INTERPRETATION REPORT

of

THE PHASE I OFFSHORE SEISMIC SURVEY
(BRAVA TO ADALE)
SOMALIA DEMOCRATIC REPUBLIC

Vol. I TEXT M6, M7

GECO
GEOPHYSICAL COMPANY
OF NORWAY A·S

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Prepared for

THE MINISTRY OF MINING AND WATER RESOURCES
SOMALIA DEMOCRATIC REPUBLIC

by

GEOPHYSICAL COMPANY OF NORWAY A.S

Stavanger, Norway
8. July 1980

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FJ/TN/hhd

THE INTERPRETATION REPORT CONSISTS OF THE FOLLOWING:

Volume I:	Interpretation Report, Text
Volume II:	Interpretation Report, Figures
Volume III:	Interpretation Report, Maps
Volume IV:	Seislog - study
Box I:	Interpreted Seismic Sections, line 1001-1069
Box II:	Interpreted Seismic Sections, line 2001-2200

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INTRODUCTION

This report presents the results of an interpretation of the seismic data collected during the Phase I Seismic Survey offshore SOMALIA conducted by GEOPHYSICAL COMPANY OF NORWAY A.S for the MINISTRY OF MINING AND WATER RESOURCES, SOMALIA DEMOCRATIC REPUBLIC.

The purpose of the survey was to investigate the petroleum potential of the shelf from BRAVA to ADALE.

This report describes the results of the survey in this specific area, whereas the report: "Regional Petroleum Geology of Somalia Democratic Republic" gives a broad compilation of all information we have been able to collect about the subject, covering the whole country.

The interpretation report summarizes the regional geology relevant for predicting the lithology of the surveyed area, describes the structural evolution of the area, followed by a map description of the three mapped horizons, together with reserve estimates for the most important structures.

The report concludes with a review of the petroleum potential for this part of the Somalian Shelf together with recommendation for further work.

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AREA I

REGIONAL SETTING

Area I is situated in the central part of the Afgoi Embayment. This embayment is to the west boundered by the Bur Acaba Uplift, situated 100 km west of Mogadishu. This uplift expose basement-rocks on the surface. To the north Afgoi Embayment either pass gradually into the Mudugh Basin or is separated from this by a subsurface continuation of the Bur Acaba uplift. Towards the south, the Afgoi Embayment continues into the Juba Basin, but is separated by a positive tectonic feature on which the Brava well is situated.

Plotting of the depth to the base of Tertiary in the different wells show a very rapidly increasing depth to this horizon from west to east. The largest subsidence during the Tertiary took place in the area just around Mogadishu, where the base of tertiary is expected to be at appr. 4.500 meters depth near the coast. In the very south of Area I Base Tertiary is expected at appr. 2000 meter depth near the coastline. Near Adale (northern end) Base Tertiary is expected around 2.500 meter depth.

STRATIGRAPHY (Fig. 1)

Early Jurassic/Triassic

ADIGRAT FORMATION

The Adigrat formation is the oldest sedimentary unit mapped in Somalia. It is an equivalent of the Karoo series and thus although assigned an age of Early Jurassic/Triassic it is likely that under the basin center the Adigrat may be as old as Permian.

In essence the Adigrat is a transgressive clastic facies.

The formation is buried very deeply in the Afgoi Embayment and is only penetrated here in the Brava well, which is supposed to be located on a horst block. This formation seems therefore to be buried too deeply in the Afgoi Embayment to have any potential except maybe for the southernmost area offshore Brava.

Middle and late Jurassic

This part of the Jurassic can be subdivided into three formations: Hamanlei, Uarandab and Gabredarre formations, mentioned in chronological order.

HAMANLEI FORMATION

This unit as recognized ranges from Callovian to Upper Oxfordian.

In the Afgoi Embayment this formation is composed of a shell facies which is lightgrey fossiliferous limestone, oolitic in the lower part and containing ammonites. Dolomite in the basal part of the formation suggests a widespread shallow shelf upon which limestone or shale was subsequently deposited.

The Hamanlei formation had shows in Bio Addo no. I.

UARANDAB FORMATION

Essentially the Uarandab is a shale which is contemporaneous with and succeeds the Hamanlei formation. Palaeontology indicates an age of Oxfordian and early Kimmeridgian.

This unit is thought to be the most probable source rock in Somalia, and gas shows were recorded in Bio Addo no. I well.

GABREDARRE FORMATION

This formation is conformably overlying the Uarandab formation, but is probably also in part a facies or time equivalent. The formation represents a shallowing of the sea and generally a return to carbonate deposition. The Gabredarre formation includes late Kimmeridgian and Tithonian deposits.

LOWER CRETACEOUS

COTTON FORMATION

During this time the Afgoi Embayment was covered by a shallow water sea, which offshore the present coast can be expected to have reached neritic depth. To the west of the Bur Acaba Uplift a restricted marine environment with evaporite deposition was located. The Cotton formation is in the Afgoi Embayment mostly clastic, escpecially shaly with more rare sand-layers. Along the southeast flank of the Bur Acaba Uplift carbonate reefs can be expected.

Upper Cretaceous.

GUMBURO GROUP.

The Bur Acaba Uplift persisted as a positive element and separates in Upper Cretaceous a deep water marine trench to the east from a restricted marine basin to the nortwest.

In the Afgoi Embayment a sub-marine trench existed and turbidites are expected to constitute the main prospecttype. Shelly carbonates should occur in a belt along the hingeline seperating neritic and platform environments of deposition.

