

Shelf Margin Deltas and Associated Deepwater Deposits: Implications on Reservoir Distribution and Hydrocarbon Entrapment, Block VI-1, Ulleung Basin, East Sea, South Korea

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Abstract

Block VI-1 covers 13,000 km² (3.2 million acres) in the southwestern part of the Ulleung Basin in water depths from 30 to 1,700 meters (100 to 5,500 feet). Approximately 20 wells have been drilled on the block since 1973. The block has 12,865 linear km (8,000 miles) of 2D seismic data and 1,500 Km² (580 miles²) of 3D seismic data. The block has three discoveries in Miocene Aged sediments. One of these discoveries, in a shelf edge delta, is currently under development.

The majority of Miocene to Recent sediments in Block VI-1 are shelf edge deltas and their associated deep water/slope deposits. Progradation of the shelf margin began in a northeastern direction and migrated to a northward direction as tectonic activity increased in the basin (Chough et al., 1997). Three distinct periods in the overall progradation relate to different tectonic periods: back-arc extension (16-12 Ma) associated with rapid basin subsidence, backarc closing (12-6.5 Ma) associated with uplift in the disturbed zone and subsidence in the undisturbed zone, and continued back-arc closing (6.5 Ma – Present) characterized by slow subsidence in the basin.

The reservoirs and hydrocarbon accumulations in the Ulleung Basin occur in shelf edge deltas and deep water sandstones-conglomerates. The shelf edge delta sandstone reservoirs are generally coarser grained and lower in porosity than age -equivalent deep water sandstones. Shelf edge delta traps form by a combination of recent regional warping and stratigraphic pinch out against shale-filled canyons. Deep water sandstones tend to be finer grained than the shelf edge sandstones, but coarse grained deep water sediments are observed. Porosity of the deep water sandstones is generally higher than the shallower water facies, but permeability is often lower. Observed hydrocarbon accumulations in the deep water facies occur in structural closures or truncation traps in areas of extreme structural deformation.

Introduction

Block VI-1 is located in the southwestern margin of the Ulleung Basin (Fig. 1). The block covers approximately 13,000 km² (3.2 million acres) in water depths ranging from approximately 30 m to 1,700 meters (100 to 5,500 feet). Most of the block lies in water less than 1,000 meters (3,000 feet) deep.

The first exploration well on the block was drilled in 1973. Approximately 20 wells have been drilled on the block; about half of the wells were exploratory. Three discoveries have been made on the block in Miocene sediments. One of these discoveries, located in a shelf edge delta, has been deemed commercial and is in development by the Korean National Oil Company (KNOC). Four additional features tested gas to the surface and also contained strong gas shows or other indications of hydrocarbons.

Regional Setting

The Ulleung basin contains a broad continental shelf and a steep slope between the Korean Peninsula and the Japanese Arc (Chough et al., 1997). The western margin of the Ulleung Basin is bound by a north-south trending basement escarpment, Figure 1. The basin has undergone significant modification in the Tertiary during the back-arc opening and subsequent closure of the East Sea (Sea of Japan) (Chough and Barg, 1987; Chough and Lee, 1992; Ingle, 1992; Yoon and Chough, 1995).

This tectonism influenced the sedimentation and trapping mechanism in the basin. Large-scale folds and faults located in the southeast corner of the block deform the Miocene strata. To the northwest, shelf slope sequences (middle-late Miocene) are relatively undeformed (Park, 1990; Yoon, 1994). Early paralic sediments were deposited during the initial stage of marine transgression in the basin and progressively deepened (Chough, 1983). A period of progradation began in the middle to late Miocene and filled the southern Ulleung Basin with predominantly shallow water sediments in coastal to neritic settings.

Chough et al., (1997) recognized three distinctive vertical stacking patterns in the overall progradational sequence. These three units relate to three distinct periods of tectonic evolution in the basin.

Succession I (A-C, 16-12 Ma) is characterized by sigmoid progradation, oblique progradation and retrogradational stacking patterns (Fig. 2). Progradation is toward the northeast. This interval was deposited during back-arc extension and is associated with rapid subsidence in the basin.

Succession II (C-G, 12-6.5 Ma) consists of four sequences each bounded at the base by an erosional truncation surface. Close to the thrust belt, each sequence is divided into two units based on the internal stacking pattern. The lower unit is retrogradational to aggradational, and the upper unit is tangential oblique progradation (Fig. 3). The lower unit is characterized by continuous high-amplitude reflections. This interval was deposited during back-arc closing that caused uplift in the disturbed zone and subsidence in the undisturbed zone.

Succession III (G-J, 6.5 Ma-Present) consists of 4 sequences (Fig. 3). Individual units show sigmoid progradation to aggradation, retrogradational, sigmoid progradation and oblique progradational stacking patterns in ascending order. These units were deposited during continued back-arc closing and the period is characterized by slow subsidence in the basin.

Progradation of the shelf margins began in a northeastern direction approximately 16 Ma. As the thrust zone became active in the southeast, the shelf margin orientation migrated from the northwest-southeast to east-west when the eastern shelfal region merged with the uplifted thrust zone to the east (Chough et al., 1997) (Fig. 4). Uplift associated with the frontal fold axis and the uplifted thrust zone was significant and significant erosion occurred on the crest of the compressive features.

Data Base

The block has 12,865 linear km (8,000 miles) of 2D seismic data and more than 1,500 Km² (580 miles²) of 3D seismic data. Approximately 20 wells have been drilled on the block. About half of the wells were exploratory. Less than 50% of the block has seismic coverage.

Reservoir System

The majority of Miocene to Recent sediments in Block VI-1 were deposited in shelf edge deltas and their associated deepwater/slope deposits. The two main reservoir systems identified are shelf edge deltas and the deeper water sands-conglomerates presumably deposited as turbidites and mass flow deposits. Figure 5 illustrates the location of the shelf edge delta play and the deepwater play. Figure 6 is a regional seismic line oriented east-northeast to west-southwest that illustrates 3 main facies belts: 1) a very sandy shelf edge delta system belt, 2) a shale-rich slope belt, and 3) a "deep water" sand belt.

