

EXPLORATION UPDATE:
**HYDROCARBON POTENTIAL OF THE PUNTLAND OUTER CONTINENTAL
SHELF, SLOPE AND DEEP WATER MARGIN.**

RANGE RESOURCES, LTD

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EXECUTIVE SUMMARY

INTRODUCTION.

Petroleum exploration has been underway in Somalia and Puntland State since the 1950's. Previous companies which conducted exploration there included Shell, Conoco, OXY, AGIP, ELF, Amoco, Amerada Hess, Standard Vac, and Sinclair, amongst others. Exploration in Somalia came to a halt with the outbreak of an internal civil war in 1990.

With major oil discoveries in the Marib and Masila basins of Yemen (Figures 2 and 3), exploration interest has been renewed in the more stable Puntland State of Somalia with current activity comprising onshore mineral exploration programs by Range Resources, Ltd, and oil exploration by Africa Oil, Inc. Range Resources is interested in pursuing exploration opportunities offshore in Puntland both on the shelf, slope and deep water areas.

This report summarizes an initial assessment of the oil and natural gas potential of the Puntland OCS region. Data used to complete this assessment includes a literature search, previous company well reports where available, several anonymous studies (Anonymous, 1988a, b) completed for the Somalia Ministry of Mines and Water Resources (MMWR), a World Bank Study completed in 1991 (Bott, et al, 1992, Robertson Group, 1991a, b), and a review and preliminary interpretation of selected existing 2-D seismic lines acquired during the 1980's by Cities Services Somalia (later OXY Somalia).

TECTONIC SUMMARY.

The post-Paleozoic tectonic evolution of the Puntland continental margin is controlled by three major events. First, the Late Permian to Early Triassic Karoo rift belt extends into the Horn of Africa region (Bott et al, 1992; Bosworth et al, 2005). These Karoo rifts are controlled by Precambrian basement trends and in turn were reactivated in part during Mesozoic and Cenozoic

time. The Karoo System is unproductive, from a hydrocarbon prospective standpoint, in the Puntland region.

Two major Mesozoic tectonic developments influenced the region. The first was the separation of India and Madagascar from Africa by plate tectonic movement. India/Madagascar separated from Africa during earliest Jurassic time (151-159 ma – Jurassic magnetic quiet zone- Callovian – Early Oxfordian; Bosellini, 1992; www.scotese.com). The initial relative movement of India/Madagascar away from Africa was in a North-South direction with the Davies fracture zone forming the western transform margin. Seafloor spreading commenced at this time and ended during Early Hauterivian time (120-121 ma; Early Cretaceous; Bosellini, 1992; www.scotese.com). Initially, India moved south and then separated and drifted north along the Puntland continental margin (Figures 4 and 5). By 94 MA (late Cretaceous), India/Madagascar was fully separated from Africa, and by 66 ma (K/t Boundary time), Madagascar had separated from India (Figure 4 and 5).

The eastern continental margin of Puntland developed initially as a left-lateral sheared margin during Late Cretaceous and Paleocene time (Bosellini, 1992) followed by subsequent right lateral movement (Anonymous, 1988a). This wrench movement left a narrow continental shelf with an initial rift of 10 km wide. The overall tectonic history is one of combined extensional-compressional tectonics, as is the case elsewhere along the East African margin (Law, 2009). This shelf is characterized by limited sediment storage capacity since inception, and a steep slope that likely favors development of extensive slides and debris flows in deeper water settings (cf. Wood, 2009).

Associated Mesozoic basins comprise a critical element in the tectonic evolution of Somalia. They originated during early Jurassic initial rifting and subsequent separation of Africa and India/Madagascar. Their NW-SE trend parallels Precambrian basement trends which were reactivated to form other regional Mesozoic basins (Bosworth et al, 2005). Many are associated with later (down-to-the coast) faulting (Anonymous, 1988b). Some of these basins extend from Yemen into Puntland and Somaliland (Anonymous 1998a, b; Bosworth et al, 2005). It was these onshore basin that were actively explored between the 1950's and 1990 in Somaliland, Puntland and southern Somalia. Promising shows were reported. Roll-over anticlines and structural traps overlying Karroo-age fault blocks comprised the major onshore plays.