The Brava well is probably sitting on an ancient horst block. The lower part of Upper Cretaceous is eroded on this block.

Shows of oil and gas are recorded from the Upper Cretaceous. Afgoi and Coriole no. 1 had significant shows of oil and Bio Addo had gas shows.

The uppermost Cretaceous formation is the Jessoma formation, composed of crossbedded, loosely cemented to quartzitic, fine to very coarse-grained sandstones. The top of this formation locally shows an erosional disconformity with the overlying Paleocene.

TERTIARY

PALEOCENE

The Afgoi Embayment is dominated by deltaic pods which seawards is expected to give way to terrigeneous turbidites. Volcanic activity took place and could have generated at an early date the necessary heat flow to cook off hydrocarbons. In these deltaic sediments encouraging shows of hydrocarbons have been reported from the Afgoi and Merca wells.

The Paleocene sediments in the Brava well, situated on a horst-block, is of deep-marine facies.

In the Afgoi Delta, it appears that basement-supported fault-block structures dominate onshore and a similar situation is proposed immediately offshore. Besides this structures related to growth-faults should be expected in this deltaic regime.

The most widespread Paleocene formation is the Auradu formation, which consists of limestones. The deepwater equivalent is the Sagaleh formation and the Marai Ascia formation is developed in a transitional facies.

EOCENE

In southern Somalia the Eocene is characterized by a great tectonic mobility as evidenced by the unconformities within the Eocene.

By Eocene time the delta front seems to have widened and covered the entire coastal area from Obbia and southward to Kenya. The Brava horst-block seems still to have excisted as Upper Eocene is missing in the Brava Well due to erosion. In the DSDP hole no. 241 Oligocene sediments also overlies middle Eocene unconformably. The Oligocene sediments in this hole, which today is situated at more than 4000 meters water depth, is shallow water marine deposits.

Deep water marine trenches are expected to have excisted offshore along the present coast during the Eocene, as evidenced by the presence of open marine Eocene deposits in the Merca Well.

Several prospects in connection with the deltaic sandbodies are expected especially on the flanks of tectonic positive features on the Brava horst and the nortward continuation of the Bur Acaba.

Gas shows has been recorded in Eocene strata in the Merca well.

OLIGOCENE - MIOCENE

Afgoi Embayment contained a modified deltaic complex in which massive carbonates developed parallel with the present-day shoreline.

In southern Somalia, a thick package of Late-Tertiary seems to contain source, cap and reservoir rocks in sufficient thicknesses and areal distribution to sustain accumulations of hydrocarbons. Viable structures with growth during deposition is the logical targets. The Brava well, drilled in this area, found an anomaleous thin section, which might indicate the presence of a positive feature, which also is verified on the offshore seismic data.

No wells drilled through these rocks in this area recorded shows of significance.

The oligocene - miocene succession is named Somal formation and consists mostly of carbonates, but sandy and shaly equivalents are also known especially from the southern part of Somalia.

PLIOCENE - PLEISTOCENE

Sediments from this period are in the Afgoi area mostly developed as clastic rocks.

VOLCANIC ROCKS

Igneous intrusions and basalt flows are a normal part of the development of a pull apart basin.

In the Merca well spilitic basalt is described as interbedded with Paleocene and Upper Creataceous strata. Other volcanics of presumed Upper Cretaceous age are described in the base of Coriole no. 1.

Reservoir and source rocks

Reservoir rocks of as well carbonate as clastic type is widespread in the sedimentary succession in the area. The oldest sediments known are of Early Jurassic to Late Triassic age. Most of the prospects in Area 1, however, is expected to be found in rocks of Tertiary and Cretaceous age. This is due to the very thick Tertiary sediments in the area, which causes that the older sediments are buried very deeply. Jurassic rocks can, however, be prospective in the northern and southern part of the area, where the Tertiary sequence is thinner.

Encouraging shows of oil and gas have been recorded in rocks of ages from Middle Jurassic to Eocene.

The shaly Uarandab formation is thought to be the most important source rock in Somalia. Offshore, however, where most sequences get more shaly, younger source rocks can be expected too.

Based on the general information available onshore Area I and especially the encouraging hydrocarbon-shows in several wells, it seems to be a good change to find commercial hydrocarbon accumulations in Area 1: The critical point here will be to define attractive prospects in reasonable water-depth.

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THE OFFSHORE SEISMIC SURVEY

Statistics

The data collected outside Mogadishu in Phase 1 amount to 3888 kms (fig. 2). These data were submitted to the processing centre in two shipments.

The first shipment consisted of 1972 kms and was received December 21, 1979.

The second shipment was received February 1st, 1980 and consisted of 1916 kms. This also included the line northwards to Alula, which is named 2002 and is 660 kms long.

The grid which this interpretation report is based on, is 5 times 10 kms. The lines normal to the cost are named from 1001 through 1069, the lower numbers in south, and the lines paralleling the cost are numbred 2001 to 2004, the lowest number near the coast.

The first shipment of data was final processed March 19, 1980, and the second one April 18, 1980.

High priority was put on the interpretation, thus the final report was finalized three months after the last data were available in the interpretation department.

Data quality

The data quality varies a lot in the area covered in the phase I shooting. This is mainly due to two geological phenomena:

- Firstly, on the shelf edge there is a lot of canyons due to sliding and slumping of the unstable sediments into deep water. The rugged sea bottom and,also,the slump masses disturb the seismic signal in a way which makes the data interpretation unreliable in certain areas. This slumping also disturbs the sedimentary sequences and makes correlations uncertain, especially for the youngest horizon mapped.