The shelf edge deltas and the deep water sandstones form two very different reservoir systems. The shelf edge facies are normally pressured, are coarser grained, and have lower porosity

(typically 12-17 %) than the deeper water facies. Identified hydrocarbon traps are a combination of regional dip and stratigraphic pinch out caused by erosion at the shelf edge that forms canyons that are later shale filled.

The deep water sandstones are usually slightly to strongly geopressed, are generally finer grained than the shelf edge deltas though conglomeratic sediments have been observed, and have higher porosity (typically 22-30%). Even though the porosity is higher in the deep water sandstones, the reservoir quality/permeability is better in the shelf edge deltas. Identified hydrocarbon traps are strongly structurally controlled.

Shelf Edge Delta System

The shelf edge deltas are sandstone -rich and are thought to have good lateral continuity. Hydrocarbon generation and migration began in the Late Miocene and is ongoing. Recent structural inversion caused by the back-arc closure formed a series of semi-regional arches less than 5 million years ago. These arches in combination with shale-filled canyons that cut into the shelf edge during low stands of sea level form structural-stratigraphic traps. Two hydrocarbon discoveries in the block are in shelf edge deltas where the updip, lateral seal is a shale-plugged canyon.

The structural evolution of the basin and its effect on the shelf edge delta reservoir system can be seen in Figure 6. Two major unconformities are marked on the regional line for reference. The lower line is the approximate location of the 13.5 Ma unconformity, and the upper line is the approximate location of the 6.5 Ma unconformity. Deposition initially occurs from west to east parallel to this seismic line. The thickness of the deposits increase eastward and then gradually thin on the eastern end of the line. By the time of the 6.5 Ma unconformity the depositional dip is at right angles to the seismic line from south to north. The 6.5 Ma unconformity is extremely erosive regionally and was relatively flat during formation. An uplift after the formation of the 6.3 Ma unconformity formed several subtle ridges that focused hydrocarbon migration. The "Gorae V" ridge and more subtle "Gorae I" ridge are marked on the seismic line and are the location of hydrocarbon entrapment in the shelf edge delta deposits. The shelf edge delta hydrocarbon traps are a combination of gentle anticlines that plunge to the north, and shale filled canyons that trap hydrocarbons as they migrate up the anticline to the south. Without the shale filled canyons, the hydrocarbons would not accumulate. Only canyons with the proper orientation across the anticlines trap hydrocarbons.

The Gorae I feature was drilled in 1993, along a minor arch. Figure 7 is a seismic line through the discovery well. The shale filled canyon forms the updip seal on a structural feature that otherwise would not seal (Fig. 8). Canyon erosion into the shelf edge with subsequent shale infill is common and is the main identified trapping mechanism for the shelf edge delta system.

Deep Water System

The incised canyons that cut into the sand -rich shelf edge deltas result in a sand -rich deep water facies. The deep water facies is generally sandstone -rich and in one well contained conglomerates. All identified hydrocarbon accumulations in this facies are associated with areas of strong structural deformation. Because of the large amount of deformation and the recent movement on the faults, there is a high risk of leaking in large structures. Two hydrocarbon accumulations, the Dolgorae V and Dolgorae III, have been identified in the deep water facies, but have not been deemed commercial.

The Dolgorae V accumulation is interpreted as deeper water sandstones trapped in a structural closure. The structure was formed by a combination of compressional and transpressional forces (Fig 9). Two key stratigraphic horizons are marked on figure 9 the 6.5 Ma and 16 Ma unconformity. Recent structural deformation in the area is illustrated by this seismic line. Strata above the 6.5 Ma unconformity is relatively horizontal while the strata below the unconformity is highly deformed and a large amount of truncation occurs at the base of the 6.5 Ma unconformity. Hydrocarbons are trapped in deep water sandstones below the 16 Ma unconformity in 4-way anticlinal

closure formed by faulting and by updip pinch out caused by truncation associated with the 6.5 Ma unconformity (Fig 10).

The Dolgorae III accumulation is interpreted as deep water sandstones trapped below the 6.5 Ma unconformity. The Dolgorae III feature is a large anticline above a large compressional fault. Figure 11 shows the details of the structure in time, and the location of figures 12 and 13. A small accumulation is associated with a truncation unconformity formed on top of the anticline. Figure 12 is a seismic line parallel to structural dip that goes through the Dolgorae 3 well. Below the 6.3 Ma unconformity the strata is steeply folded. Above the unconformity the strata is more horizontal. Figure 13 is a structural strike line across the anticlinal feature. A major angular unconformity below the 6.5 Ma unconformity is clearly visible on seismic; hydrocarbons are trapped below the unconformity. A gas column of at least 100 m is supported by this truncation trap. The pressure gradient increases below the 6.5 Ma unconformity and increases with depth.

Hydrocarbon System

The source rock for the Ulleung Basin was deposited in the Oligocene during back-arc extension (KNOC internal reports). All indications are that the generation and migration was relatively recent and is probably ongoing. Hydrocarbons probably migrated up deep-seated faults over short distances. The potential traps in the shelf edge delta systems did not form until recently (< 5 mybp.) and therefore limit the timing of the hydrocarbon migration.

Conclusion

The reservoirs and hydrocarbon accumulations in the Ulleung Basin can be divided into 2 end members, shelf edge deltas and deep water sandstones-conglomerates. The shelf edge delta sandstone reservoirs are generally coarser grained and lower in porosity than age equivalent deep water sandstones. Hydrocarbon accumulations in the shelf edge delta system have both a structural and stratigraphic component. Shelf edge delta traps form because of a combination of recent regional warping and lateral updip stratigraphic pinch out. Hydrocarbon migration in the basin began relatively recently and is thought to be ongoing today. Hydrocarbons are trapped against shale-filled canyons that cut across broad, more regional highs that rise toward the south of the basin. Without the presence of the updip, lateral seal, the hydrocarbons would not accumulate. The deep water sandstones tend to be finer grained than the shelf edge sandstones, but coarse grained deep water sediments have been observed. Porosity of the deep water sandstones is generally higher than the shallower water facies, but permeability is not higher than in the shallow water facies. Observed hydrocarbon accumulations in the deep water facies are associated with areas of extreme structural deformation. The hydrocarbon accumulations are trapped in anticlinal structures or at the edge of anticlinal features in large truncation traps formed by erosion on top of the anticlinal feature.