The Marib and Masila basins of Yemen extend onshore in Somaliland and Puntland as the Berbera and Al Medo basins (Figure 3). These Puntland and Somaliland basins attracted interest with successful discoveries in the Marib and Masila basins. The Nogal basin was actively explored by Conoco as recently as 1988 to 1990.

Formation of the Gulf of Aden is the second major tectonic event to control the development of the Puntland continental margin. It formed in response to a combination of basaltic plume

development in Ethiopia and SW Yemen at around 31 ma (Early Oligocene) followed by rhyolite volcanism at 30 ma (Bosworth et al, 2005, Hughes et al, 1991). This volcanism spread into western Saudi Arabia. Accompanying this volcanism was regional extensional faulting until 25 ma ((late Oligocene; Bosworth et al, 2005). The Gulf of Aden was initiated during mid-Oligocene time (around 28 ma) by linkage of the Owen fracture zone with the Afar plume in Ethiopia. This extension was driven by slab pull beneath the Urumieh-Doktar area on the north side of the Arabian shield (Figure 6, 7, and 8). Rifting began with the onset of development of the Afar plume around 31 ma. In the Gulf of Aden, the position of accommodation zones was influenced strongly by Mesozoic rift basins.

Ocean floor spreading initiated the Sheba Ridge around 19-18 ma, and propagated west into the Central Gulf of Aden by 16 ma (Early Middle Miocene; Figures 6, 7, and 8); Bosworth et al, 2005). NW-SE-oriented Mesozoic rift basins straddling both Yemen and Puntland and Somaliland were rifted apart and occur on both sides of the Gulf of Aden (Figure 8). These initial rift basins were 60 – 80 km wide. The stratigraphies of the Gulf of Aden Margins match (Figure 9) confirming the pre-rift extent of NW-SE trending Mesozoic basins from Yemen to Puntland and Somaliland.

Because the Gulf of Aden is geologically young, the Puntland and Somaliland margin is characterized by a narrow shelf flanked by the rift shoulder of the Migiurtinia Highlands (Figure 8; Bosworth et al, 2005). These give rise to local fan deltas along the North Puntland coast (Sgavetti et al, 1995; see later discussion on play concepts).

SOURCE ROCKS:

A review of potential source rocks is required to assess petroleum potential from a global perspective shows that six global major episodes of source bed generation are known (Figure 10; Klemme and Ulmishek, 1991). Of these, the Upper Jurassic, Aptian-Turonian and Oligocene-Miocene episodes are represented in the stratigraphic column of Puntland and Somaliland (Figure 10, 11, 12, and 13; Ali, 2006).

Oil seeps associated with Late Jurassic outcrops were reported by earlier workers (Anonymous, 1988a, b) from British and Italian colonial days in the Bihendula and Dagah Shabel regions in the Berbera basin of Somaliland. These seeps were generated from the Daghani Shale and the Gahodleh Shale. Their discovery led to early drilling during the 1950's by Standard Vacuum of the Dagah Shabel-1, Dagah-Shabel-2, and Dagah Shabel-3 wells. Although shows were encountered, the area was deemed non-commercial. Similarly, the AGIP Cotton-1 well was drilled in the Daban basin and again results were no different than the Standard Vacuum wells. That drilling showed lignite in the Eocene/Oligocene Lower Daban Series was also a potential source rock (Anonymous, 1988a, b; Robertson Group, 1991,a, b).