- Secondly, the data in some areas are strongly disturbed due to multiple energy, that is energy which is reflected from strong reflectors and repeated several times in the water layer. The reason for this may be strong variation in the sediment velocity caused by changing lithology and, also, very high velocity in the sea bottom. This is especially thrue when approaching the shoreline.

INTERPRETATION

The first step in the interpreation was a detailed analysis of selected lines from different parts of the area. The lines were selected on basis of data quality and how representative they were for the geology in the area. These lines were analysed in detail by using the seismic stratigraphy method (Vail et al.1977). During these analysis the seismic section is divided into as many depositional sequences as possible (fig. 3). The internal reflection pattern and the outer three-dimensional form of the depositional sequences can give some indications about the depositional facies and the lithology. Velocity analysis also give valuable information. This is further elaborated on in the chapter about the Seislog Analysis.

The defined reflectors are thereafter traced around in the area and the most regional ones are mapped through the whole grid.

One of the major problems during the interpreation of the actual data was that very few reflectors have regional occurrence. Most of the reflectors change character and amplitude very fast. In addition, the very large faults make correlations from one fault block to the next one very difficult. The varying data quality also makes the mapping difficult. Four horizons, however, have been mapped across the whole area.

The sedimentary succession in Area I is subdivided into two different units: A lower relative stable one where most of the tectonism is basement controlled, and a upper unit which

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many places is characterized by a rather chaotic reflection pattern which is thought to be caused by slumping and sliding tectonics. The green (G) reflector most places marks the boundary between the two units. The deeper blue (B) reflector is also mapped because it displays the basement-controlled tectonism even more pronounced than the green horizon. From the upper sequence two (three) horizons have been mapped. Correlation of the orange (O) one, which is very young, is uncertain many places because of the very large offsets along many of the listric faults. A map, however, has been prepared of the horizon, and this map shows all the major structures in the uppermost unit even if this horizon doesn't represent an isochrone. In the lower part of the upper unit another horizon has been mapped. This is drawn in red (R), but in the southern part of the area a somewhat shallower horizon has been mapped instead. This horizon is marked by violet (V). Besides these five different coloured horizons which have been correlated across the whole area, several extra mapable horizons are marked by yellow (dashed). These yellow reflectors are not correlated from line to line and often not even from fault block to fault block. These reflectors are only marked to accenturate the structuration on the different profiles.

A shotpoint 7160 on line 2003 (fig. 7) a big fault, which downthrows the green and blue reflectors deeply toward the south, is marked. The correlation across this fault is uncertain and it is possible that the green and blue reflectors south of this fault represent older horizons than further north. If so, they most possibly correlate with the two strong reflectors seen below the blue horizon north of the fault. The velocity information on the section

doesn't give any certain answer to the problem either.
This problem exists only in the eastern part of the area, and on line 2002 we believe that the blue and green reflectors have the same age both in the southern and northern area.

DATING OF THE REFLECTORS

No offshore wells have been drilled in the area covered by this survey. This makes the dating of the mapped horizons very difficult and uncertain. Several onshore wells have been drilled in the area. However, no land seismic data have been available for us, so we are not able to correlate the information from the wells to the offshore area. The information from these wells is, therefore, most useful in giving indications about the depositional facies and lithology for the different formations. Correlation lines between different wells located along profiles oriented as per-pendicular as possible to the coast, have been drawn, in an attempt to estimate on which depth different geological horizons should be expected.

This method has several large uncertainties:

a) Most wells are located structurally atypical. This is caused by the fact that most wells are located at structural heights. Correlations between wells in such positions are rarely representative for the general dip of the horizons.

b) Faults with very large down to the coast offsets are very commonly seen, more or less paralleling the coast. These faults make, of course, the correlation very uncertain.

c) Accurate velocity information is not available. The stacking velocities are in general not reliable. This makes the conversion from two way travel time to meter very unaccurate.

The dips which show up by plotting these profiles, however, are of the same magnitude (around 2^{o}) as the dip seen on the seismic profiles close to the coast.

When the depth estimates to the different geological horizons deduced from the subsidence profiles are plotted on the seismic profiles they don't give any straight-forward answer to the age of the mapped horizons. For instance, the Top Paleocene horizon from the different subsidence profiles correlates onto the seismic from below the blue reflector too close to the red horizon. However, most profiles indicate a correlation just below the green horizon. This method, therefore, doesn't give any firm dating of reflectors, but it indicates that the green reflector has an Early Tertiary age. This reflector represents most places a clear unconformity.

A very widespread unconformity in Late Eocene/Early Oligocene is well known in the northern part of East Africa. For instance, is the Upper Eocene missing in the Brave well because of erosion. Also, in the DSDP well 241 which today is situated in more than 4000 meter of water, Oligocene sediments are found above Middle

Eocene sediments. Therefore, we expect the green horizon to represent this unconformity. Unconformities are often caused by change in relative sealevel. Charts of global cycles of relative sea level changes have been published by P. Vail (1977), and the most pronounced sea level drop in the Tertiary happened in Middle Oligocene. From the information we have, it seems like the major unconformity in Somalia is somewhat older, but we don't know how exact the dating is, so it is possible that the unconformity is situated in Middle Oligocene.