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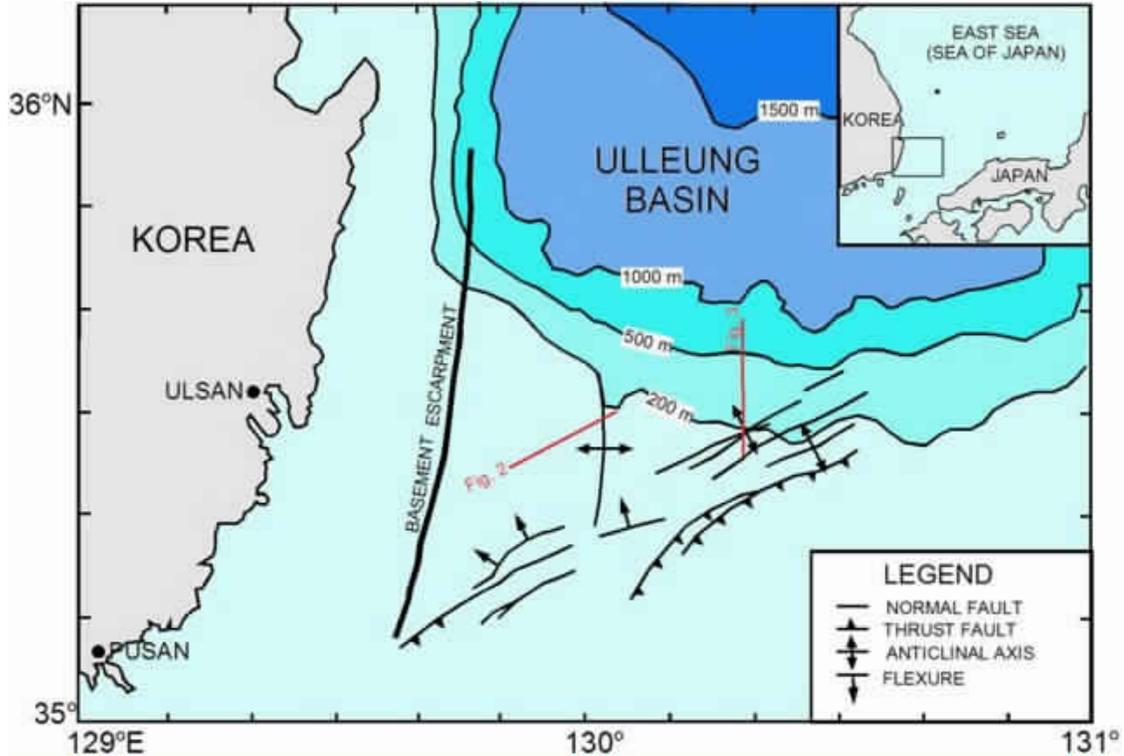


Figure 1. Map of the southwestern margin of the Ulleung Basin (Yoon, 1994).

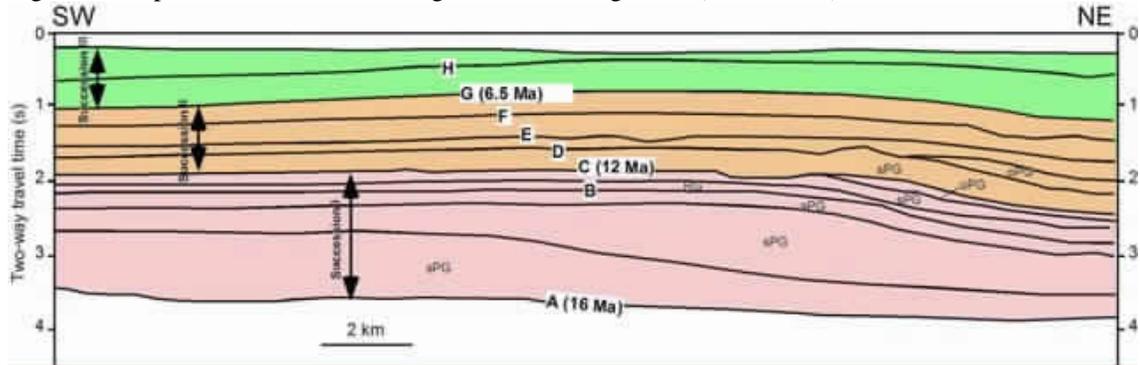


Figure 2. Sketch made from seismic data of major stratigraphic packages from the undeformed region. Succession I was deposited during back-arc extension and rapid regional subsidence. Succession II was deposited during back-arc closing which formed compressional features associated with rapid uplift in parts of the study area (Chough et al., 1997). See Figure 1 for location.