Drilling by Shell in the Gulf of Aden at the Bandar Harshau-1 and the Dab Qua-1 wells confirmed the lateral extend of the Daghani Shale, as well as source beds of Aptian-Albian shales (Jesomma Shale) and Middle Eocene shales (Anonymous, 1998a, Ali, 2006). Thus, good source rock potential appears to exist in the Puntland margin (Table 1).

The stratigraphic relationship of source rocks to reservoirs, seals and traps are shown in Figures 11, 12 and 13, demonstrating the presence of a petroleum system.

STRATIGRAPHIC SUMMARY.

A summary of the stratigraphy of Puntland is shown in Figure 11-14. The generalized stratigraphy (Figure 11) illustrates most of the major stratigraphic relations of coastal Puntland, with lateral variability characterizes most of these units (Figure 14).

Several regional formations are documented. They include the Adigrat Sandstone (Middle Jurassic) which locally contains limestone horizons, the Bihen Limestone (late Middle Jurassic), and the Taleh Formation, a regional gypsum unit (Lower Eocene) which acts as a major regional seal.

The most diagnostic feature of Puntland’s onshore stratigraphy is the presence of a major lithologic and facies shifts from West to East. These shifts range from fluvial and shoreline sandstones in the west tonguing laterally into coastal, shelf and platform carbonates to the east. The limestones include oolitic, grainstone and dolomitic facies. Regional source bed shales, such as the Dagani Shale (Upper Jurassic) and the Gahodleh Shale (Upper Jurassic), show lateral facies variation into both sandstones and limestones.

The basic control on these regional facies and associated environmental shifts appears to be paleoclimate (Figures 15 and 16). Throughout most of the Mesozoic and Cenozoic, the Puntland region was subjected to an arid climate, with a tropical period during the Cretaceous and Paleocene (Figures 15 and 16). This climate shift was controlled first by the interior location of Puntland during the earliest stages of breakup of Pangea, and later northward shift of Africa to its present latitude into the Hadley zone. These shifts (see section on potential play concepts)

TABLE 1. SOURCE ROCK POTENTIAL IN PUNTLAND AND SOMALILAND (From Ali, 2006)

SOURCE ROCK AGE AND UNIT	TOC %	QUALITY AND TYPE.
<i>PUNTLAND – Bandar Harshau-1:</i> Upper Miocene (Syn-Rift Shale)	1.92%	Immature; Hydrogen Index = 268 mg/g; Genetic Potential -5.41 kg/ton; No Vitrinite reflectance.

Jesomma Shale (Upper Cretaceous)	3.26%	Overmature; Hydrogen Index = 0.17 mg/g; Genetic potential = 0.84 kg/ton. Vitrinite reflectance = 1.0' Type II/III organic matter.
Cretaceous Shale	1.1%	Hydrogen Index = 35 mg/g; Genetic Potential = 0.48 kg/ton
Lower Cretaceous Shale	1.26%	Hydrogen Index = 21/mg/g; Genetic Potential = 0.35 kg/ton; Type III organic matter.
<u>PUNTLAND – Dab Qua -1:</u> Middle Eocene Shale	3.0 %	Very good oil source; Type I organic matter.
Jesomma Shale (Upper Cretaceous)	5.0%	Good oil and gas source; Type II; Genetic Potential = 8 kg/ton.
Daghani Shale (Upper Jurassic	0.53-1.18%	Fair oil and gas source; Type II/III organic matter. Thins (6 m) shale: Type I/II organic matter.
<u>SOMALILAND - Bihendula Outcrop:</u> Upper Daghani Shale (Jurassic)	2.01	Good oil source; Type = Amorphous algal; Hydrogen Index – 537 mg/g; Genetic Potential = 11.47 kg/ton; Vitrinite Reflectance = 0.5-1.0
Gahodleh Shale (Jurassic	1.43%	Fair Oil Source; Hydrogen Index = 434 mg/g; Genetic Potential = 6.76 kg/ton; Vitrinite Reflectance = 0.4 -0.9
<u>SOMALILAND- Dagah Shabel Wells</u> Jurassic calcareous shale	0.75%	Good oil source; Type = Amorphous algal; HC/non HC = 0.57; Vitrinite reflectance = 0.6
Daghani Shale (Jurassic)	0.46%	Fair to good source for condensate and gas; Type = amorphous; HC/Non HC = -.44
<u>SOMALILAND - Daban Basin:</u> Eocene/Oligocene (lignite from Lower Daban Series)	11.3%	Potential gas: immature. Hydrogen Index = 104 mg/g; Genetic potential = 12.17 kg/ton; Vitrinite Reflectance = 0.4