The blue horizon then could represent Top of Cretaceous (Base Tertiary). The reflectors shallower than the green one is then of Miocene to recent age. The red and violet are expected to be situated in Early Miocene and the orange reflector (as far as it represents one specific horizon) is thought to be of late Miocene or Pliocene age.

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STRUCTURAL EVOLUTION OF THE SURVEY AREA

Coastal Somalia against the Indian Ocean can structurally be characterized as a passive continental margin, where the transition from continental to oceanic crust is thought to be located just east of the Seychelles Islands. This means that the whole Somali Basin is underlain by continental crust.
Passive margins are characterized by a tensional regime, which means that normal faulting is the dominant structural style. This is also thrue for the Somalia Indian Ocean coast area.

No signs of compresssional forces are seen, but strike slip movements in some of the large faults can't be ruled out.

As mentioned earlier, the sedimentary succession in the area can be subdivided into two different structural units, separated by the green horizon.

The lower unit is mostly characterized by basement controlled normal faulting, mostly down to the basin.

The upper unit, which is thought to be of Neogene age, has many places, especially in the northern and southern area, a chaotic reflection pattern, which could be caused by slumping and sliding. Around Mogadishu the unit looks more stable.
The reasons for these unstable conditions during the Neogene are very high sedimentation rates of mostly clastic sediments (sand/shale), leading to undercompaction, combined with the location

of the area very close to the shelf break, which during this interval constantly has been situated close to its present position. South of Mogadishu most of the growth faulting, slumping and sliding seems to have been caused by a plastic layer (most possibly undercompacted shale) just above the violet (V) reflector (fig. 4).

Growth faults create especially in the northern area big rotated structures (fig. 5 + 6). These big faults offset the sediments to down below the blue horizon, but most of the growth has taken place at a late stage (fig. 5 + 6).

Unstable conditions still exist on large parts of the shelf in the area. This is seen by numerous recent canyons (fig. 7) and recently deposited slump masses (fig. 3). Fig. 8 shows the area that today is characterized by unstable conditions. Such conditions can be critical for petroleum activities. Not so much for exploration drilling, which can be conducted from semi-submersible rigs or drillships, but more for an eventually production phase with installations fixed on the sea bottom.

The recent canyons are not oriented perpendicular to the coast, as it could be expected, but more north-southward. This is seen from the fact that these canyons also are crossing the coast perpendicular lines. The canyons are often seen to be located above faults,and movements on these could have triggered the slumping.

or Canyons cause apparent faults

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On line 1014 (fig. 9) a diapir-like structure is seen. As this phenomen only is seen on one line,not too much attention is paid to it, but on the line towards Kenya (2001) several swell -like features are seen (fig. 10). These structures can be caused either by salt or plastic clay. Salt, however, is well known in the Karoo sequence, for instance offshore Kenya, where it is thought to have an Upper Triassic age (not drilled).

MAP DESCRIPTION

Structural maps in two-way travel time of three horizons have been prepared. These horizons are the orange, the green and the blue ones.

As mentioned earlier, many uncertainties exist in the correlation of the horizons. These uncertainties are mainly caused by the following reasons.

a) Complicated geology with many large faults

b) Lack of regionally consistant reflectors

c) Problematic data quality in several areas

These problems are caused by difficult removeable muliples of different kind, side sweep and distrubances caused by the uneven sea bottom.

However, we feel that we have been able to map the blue and the green horizons with acceptabel confidence. The orange horizon, however, is more disputable, but even if the mapped horizon not represents exactly the same horizon across the whole area, it at least displays the structuration in the upper unit.

The survey grid is sufficiently dense to give an evaluation of the prospectivity of the area and to grade the potential of different parts of the area.

The structure maps are prepared in scale 1:100.000 and the area is divided into three parts.

All maps have depth in two-way travel time. A conversion to meter will not change the picture very much, but will, of course, change the outline of the structures.

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BLUE HORIZONS (MAP I, II & III)

The blue horizon which is the deepest regionally mapped one and is thought to be located near Top of Cretaceous, is displayed in Map I, II and III.

The maps show a very complex situation with many faults of different orientation. Especially the southernmost area (Map I) is heavily faulted, compared to the area around Mogadishu (Map II) and further north (Map III) where the horizon has a much more gentle dip towards the ocean.

On the two northermost maps (II and III) a coast parellel fault system is dominant, but also north-south oriented faults are common.

The southern map (I) displays a very complicated fault picture and besides the two already mentioned orientations (NE-SW + N-S) and east-west system is seen, but this is less pronounced.

The general picture is an increasing depth to the horizon away from the coast. Near the coast the horizon is found at a depth around 3,50 sec two-way travel time (T.T.T.) (approx. 5.200 m) in the Mogadishu area, where the subsidence has been greatest in post-blue time. In the northern area the horizon is found around 2.25 sec T.T.T. (approx. 3.400 m) near the coast, and in the south between 1.75 and 2.00 T.T.T. (approx. 2.600 - 3.000 m) depth.

In the eastern part of the survey area the horizon is found at a depth ranging from 3.50 to 4.50 sec T.T.T. (approx. 5.200 - 6.700 m), shallowest in the north and deepest in the south.

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However, an updoming is seen just seawards of the shelf break. This doming creates a large structure B VII. LIne 1038 (fig. 3) shows this structure between sp. 750 and 1266.
The long lines out in deep water show a still increasing depth to the horizon, but the depth below sea bottom is usually diminising oceanwards. This is caused by starved sedimentation outside the shelf break during the deposition of the post blue sequence.