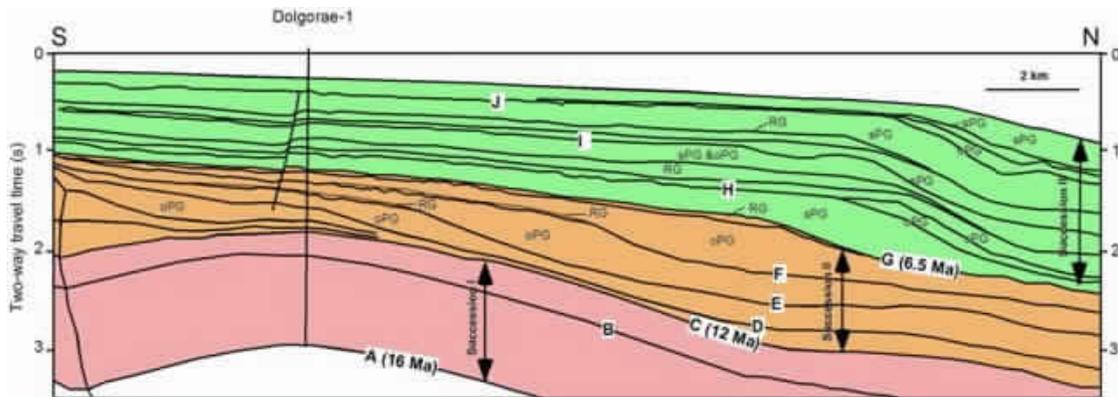


Figure 3. Sketch made from seismic data of major stratigraphic packages from in front of the uplifted thrust belt. Succession I was deposited during back -arc extension and rapid regional subsidence. Succession II was deposited during back -arc closing which formed compressional features associated with rapid uplift in parts of the study area. (Chough et al., 1997). See Figure 1 for location.

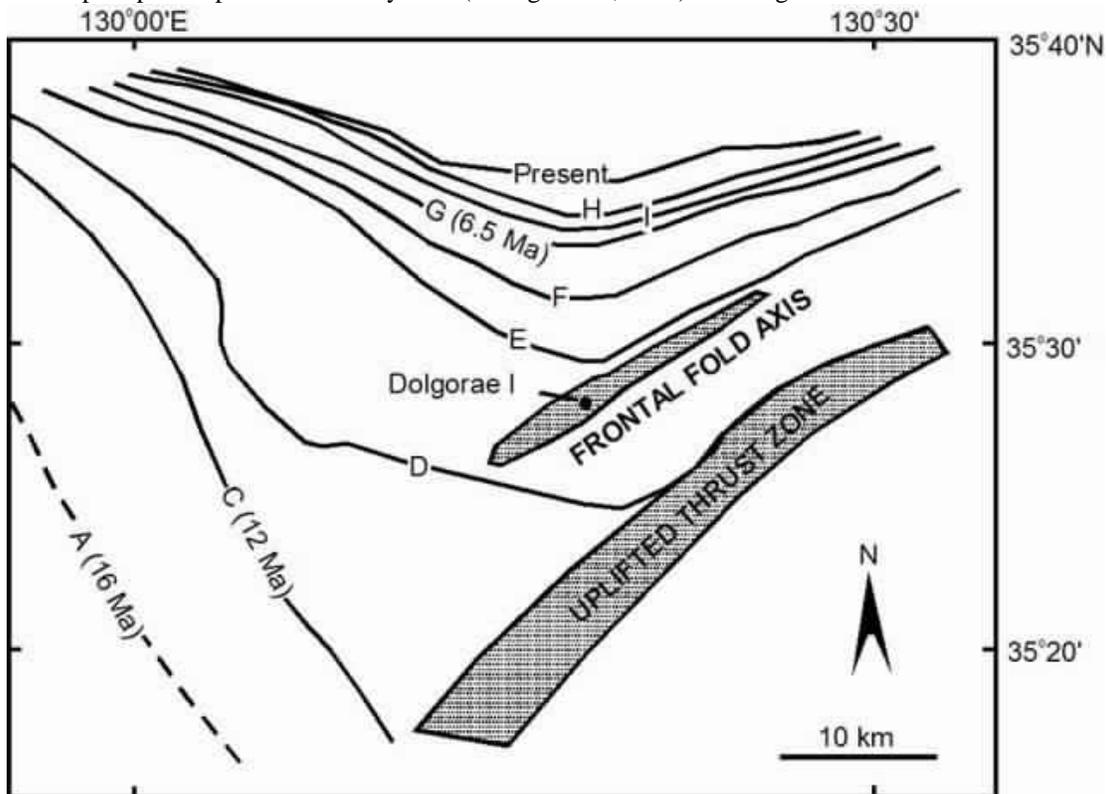


Figure 4. Paleoposition of the shelf margin from 16 Ma until Present. The shelf margin orientation migrates from northwest-southeast trending to east-west trending as the thrust zone becomes active in the southeast (Chough et al., 1997).

