FINE GRAINED TURBIDITE RESERVOIR FACIES OF THE KESAN GROUP: TIGHT GAS EXPLOITATION IN THE THRACE BASIN OF N.W. TURKEY

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Summary

Full diameter core from the Eocene Kesan Group in Baglik-1 provides an excellent example of fine-grained turbidite facies that exemplify one of the principal reservoir targets in the Thrace Basin of N.W. Turkey. The core displays a 13.5m thick turbidite channel - margin and levee/overbank facies association eroded into bentonitic fine-coarse grained mudstones deposited in an offshore transition environment of deposition, likely on a prograding clastic ramp. The lower bounding surface of the turbidite facies association is interpreted as a lowstand surface of sequence stratigraphic significance marking an abrupt basinward shift in facies associated with a fall in relative sea level. Turbidite channel margin facies are interbedded very fine- to fine- grained sandstones and fine- to coarse- grained siltstones characterized by amalgamated Bouma A-B (Ta-b) and A-B-D (Ta-b-d) beds. Dish structures, flame structures and fluid injection dikes are common. Episodic sedimentation by sediment gravity flows (turbidites and minor debris flows) is inferred from the sedimentary structures observed. The overlying turbidite channel overbank facies is an interbedded shaley siltstone and fine- to coarse-grained sandy siltstone with ripple and planar laminations, brecciated claystone beds and soft-sediment deformation inferring rapid episodic sedimentation along with overbank and suspension deposition.

Eocene sedimentation was strongly influenced by the collision and exhumation of complex sutured terrains as well as extensive local volcanism. Reservoir sandstone facies of turbidite channel margin origin are texturally and mineralogically immature feldspathic litharenites. Mean porosity at overburden conditions from core analysis is 10.1% with a range from 2.6 to 15.2%. Porosity has been reduced by calcite cementation and compaction. Thin section petrography confirms that approximately 50% or more of this porosity is ineffective and the majority is microporosity. Klinkenberg permeability values (Kmax) from core analysis are routinely less than 0.3md.

The cored interval within Baglik-1 was part of a 4-stage frac which yielded an IP of 2.9 MMcf/d. In 2013 the first horizontal well in the Thrace Basin offsetting the Baglik-1 was drilled and completed. The

425m lateral section included that part of the Kesan Group equivalent to the cored interval presented in this study at approximately 1110m drill depth. A 7-stage frac within the equivalent interval was less successful due to mechanical issues and yielded an IP of 0.6 MMcf/d.

Geological Setting

The Thrace Basin, located in northwest Turkey, is bordered by the Sea of Marmara to the southeast, Aegean Sea to the southwest and Bulgaria and Greece to the north and west (Figure 1) and is the most significant natural gas producing basin within the country.

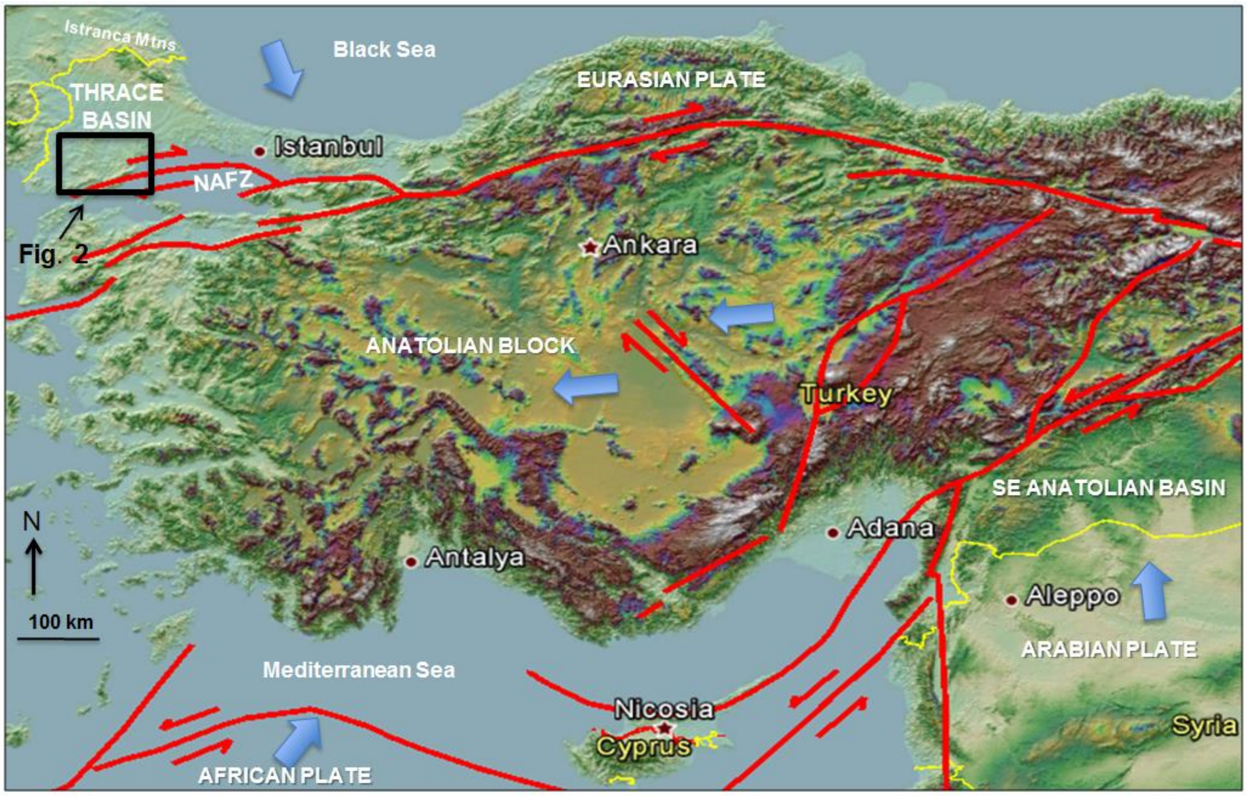

Figure 1. **Physiographic map of Turkey and adjoining land and water masses showing major structural lineaments. Note that the Thrace Basin is located in the northwest corner of Turkey and is bounded to the south by the North Anatolia Fault Zone(NAFZ). The black rectangle shows the outline of Figure 2 outcrop belt. Blue arrows indicate directions of plate movement.**