Line 1054 (fig. II) shows another domal structure (B XI) between sp. 200 and 550. This structure is caused by a rotation along a large listrict fault, but the structure is not dependant on a tight fault.

Most of the other closures shown on the maps of this horizon are fault-bounded at least on one side and are, therefore, dependant on tight fault planes to have any hydrocarbon potential.
One of these structures is B.III, which is fault bounded to the south along a fault with a big offset. Line 1014 (fig. 9) displays this structure between sp. 600 and sp. 50. This line also shows the diapir-like structure(sp. 1050-1150) caused by movement of salt or plastic clay along a fault plane. Line 2003 (fig. 7) shows another profile across the same structure between sp. 6900 and 7170. Most of the other structures shown on the maps are less well defined and have a less volume and, therefore, also smaller possible hydrocarbon reserves. Later an evaluation of the possible potential in selected prospect will be given.

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GREEN HORIZON

The maps (IV,V and VI) displaying the structuration of the green horizon, which is estimated to have an early Tertiary age show mainly the same picture as the maps of the blue horizon. However, the green horizon is less faulted than the blue one, but all the major faults offset both horizons.

The general picture is an increasing depth to the horizon away from the coast. Near the coast the horizon is found at a depth around 1.75 sec T.T:T. (app. 2.200m) in the southern and northern area. The area around Mogadishu however has subsided more rapid in post-green time and here the horizon is found at a depth of around 3.00 sec T.T.T. (app. 3.700 m). In the deepwater part of the survey area the horizon is found at at depth varying between 3.00 and 4.00 sec T.T.T. (app. 3.700 - 5000 m), shallowest in the northern area and at an increasing depth towards the south.

Most of the closures mapped in the green horizon were also found on the maps of the deeper blue horizon. The numbering of the closures in the green level is, therefore, in accordance with the numbers given the structures in blue level. B-I and G-I are therefore the same structure displayed on two different levels. No large structures are defined in the green horizon, which didn't excist in the blue horizon, but the sizes and the configurations of the structures are, however, often rather different.

One of the major prospects is also in this level the structure seen on line 1038 (fig. 3) between sp. 750 and 1266. This prospect is called G-VII/VIII because the structure on blue level was divided into two prospects, B-VII and B-VIII.

Another large and rather certain closure is G-XI, (fig. 11) and is a dome caused by a listric fault.
G-III is somewhat smaller than B-III.

G-I which is seen on line 1006 (fig. 12) east of sp. 300, on the contrary is larger in green than in blue level. This structure, however, is rather uncertain, because of poor data, but a bit higher than the green horizon a structure is certainly developed.

The other structures have less areal closure and will certainly have less possible reservoirs.

ORANGE HORIZON (Maps VII, VIII & IX)

The orange horizon is the shallowest mapped horizon. As mentioned earlier, this horizon is difficult mapable because of changing character and large offsets along many of the faults. The horizon is hardly mapable on the NE-SW lines except for line 2001, because it is located at very shallow depth, where the data are very much disturbed by the uneven sea bottom. However, the maps show, even if the horizon isn't exactly the same across the whole sea, the structuration of the upper part of the sedimentary sequence.

The horizon is expected to have an Upper Miocene to Pliocene age.

Most of the faults are down to the basin and have an orientation parallel to the coast. Except for the disturbances caused by faulting, the horizon shows a general dip away from the coast and the depositional strike is paralleling the coast.

Near the coast the horizon is found at a depth varying from 0.30 sec. to 1.0 sec. (app. 300 p 900 m) shallowest in the north. Underneath the southeastern part of the survey area the horizon is found at a depth varying from 1.75 - 2.75 sec. T.T.T. (app.1700-2700 m), deepest outside Mogadishu and at shallower depth in the northern and southern areas.

No large prospects have been defined at this level, but the structuration is increasing downwards in the sequence between the orange and green reflectors, and prospects can certainly be defined in this sequence, especially in connection with the growth-faults.

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PROSPECT EVALUATION

Trap Types

As hydrocarbons are lighter than water, which is the normal pure fluid, they tend to migrate upward when they have been expulsed into the reservoir rocks. To collect the hydrocarbons and make commercial accumulations of them, therefore, high lying parts of reservoir rocks (porous/permeable rocks) surrounded by impermeable rocks (f.ex. shale) are needed.

The traps can either be created during deposition or by tectonic movements (or by a combination). Traps formed by tectonic movement distrubing the originally flat laying layers, are called structural traps. The most important ones are (fig. 13).

a) Anticlines
b) Domes - created by 1)salt/shale movement
   2)Differential subsidence above a horst
   3)rotation on the downthrown side of a listric fault.
c) Fault blocks ⟨ horst / rotated fault blocks
d) Unconformity traps
e) Traps in connection with diapirs

Stratigraphic traps which are created by the original deposition, are caused by changing lithology. Amongst those the following are important (fig. 13).

a) Reefs
b) Pinch out traps
c) Fan-deposits on the downthrown side of a fault
e) Turbidites

In an early exploration phase structural trap-types attract most intension because they can be recognized on the reflection seismic data. The stratigraphic traps, on the other hand, are usually difficult to locate on the reflection seismic data without a good knowledge about the lithological column in the area and the depositional facies. Such information is in an offshore area not available before several wells have been drilled.

Statigraphic traps, therefore, are much more important in a more mature exploration phase.