avored carbonate rock development during drier periods and sandstone accumulation during wetter and transitional periods.

In the Gulf of Aden offshore, stratigraphic data from two wells the Shell Bandar Harshau 1 and the Shell Dab Qua 1 wells (Figure 17), show pronounced thickness changes and disappearance of certain lithologies are evident in the 50 km distance between these wells.

Similarly, in the offshore of northeast Puntland, five wells (Figure 18) show both lateral changes in facies, with increasing shaliness to the East. Bathyal shales were evident in the Ghumbah 1 and Ras Binnah 1X wells. A large Miocene channel system was observed at the Oxy Ghumbah 1 well but at the well site, the channel fill consisted mostly of shale with thin sands (Occidental of Somalia, Ltd, 1987). Upper Jurassic source beds are absent in the Ghumbah –1 and Ras Binnah 1X wells.

Major onshore potential reservoirs with oil or gas shows include the Adigrat Formation (Lower Jurassic; sandstone), the Wanderer Limestone (Upper Jurassic), The Jesomma Sandstone (Cretaceous; sandstone), the Paleocene Aurada and Allah Kajid Formations (Carbonates), and the Oligocene Duban Sand. Although characterized by good reservoir properties, drilling in the Adigrat has been unproductive. Shows are reported from the other reservoir formations listed (Ali, 2006, Anonymous, 1988a, b, Barnes, 1976, Robertson Group, 1991a, b, Sinclair, 1968). Sealing formations include the top of the Daghani Shale (Upper Jurassic), the Gawan Limestone (Upper Jurassic), the Tisje Limestone (Upper Cretaceous), and the Taleh Anhydrite (Eocene).

PREVIOUS EXPLORATION, OFFSHORE PUNTLAND (From Anonymous 1988a, b, Occidental of Somalia, 1987)).

Offshore drilling on the shelf regions of the Gulf of Aden and the Eastern Shelf of Puntland during the 1970’s and 1980’s by Shell, ELF-Somalia, AGIP and OXY proved to be very disappointing. Eight wells were drilled in Offshore Puntland (Figure 18; See Figure 19 for Well map) No commercial hydrocarbons were found. Two wells, in the Gulf of Aden, the Shell Bandar Harshau 1 and the Dab Qua 1 had shows, but not of commercial grade.

The exploration targets were selected primarily from seismic mapping. All wells targeted structural highs, either an anticline, or a dome, or a fault block. The targets generally showed four-way closure, either as a fault-bounded block, or an anticlinal or domal closure. The OXY Ghumbah 1 well (Figures 21 and 22) was drilled on a broad anticlinal feature in the Lower Cretaceous and Jurassic (Figure 22).

In short, past exploration efforts in the Puntland Offshore were unsuccessful. Table 2 provides a summary of key drilling results.

TABLE 2. SUMMARY RESULTS OF OFSHORE DRILLING, PUNTLAND (From Anonymous 1988a, b, ELF-Somalia, 1974a, b, Occidental; of Somalia, Ltd, 1987)).