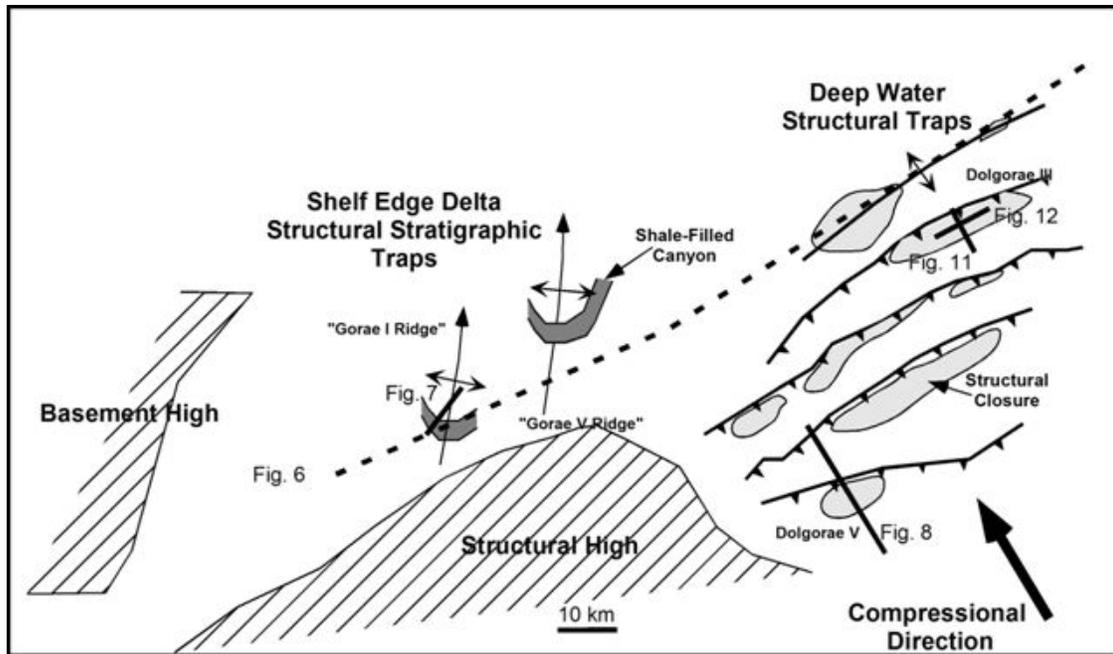


Figure 5. Play concept map for Block VI-1. Shelf edge delta hydrocarbon accumulations are located in the relatively undisturbed area toward the west of the block; hydrocarbons are trapped by a combination of noses or ridges that rise to the south, and shale filled canyons that form the updip lateral seal of the trap. Deep water hydrocarbon accumulations discovered to date are associated with large compressional features to the east of the shelf edge deltas. Stratigraphic traps are anticipated in the deep water facies, but have not yet been discovered.

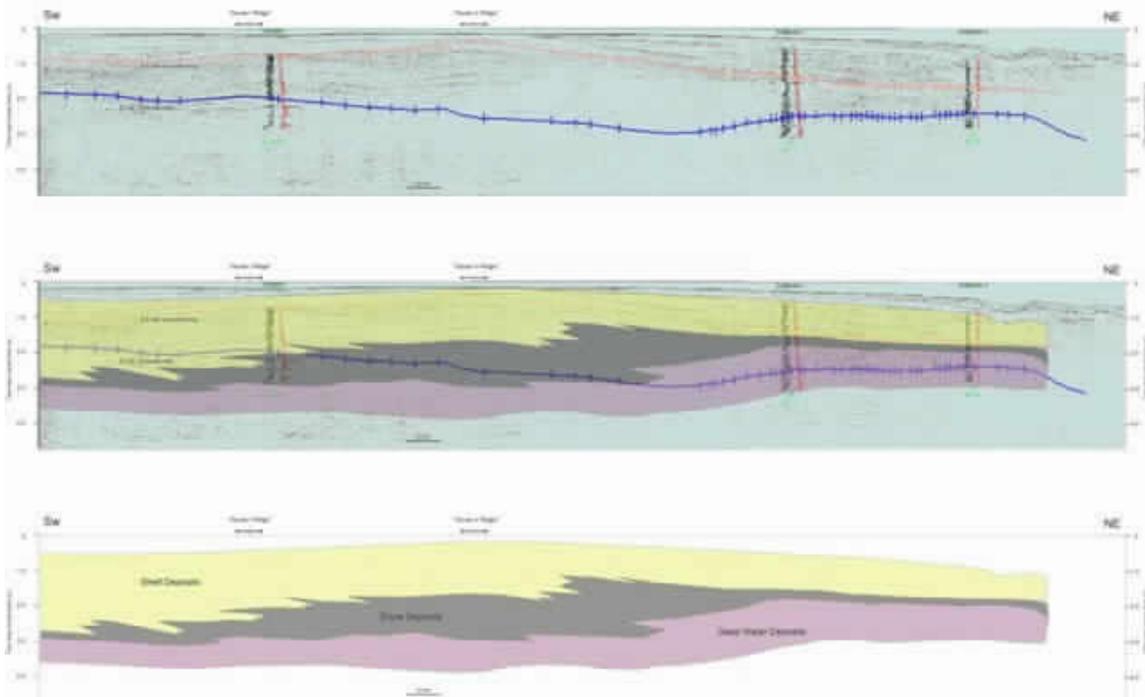


Figure 6. Regional seismic line along depositional dip. Yellow = shelf deposits (sand -rich), Gray = shale-rich slope deposits, Magenta = deep water deposits (sand-rich). The shelf deposits are typically normally pressured. Slight geopressure begins in the slope deposits and increases with depth. See Figure 5 for location.

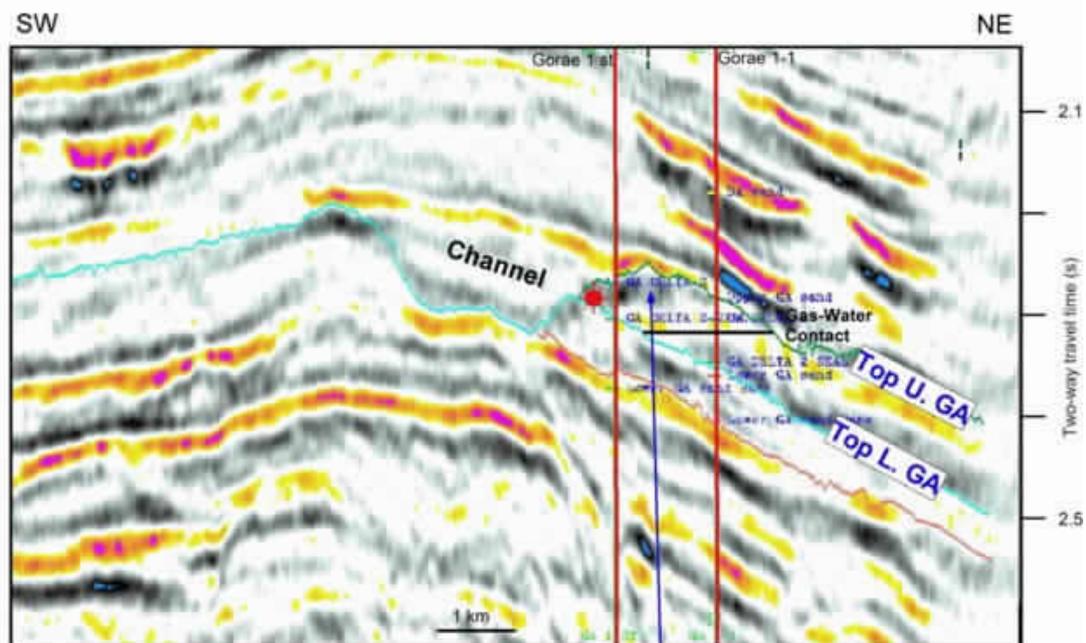


Figure 7. Seismic line through discovery well in the Gorae I feature and subsequent appraisal well. Hydrocarbons are trapped in the U. GA formation by the updip shale plug filling the channel/canyon cut into the shelf edge. Note brightening of reflectors where ever any channel thins. See Figures 5 and 8 for location. (Montie et al., 2002)