However, two types of stratigraphic traps can be recognized on good reflection seismic data and those are the reefs and the turbidites.

In the actual area all of the mapped prospects are of the structural type. Most of the structures are created by faulting, but they are not all dependant on tight fault planes.
For instance, structure XI which shows up in both the blue and the green map, is caused by a fault but because of the rotation of the downthrown block a roll-over is created giving an anticlinal-like trap.

Prospect VII/VIII is a dome-like feature, but the generation of it is not clear.

Nearly all the other mapped prospects are dependant on tight fault-planes at least on one side.

If the structure on line 1014 is a diapir, traps against it are possible.

All the prospects in the area can be explained by a tensional regime, and no compresssional features (f.ex. anticlines) are seen.

From the onshore geology we suspected that both reefs and turbidites could be possible trap-types in the area, but the only possible reefs seen are very shallow, and no clear turbidites are seen, but we still suspect them to be a possible play, especially in the sequences above the green horizon.

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Reserve Estimation

There are different methods for evaluating a sedimentary basin. The status of the exploration in the area is important because it governs the knowledge about the area and, therefore, which parameters are known, and which have to be estimated or even guessed.

In an undrilled basin like the one offshore Mogadishu, the basic questions for reserve estimation should be:

1) The probability of finding petroleum?
2) Which type of petroleum?
3) Possible size of the reserves?

The answer to the first question is dependant on an analysis of the geological history of the area and should be broken up into questions like the probability of finding source rocks and reservoir rocks, trap types, time for creation of traps compared with the time of hydrocarbon migration, temperature etc. Those items are discussed in the other chapters.

The answer of the second question is always difficult to give in an undrilled area. Below a certain depth, dependant on the age of the strate, one will only find gas due to high temperature. If, however, the temperature is in the oil and gas window, the type of source rock will be the most important factor to decide whether gas or oil will be generated.

To indicate the answer of the third question, the size of possible reserves, one has to make the assumption that petroleum has been generated and migrated into the reservoir, where it has been capped by a suitable seal. If this is the case, the recoverable hydrocarbons are given by the following expresssion:

$$V_{HC} = V_R \times \alpha \times \phi \times S_{HC} \times 1/B_o \times R$$

where

V_{HC} = Volume of recoverable hydrocarbons

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V_R - Rock volume
α - Net/gross ratio
$\emptyset$ - Porosity
S_{HC} - Hydrocarbon Saturation
B_O - Shrinking factor for oil (extension factor for gas)
R - Recovery factor

In areas which have been explored over a time, and a lot of information is available about the mentioned parameters, one can draw empirically curves for each of them, or give them as probability functions. A commonly used method is to run a Monte Carlo simulation to construct a new probability curve for the expected hydrocarbon volume.

In our case offshore Somalia, where no near well information exist, the best one can do is to base the different parameters in the given formula on empirical relations based on wells in comparable basins world wide.
We estimate the volume of the structures from the seismic structure maps, and estimate a total hydrocarbon column of 280 m as an average. The other parameters are set as following:

α = 50% (net/gross ratio)
$\emptyset$ = 20% (porosity)
S_{HC} = 70% (hydrocarbon saturation)
B_O = 1,5 (shrinking factor)
R = 30% (recovery factor)

To get the reserves in tons rather than in volumetric units, a density of 0.85 ton/m^3 is used. All calculations are based on oil as the hydrocarbon type.
Thus we have the following relation between tons of recoverable hydrocarbons and volumes of the structures (down to 280 m).

$$\frac{H_c \text{ (tons of hydrocarb.)}}{V_{280} \text{ (volume of structure)}} = \underline{1.19 \times 10^{-2}}$$

We have then made some reservê estimates for the largest structures as following:

A. Blue Horizon

Structure B III

Volume 17.99 x 10^9 m^3

Recoverable reserves 214 x 10^6 tons

Structure B VII

Volume 8.24 x 10^9 m^3

Recoverable reserves 98 x 10^6 tons

Structure B XI

Volume 2.61 x 10^9 m^3

Recoverable reserves 32 x 10^6 tons

B. Green Horizon

Structure G I

Volume 4.7 x 10^9 m^3

Recoverable reserves 56 x 10^6 tons

Structure G VII

Volume 17.52 x 10^9 m^3

Recoverable reserves 208 x 10^6 tons

Structure G XI

Volume 11.375 x 10^9 m^3

Recoverable reserves 135 x 10^6 tons

GENERAL REMARKS

It is misleading to give reserve estimates for the different structures without mentioning the risk involved with each structure. For instance, a structure like GI will be a much more risky prospect than GVII, since GI is dependant on a sealing fault. However, without relying too much on the estimated figures, they give a good indication of the possible magnitude of the hydrocarbon reserves one may deal with if all other conditions are fulfilled.

As the area is nearly unproven except for the small shows onshore, we would estimate the chance to find hydrocarbons in the well defined structures to be 1/5 and in the less well defined structures to be in the order of 1/10.

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CONCLUSION AND RECOMMANDATIONS

The seismic grid shot in Area I has during the interpretation shown to be sufficient to give an evaluation of the prospectivity of the area. Of course, more seismic data are needed to give a better definition of the different structures before a definite well location can be picked.
However, collection of this type of seismic data may be performed by the companies who get concessions in the area.