MMWR Well Number	WELL NAME	RESULTS

52	<i>GULF OF ADEN:</i> Shell Dab Qua 1	Located on fault closure. Sand and shale down to 3517' undercompacted with high porosities. Carbonates below with poor porosity. Minor oil shows in Eocene and Cretaceous (3600-6800 feet). Tests show 20% porosity in Eocene Limestones (4036-4068 feet) with no hydrocarbons. Paleocene carbonates with 12% porosity and >50% hydrocarbon saturation but no hydrocarbon recovery.
54	Shell Bandar-Harshau 1	Located on large NE-trending anticline cut by E-W faults. Minor hydrocarbon shows from 2050-3620' (Miocene to Lower Eocene). Good show from 4547-4577' in Sandstone (Oligocene to Mid Miocene). No petrophysical indication of hydrocarbons.
43	<i>EAST PUNTLAND SHELF;</i> ELF Hafun 1	No hydrocarbon shows.
44	ELF HAT 1	Drilled on large anticline. Porosities between 7200' and 7600' unusually high. No hydrocarbon shows. (ELF-Somalie, 1974a)
45	ELF Gardufui 1	Drilled on structural closure. Tertiary mostly shaly limestone and mudstone with Porosities from 10 -15%. Permeability was poor. Upper Cretaceous mostly porous limestone and shale. Porosities of 20% common. Test showed minor gas. No commercial hydrocarbons (ELF-Somalie, 1974 b).
46	AGIP Garad Mare 1	Goal was structural high. Later seismic by Conoco showed well section to be highly faulted. Upper Cretaceous Gira Formation porous limestones were water wet. Adigrat Sandstone with 15-20% porosity. No hydrocarbons.
55	AGIP Ras Binnah 1	Drilled on E-W horst block. Upper Jurassic to Neocomian carbonates with 25-30% porosity but water wet. No hydrocarbons present.
57	OXY Ghumbah 1	Drilled on E-W seismic dome bounded on N by normal fault. 6 stratigraphic hiatuses. Gas show from 2900-3600 feet in thin sands within muddy Miocene channel fill. Adigrat Sandstone was water wet. Expected Jurassic sources rocks were absent. No hydrocarbons. (Occidental of Somalia, Ltd,1987)

Nevertheless, the area shows potential. As stated, past drilling focused on seismic structural highs. In the writer's opinion, the area must be reconsidered in terms of new play concepts from shelf and deep water areas that were unknown during the 1970's and 1980s. (See Section on Play concepts).

INTERPRETATION OF SELECTED CITIES SERVICES – SOMALIA (OXY – SOMALIA) SEISMIC SURVEYS OF 1981 AND 1983.

Cities Services-Somalia contracted two sets of 2-D seismic surveys east and northeast of the Hafun Peninsula in 1981 and 1983 (Figure 21). Occidental Somalia, LTD (1987) used these data to drill the Ghjumbah-1 well, a dry hole. It is the only well drilled within the 1981 and 1983 seismic survey data set.

The Ghumbah-1 well was located on a basement high flanked by a fault (Figure 22) and a presumed stratigraphic pinchout downdip. However, the north-dipping fault immediately to the northeast of Ghumbah-1 is not evident at SP-1740 (Figure 23), although several southeast-dipping normal faults were observed.

An initial survey of 15 seismic lines disclosed that normal faulting is subtle and involved small-scale displacement (approximately 0.05 ms or less). The seismic stratigraphic pattern is characterized by a horizontally layered system, disrupted by at least three major channel systems and several smaller ones with relief of no more than 1.0 ms. Individual biostratigraphically-defined sequences (Figure 23) show lateral changes in thickness, and erosional boundaries between them. Biostratigraphic gaps match well with recognized seismic sequence boundaries (Robertson Research, 1987).

Cliniform seismic signatures occur in distinct sediment packages. They merged into maximum flooding surfaces which are traceable only within short distances. Sediment packages with opposite dipping cliniforms are also present, particularly within the Upper Miocene, and may indicate the presence of delta bar finger sands or upper slope fans. Although seismic quality is fair, gas chimneys were observed in several seismic lines (CS-83-124) usually within the Upper Miocene and Pliocene. These appear to be biogenic gas (Fallgatter, 1987).