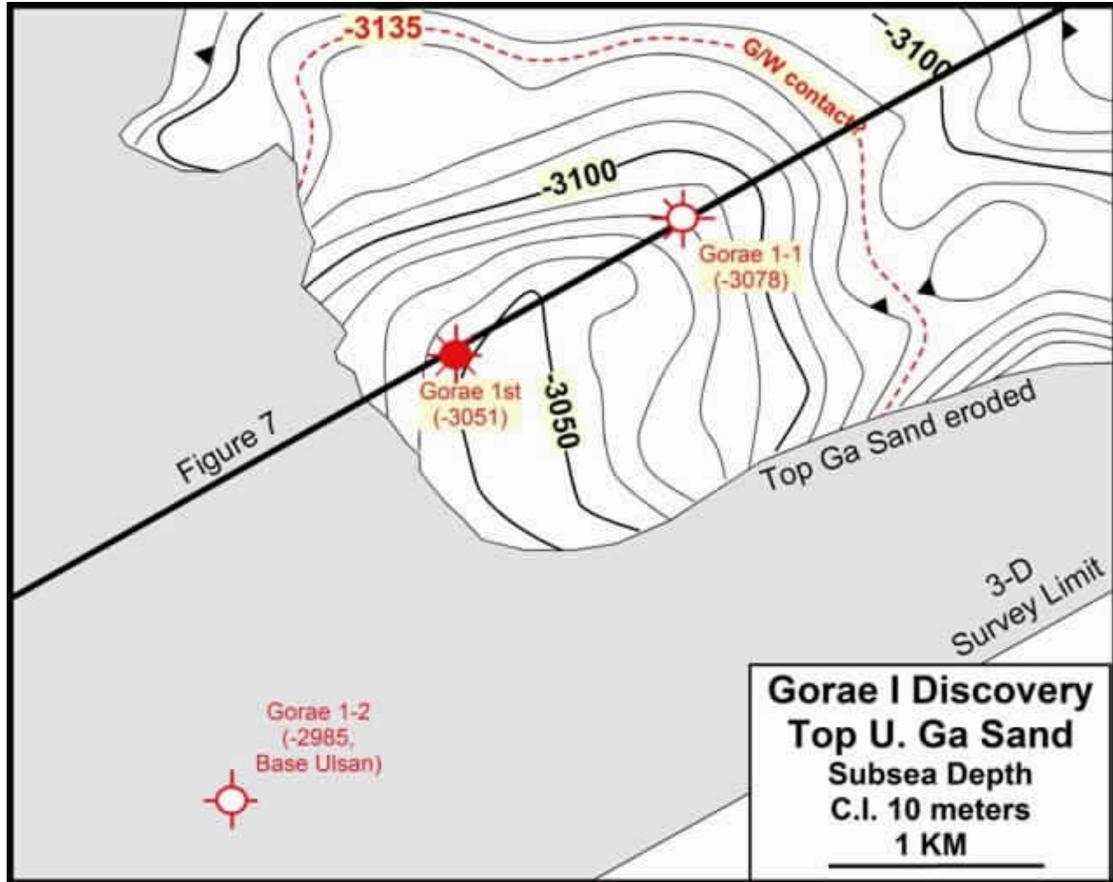


Figure 8. Structure map at the top of the Gæservoier sand. The updip-lateral seal for the accumulation is a shale-filled canyon. The trap is filled to the spill point with gas. (Montie et al., 2002)

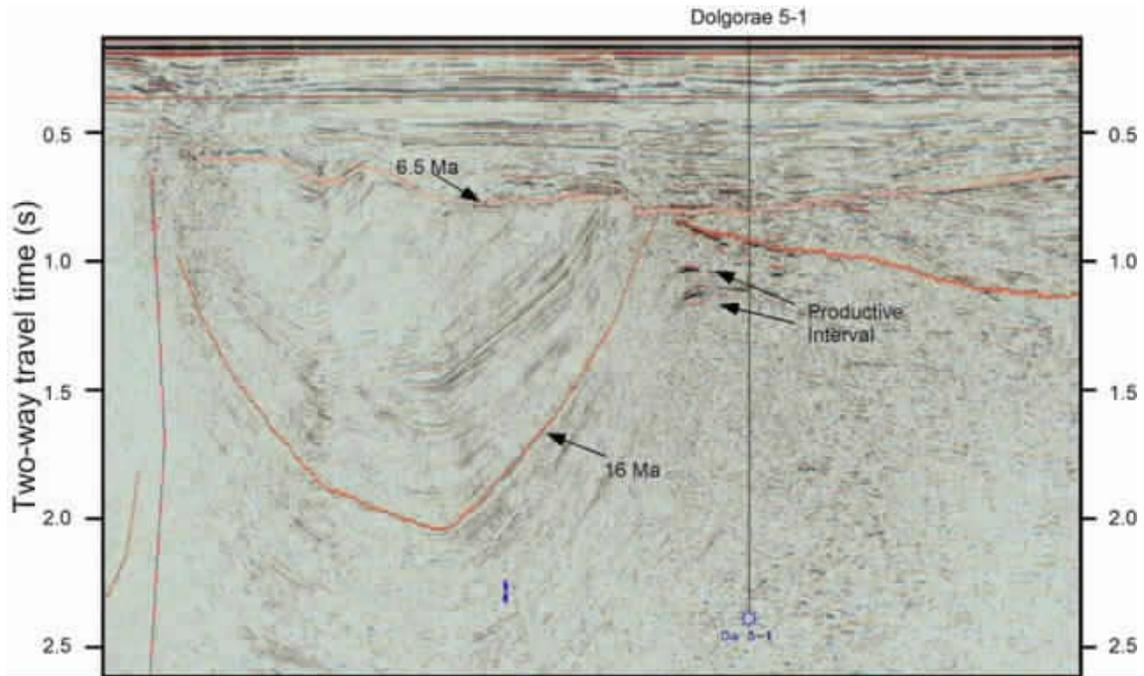


Figure 9. Seismic profile through the Dolgorae 5 field. The discontinuous higher amplitudes are gas accumulations. Note the large amount of deformation below the 6.5 Ma unconformity, and the relatively undisturbed strata above the unconformity. See Figure 5 for location. (Montie et al., 2002)