The Upper Jurassic Uarandab formation is expected to be the most important source rock in Somalia. However, in most part of the area covered by this survey this formation is buried very deeply and is most certainly overcooked.
Of course, hydrocarbons could have been generated from this formation at an earlier stage and migrated upward and been trapped and preserved in shallower layer. It is, however, our opinion that the prospectivity of the upper sequence (above the green horizon) is dependant on the existence of younger source rocks. The chances that younger source rocks exist - e.g. Cretaceous and Tertiary shales are good because this area during these periods have been in a more deep marine facies than the area, where the onshore wells have been drilled.

We expect that rocks with fair to good reservoir characteristics exist at several levels in the stratigraphic succession, both Carbonates and sandtones.

Another important factor to consider when the prospectivity of an area is evaluated, is the "timing". "Timing" deals with the interplay between when the structures were created and when the hydrocarbons were expulsed. It is very important that the structures defined on the reflection seismic data were created before the hydrocarbon-migration took place, else no hydrocarbon will be trapped in the structure.

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In the actual area an evaluation of the timing is very difficult if not impossible, because it is unknown in which sequence the source rock is located - if existing at all. Generally, however, it can be said that the many of the structures in the upper unit (above the green horizon) are very young and, therefore, the risk, that these structures are dry, is rather high. We feel more confident about the structures mapped in the green and blue horizons.

However, the large risk connected with the structures in the upper sequence don't mean that they shouldn't be explored.

The status of the exploration in Area I now is, that enough information is available to pick out smaller areas for allocation of concessions. It could be reasonable for instance to divide the area into 3 concessions, each covering one of the map sheets. These concessions,we think,would have a reasonable size. However, it is very important that companies interested in the area present their own view on the geology, because different companies will certainly have rather different evaluations while no straightforward interpretation is possible from the data.

The concession policy can't be decided before the interest from the companies are known. Both positive and negative aspects concerning the attractiveness of the area have shown up during the interpretation.

Amongst the positive aspects are:

1) A very thick sedimentary succession exist
2) Some well - defined large structures exist
3) The small but significant hydrocarbon-shows in several onshore wells
4) The vicinity to the coast

Amongst the negative aspects,the following are the most important:

1) The very unstable sea bottom in large part of the area
2) No commercial fields found onshore by the many wells drilled
3) Most of the large structure are located at relatively deep water
4) The very low number of commercial fields in East Africa in general

Point 2 and 3 between the negative aspects, we think, are not too critical. Most of the wells in Somalia, and onshore East Africa in general, are drilled on poor data, and many of the wells are certainly not drilled at an optimal location. The exploration status are at all not on a level where the area could be declared uncommercial, especially not offshore, where very few wells are drilled. In Somalia only two deep offshore wells have been drilled and these are drilled far away from the actual area.

Point 3 is not too critical either, because drilling and production take place at still increasing water depth. But of course, deep water makes development expensive, and, therefore, the fields have to be larger to be commercial. However, commerciality depends very much on the taxation etc.

We think that the most critical aspect between the negative ones are the unstable conditions on large parts of the shelf. These conditions are not critical for the exploration phase, but will create very big problems and risks in a production phase.

The best way to proceed now will be to get the companies interested in the area and sell the data to them, and then, when all the different evaluations are made by the companies, to see how big the interest is for the area. We expect that with the shortage of oil and the increasing prices on the world market several companies will be interested in getting a concession in the area.

REGIONAL RECONNAISSANCE LINES

Two long, coast parallel, regional lines have been collected. One (2001) is going from Brava southwards to the Kenya border and the other (2200) is stretching from the Garad Mare well between Obbia and Eil to the Horn of Africa.

No coast perpendicular lines are shot and this makes the interpretation difficult, but these lines, however, give good indications about which areas that seem to contain interesting structures.

Only a short description of these two lines will be given.

LINE 2200

This line which is stretching from the Garad Mare offshore well drilled by Agip in 1977 to the Gardufui well drilled by Elf in 1975 near the Horn of Africa.

Information from these two wells gives very valuable knowledge about the ages of the different reflectors and about the lithology of the different sequences. The information from the Garad Mare well is the most valuable, because the seismic data are of excellent quality here, whereas the data are very poor at the northern end of the line where the Gardafui well is located.

Five reflectors have been mapped and the ages of these are:

Orange	=	Top Paleocene
Green	=	Top Cretaceous MAASTRICHTIAN
Yellow	=	Intra Cretaceous
Red	=	Top Jurassic unconformity TURONIAN
Blue	=	Top Adigrat formation (= Top Lower Jurassic) NEAR BASEMENT.

The colour code, therefore, has nothing to do with the one used in Area I.

Late Tertiary sediments are either very thin or missing in the Garad Mare area, as Lower Miocene was found 150 m below sea bottom.

The whole Tertiary section in the Garad Mare well is shaly. The Cretaceous is dominated by carbonates and below a hiatus Upper Jurassic Marls and limestones were penetrated. The Middle and Lower Jurassic Hamanlei formation is a carbonate sequence. The deepest penetrated sediments were continental clastics belonging to the Adigrat formation of Upper Triassic to Lower Jurassic age.

The Gardfui well is less useful because of poor seismic data at the well location. A lot of strong structuration is seen on the shallow part of the seismic section in that area, for example between sp. 12400 and sp. 12800. This structuration seems to be caused by halokinetic movements.

The Tertiary sequence is dominated by carbonates but gets much more shaly at the base (Paleocene/Lower Eocene). The youngest sediments penetrated were of Early Oligocene age.