SEISMIC LINE CS-81-32. This fair-quality seismic dip line (NNW-SSE) is a key line used by OXY to locate the Ghumbah 1 Well (Figure 23 and 24). It typifies the features observed on the initial 15 lines examined earlier.

Ghumbah -1 was located 500 meters South-Southeast of a basement normal down to the north fault at SP-1760, presumably forming a faulted high (Figure 22). However, no such fault was shown on their own seismic/well display (Figure 23). Instead, two small normal basement faults were identified at SP-1765 and SP-1778. Similarly, two normal down to the north faults at SP-1870 and SP-1600 were not evident either. The basis for drilling at this location remains in doubt.

Other faults were observed between SP-950 and 870 and were limited to the Middle Miocene. These show vertical displacement of less than 0.05 ms, and sole out over a short distance.

The most obvious features on this seismic line are major and minor channels. The largest is an Upper Miocene channel fill through which Ghumbah-1 was drilled. The recovered cuttings from the channel fill consisted mostly of mudstone with thin interbedded sands (Figure 25). This channel cuts into Lower Miocene shales. A second Upper Miocene channel was observed between SP- 680 and 630, but was shallower in depth. As a consequence, the Middle Miocene sequence thickens to the South-Southeast from SP-1640 to the southeast end of the seismic line. Another Upper Miocene channel was mapped from SP-1930 to 1560.

A thick channel separates the Pliocene Sequence from the Upper Miocene Sequence between SP-1070 and 1000.

The second most obvious feature was a series of clinoforms represented by downlapping signatures within the entire Miocene section. These define Maximum Flooding Surfaces, but their lateral persistence could not be traced very far beyond the clinoforms. An Upper Miocene clinoform was observed at SP-1150 to 100.

Moreover, both Upper Miocene (SP-1995 to 1780) and Lower Miocene (SP-1595 to 1487) mound-like features were defined by opposite dipping clinoforms, suggesting development of a possible upper bathyal slope fan (Anonymous, 1988a; Robertson Research, 1987), or distal distributary delta system. However, these mound-like signatures lack an associated gull-wing signature.

The multiple channels in the Upper Miocene sequence and the Pliocene channel are suggestive of imbricating shifts of distributary channels in a muddy delta system. Such channels may have shed sediment into a series of upper slope fans at the end of incised valleys.

In addition, the Santonian Sequence was found to erode into the Turonian Sequence at SP 1860-1810, SP 1900-1894, and SP 1950-1940. The Turonian was observed to thicken to the North-Northwest.

The oldest unit penetrated by Ghumbah-1 was the Adigrat Sandstone generally considered to be of Jurassic age (Ali, 2006; Anonymous, 1998a, b), although Occidental of Somalia (1987) reported recovering Triassic pollen (Robertson Research, 1987). Within the Adigrat Sandstone, a channel was mapped between SP-1630 to 1605, confirming its fluvial origin (Occidental of Somalia, 1987, Roberts Research, 1987). The seismic contact with the basement below the Adigrat appears gradational.

The most characteristic observation at the Ghumbah -1 is the erosional removal of potential Upper Jurassic source beds. No intervening package of sediments between the Adigrat Sandstone and the overlying Lower Cretaceous was observed on this seismic line.

SEISMIC LINE 83-127:

NEW PLAY CONCEPTS RELEVANT TO THE PUNTLAND OFFSHORE.

Since drilling in Puntland's offshore during the late 1980's, new findings in offshore exploration in the Gulf of Mexico, the Gulf Coast, the Brazilian margin and West Africa provide a set of new relevant play concepts that may yet led to oil and natural gas discoveries in the region. Few, if any of these have been applied to the Puntland offshore. Next steps in our evaluation will be to prioritize future locations for exploration of the Puntland Outer Continental Shelf and make recommendations as to the acquisition of additional seismic data subsequent drilling.

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