone is extremely vast in the region. This study only estimated the observed exposed shale on the mentioned areas above (Figure 2). Based on our observation in each area the shale is estimated to cover an area of:

- Bizet shale = 2.65 km^2
- Edaga Arbi shale = 21.11 km^2
- Nebelet shale = 4.18 km^2
- Atebe shale = 2.44 km^2

The shale covers total area coverage of 30.38 km^2 and based on the section observations the average possible mineable bed thickness is about 55 meter (exposed thickness). Therefore, the resource of the observed area is to be 3.89 billion tonnes of shale.

Summary

The shale in Tigray region is found dispersed under the Adigrat Sandstone all over the erosion remnant of sedimentary chain ridges. It is formed during the glacial retreat followed by marine deposition of shale in the Werri glacial basin created by

enormous load of the glaciers. It is black, friable, shows brown streak, and laminations of shaly limestone which their frequencies increase to the top of the layer. These are an evidence of frequent and continuous deposition of the shale in different environmental conditions. The shale have been displaced by tectonic faults which caused a closely spaced regular fractures which trends to towards N30^{0}W dipping 80^{0}E and N70^{0}E dipping 75^{0}NW. It is also observed intruded by sub-volcanic dykes which trend the same trend as the fault towards N30^{0}W dipping 80^{0}E.

Even if, the kerogen value is not yet analyzed, the geological characteristics of the shale and the amount of resource in Tigray show that it is possible to be mined by in-situ retorting underground method. However, the resource is exposed and it will be more economical if mining is conducted by open cast. The by product, ash, can be used in many industrial purposes by the government, company, and/or by the local people of the area.

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