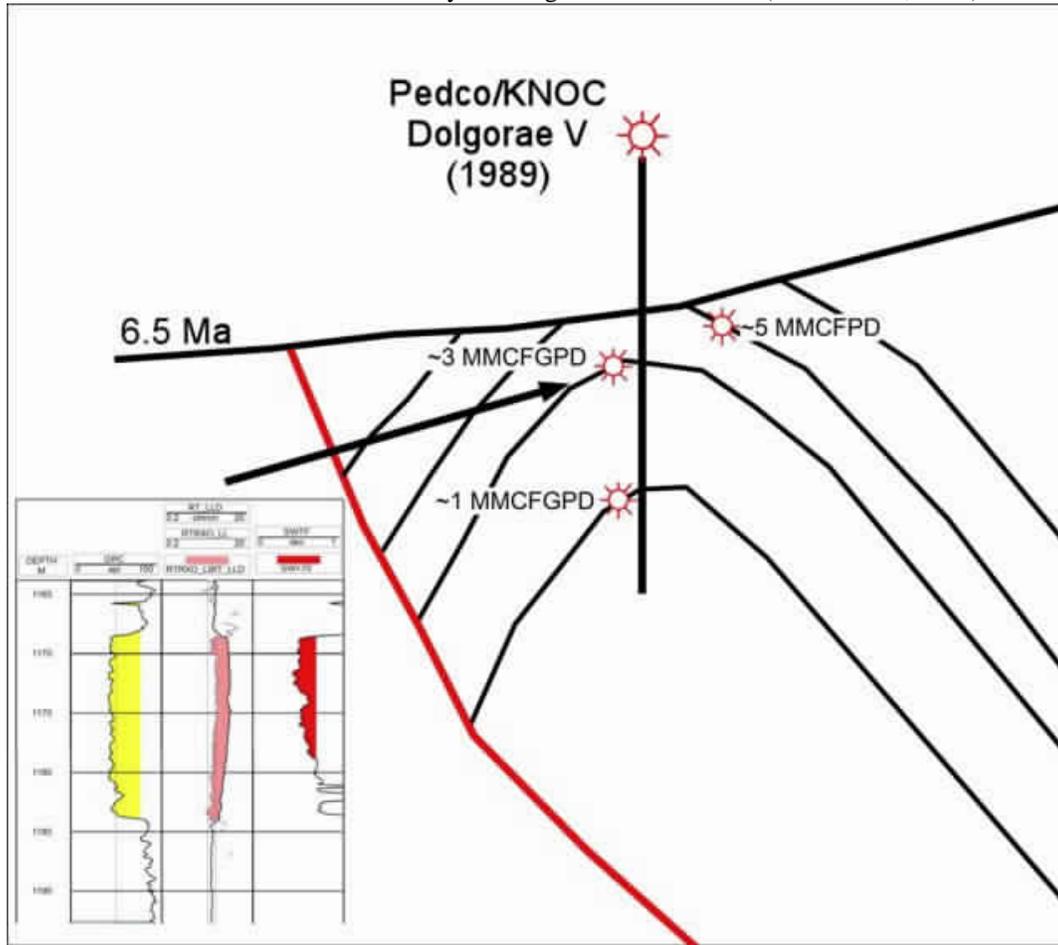


Figure 10. Schematic sketch of the Dolgorae 5 field. Trapping of the hydrocarbons is a combination of 4-way closure caused by thrusting, and an angular unconformity trapping hydrocarbons below the 6.5 Ma unconformity. (Montie et al., 2002)