The Upper part of the Cretaceous (Senonian) is shaly with some limestone-layers. The lower part is much more calcareous with numerous lithological changes between carbonates and shales. The well bottomed in Barremian shales.

The Garad Mare well is located at sp. 1930 and the Gardafui at sp. 13150. As the line shows, the Garad Mare well is drilled at a well-developed fault-block structure. The structure on which the Gardafui well is drilled, isn't cleary displayed on this seismic line, but could also look like a fault block.

The line (2200) displays a complete different geological situation than the one in Area I. The most pronounced difference is that the Tertiary section is much thinner and more stable in this

northern area. Both wells contained a very thin or completely missing upper Tertiary section, as Lower Miocene sediment was found at 150 m below sea bottom in Garad Mare and Lower Oligocene sediments are the youngest dated in Gardafui.
Top of Cretaceous is found at 1465 m depth in the Garad Mare well and at 1530 m in the Gardufui well. This means that much less subsidence took place in this northern area during the Tertiary, and the Mesozoic formations are, therefore, found on a much more prospective depth, than in Area I.
This means that in this northern area the Mesozoic is the main target, whereas the Lower Tertiary and only the upper part of the Mesozoic are the prospective sequence in Area I.

As line 2200 shows, the most prominent trap-type seems to be fault-blocks in the northern area. Several big fault structures are possible along most of this part of the coast. The Jurassic Cretaceous sequence is along the whole line found at a depth from 1.0 - 2.0 sec. T.T.T. (1200 - 2500 m) for the top of Cretaceous down to 2.0 sec.- 3.5 sec. T.T.T. (2.500 - 6.500 m) for the top of Adigrat, which is the lowestmost prospective unit.

The reflectors are mapable along the whole line, except for the blue (Top Adigrat) which, because of its depth, often is somewhat uncertain. The intra-Cretaceous reflector (yellow), however, has more character than the Top Cretaceous reflector (green) and is, therefore, mapped with more confidence. The orange (Top Paleocene) looses its character and is not mapped north of sp. 8.500.

Several places the green reflector is onlapping towards the yellow one on structural highs, and the green-yellow sequence generally varies quite a bit in thickness, because it many places seems to smooth out the relief created by the faulting.

All the faults, except one, are normal faults, many places creating rotated fault-blocks. The only exception is the fault at sp. 3.500, where the reflectors from green and downwards are downfaulted towards the south, whereas the orange reflector seems to be downfaulted to the north. This apparent reversal of the fault-movement could be caused by a strike-slip component in the fault.

Between sp. 4.500 and 5.900 the seismic data look very chaotic, possibly due to slumping and sliding tectonics. Across this zone it is impossible to correlate the reflectors with any confidence, and a jump correlation has, therefore, been made.

From sp. 8.500 and northwards to approximately sp. 10.500 the Top Jurassic reflector (red) gets very shallow (around 1 sec. T.T.T.) and in this area it seems like the whole Cretaceous sequence is missing.

From Ras Hafun and northwards the data change character and look much more chaotic. This is supposed to be caused by slumping and sliding in the upper part of the section.

Many places in the southern part of the area strong amplitude anomalies are seen in the shallow part of the section.
These anomalies are mostly connected with a layer at around 1.0 sec. depth. Often the anomalies are seen above major faults, for example at sp. 1600.
These anomalies are thought to represent shallow gas pockets.

The Gardafui well had reasonable good reservoir rocks in the Tertiary carbonates, whereas the Cretaceous sequence had poor reservoir quality. The source rock studies showed favourable maturation, but sapropelic material was rare and the source rocks, therefore, were mostly gas-prooned.

The Garad Mare well had minor gas shows in shales and limestones of Lower Jurassic age. The Gira limestone (Upper Cretaceous) had good porosity but was salt water bearing. The Hamanlei limestones were dense and the Adigrat formation had low permeability.

The results of these two wells both indicate that hydrocarbon generation has taken place, but gas seems to be the most likely hydrocarbon type. Intervals with good reservoir quality were encountered in both wells.

The negative results of these two wells, in our opinion, cannot rule out the possibility to find commercial hydrocarbon accumulations in the area. Especially the area between Garad Mare and Ras Hafun seems to have a favourable structuration.

LINE 2001

This line is a coast parellel line going through Area I and continuously down to the border aginst Kenya.

Here only a short description of that part of the line that lies south of Brava will be given. The same reflectors as mapped in Area I are follwed southwards to Kenya, but of course, the lack of coast perpendicular lines makes the correlation of the reflectors uncertain over such a long distance.

The colour code is the same as in Area I, and that means that the ages of the reflectors are estimated to be the following.

Orange	=	Late Miocene/Pliocene
Violet	=	Early Miocene
Green	=	Top Eocene (Mid-Oligocene?)
Blue	=	Top Cretaceous

However, it must be remembered that these datings are based on very uncertain information and correlations.

The line shows very interesting structuration, especially in the area north of Kismayo. Several large fault blocks are seen here. Much of this faulting seems to be associated with swell-structures deeper in the section. These swells can be caused by movements

either of plastic shale or, more likely, salt.
Salt of supposed Late Triassic age (not drilled) is known from offshore Kenya. However, no diapirs are seen on the profile.

The northernmost part of this heavily structurated area was covered by a 5 x 5 km grid in the phase IIshooting by GECO in April/May 1980, and a more extensive description will be given when these data are available.

The part of the line situated south of Kismayo shows a much more gentle picture with only few major faults and a very gentle dip of the mapped reflectors.