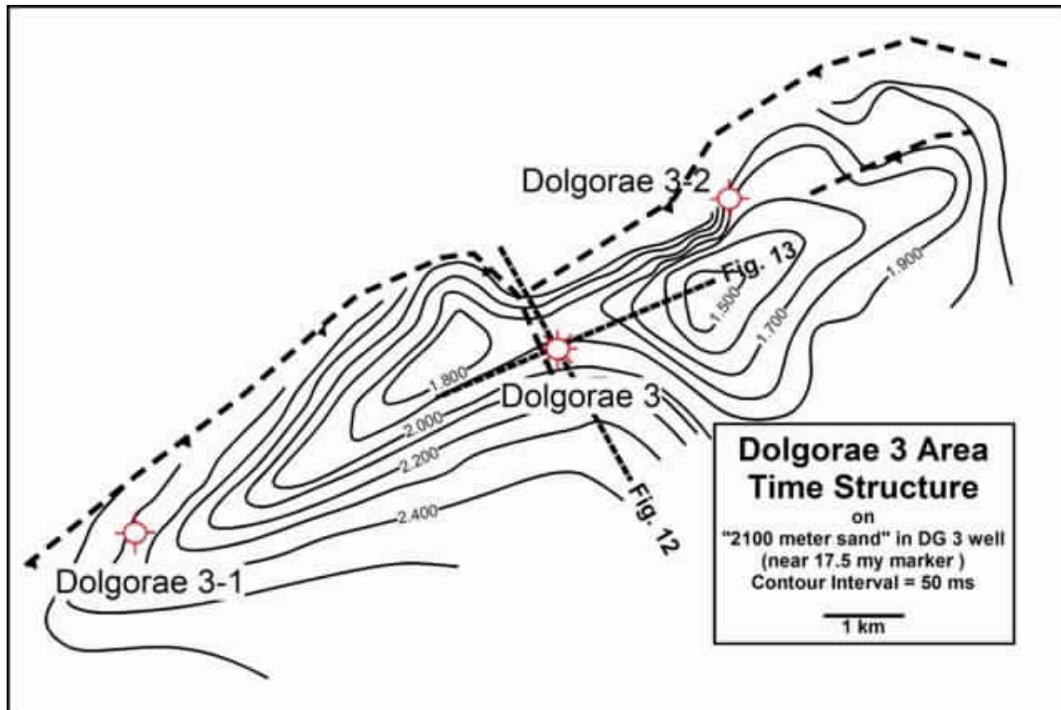


Figure 11. Time structure map on the 2100 m sand. The anticlinal feature is formed by a thrust which cuts the strata to the northwest. The Dolgorae 3 well is drilled in a small saddle between two structural culminations. (Montie et al., 2002)

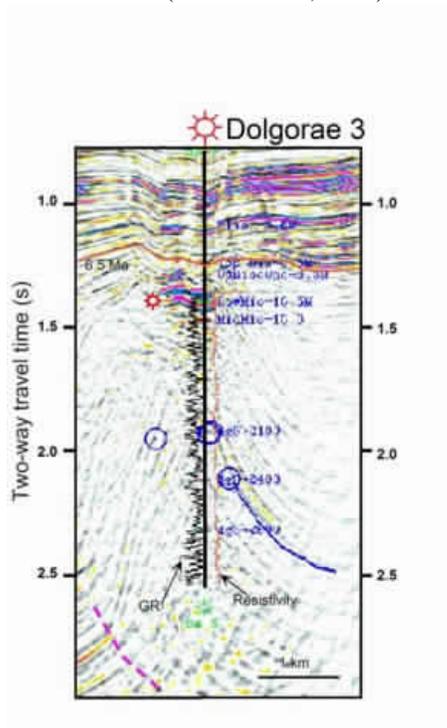


Figure 12. Seismic profile along structural dip illustrating the trapping geometry in the Dolgorae 3 well. Hydrocarbons are trapped by a major angular unconformity (6.5 Ma unconformity). Erosion is caused by the rapid uplift of the strata. Above the unconformity, the strata are only moderately deformed. See Figures 5 and 11 for location. (Montie et al., 2002)

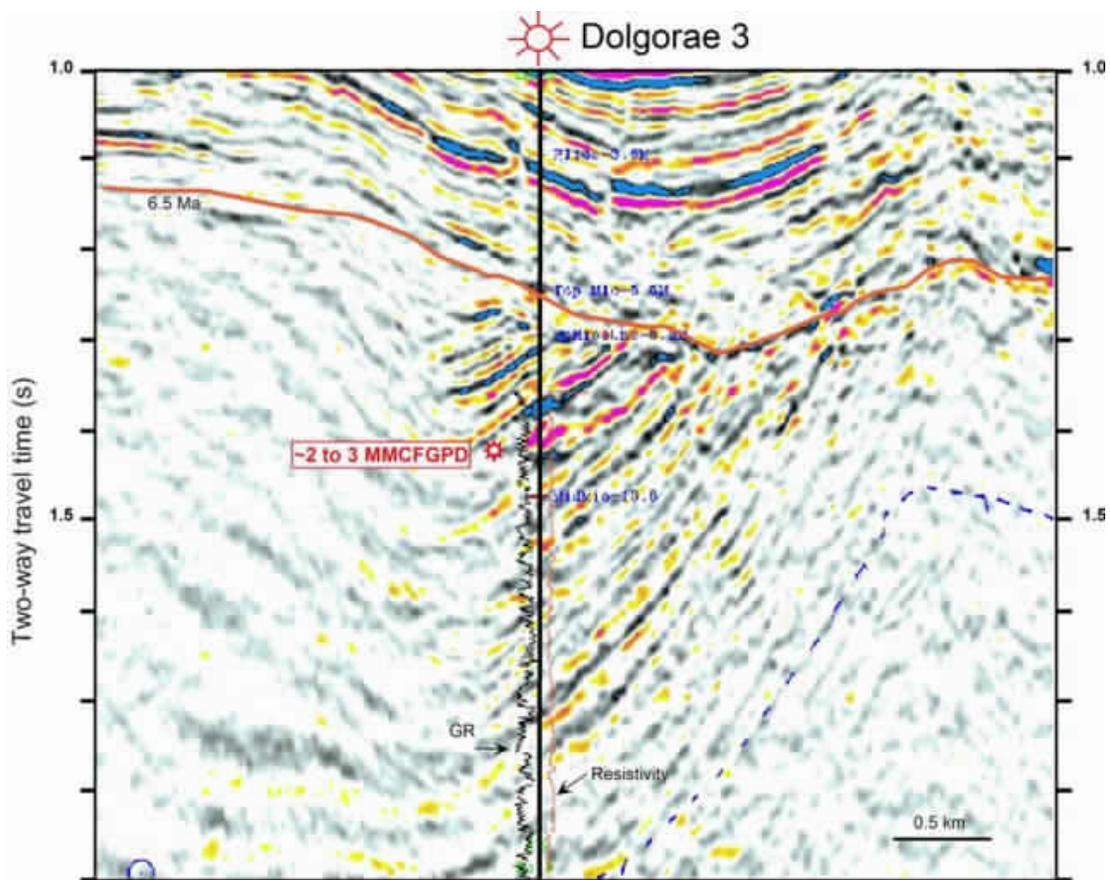


Figure 13. Seismic profile along structural strike illustrating the trapping geometry in the Dolgorae 3 well. Hydrocarbons are trapped by a major angular unconformity (6.5 Ma unconformity). Erosion is caused by the rapid uplift of the strata. Above the unconformity, the strata are only moderately deformed. See Figures 5 and 11 for location. (Montie et al., 2002)