The Istranca Mountain Belt and North Anatolian Fault Zone are major tectonostratigraphic elements that bound the basin geologically to the north and south. Basin formation was initiated in the Late Cretaceous with collision of the Eurasian and African Plates and suturing of terranes within the Anatolian Block (Figure 1). Structural stages included transtensional faulting beginning in the Paleocene that is active to this day (Okay et al, 2004; Siyako and Huvaz, 2007), Miocene uplift and inversion, followed by right lateral movement of the North Anatolian Fault in the Pliocene. Accommodation space from tectonic subsidence has resulted in a Tertiary sequence of mostly siliciclastic and volcaniclastic sediments that is up to 9000m thick. This is disproportionately thick in comparison to its relatively limited 160 x 200km areal extent. Numerous natural gas fields within stacked sandstone reservoirs occur along fault bounded closures. Tertiary outcrop, including the Middle Eocene to Oligocene aged Kesan Group, flanks the southern rim of the Thrace Basin (Figure 2) and provides the opportunity to make sedimentologic and stratigraphic observations that facilitate the exploration for hydrocarbon bearing reservoirs in the relatively proximal subsurface.

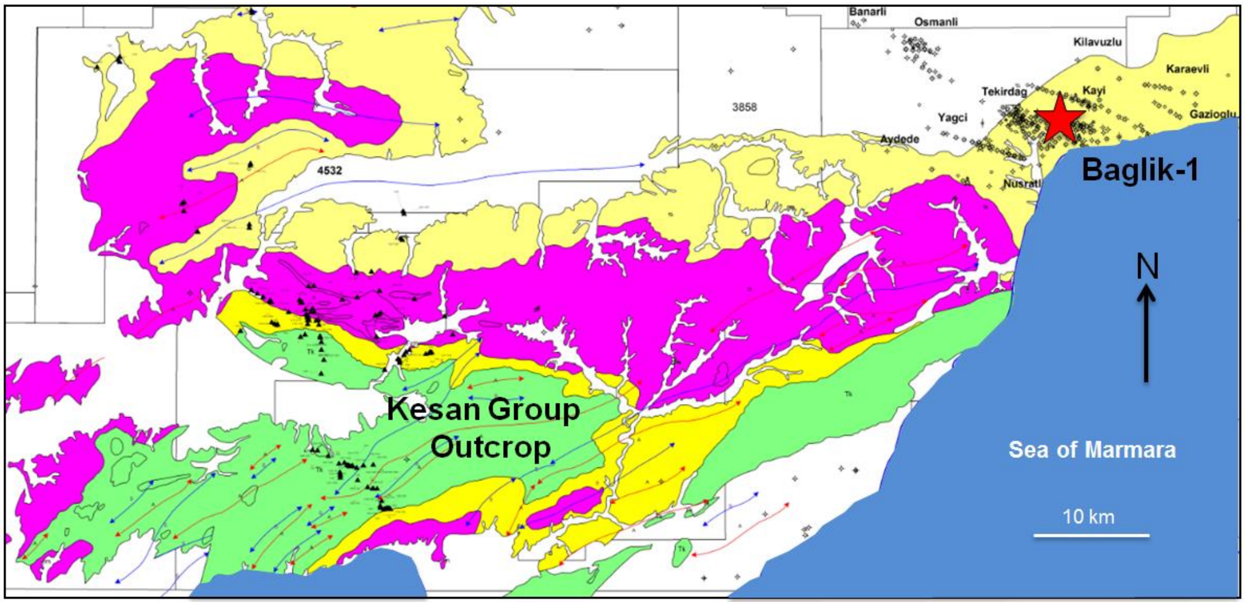

Figure 2. Surface geology map along the southwestern rim of the Thrace Basin showing the location and extent of the Kesan Group outcrop belt (green). Note location of the Baglik-1 well in the northeast corner of the map (red star).

The Kesan Group is highly variable in thickness and lithofacies, both in the outcrop belt and subsurface (Figure 3). Siyako and Huvaz (2007) report that there are 500 to 1500+m of conglomerates, sandstones, siltstones, shales, limestones and volcanics within the Kesan Group. The majority of the subsurface deposits within the Thrace Basin Center are fine- grained volcaniclastic to siliciclastic sandstones and siltstones. These lithofacies are the target of tight gas exploration in the Kesan Group as characterized by the Baglik-1 core presented in this study. The heterogeneity in lithology and mineralogy of the Kesan Group and much of the sedimentary fill within the Thrace Basin is attributed to multiple phases of tectonism and volcanism coincident with sedimentation during basin evolution (Huvaz, 2005). Sedimentary facies of the Kesan Group have previously been interpreted as being deposited in deltaic, fluvial and shallow to deep marine environments of deposition (Siyako and Huvaz, 2007).

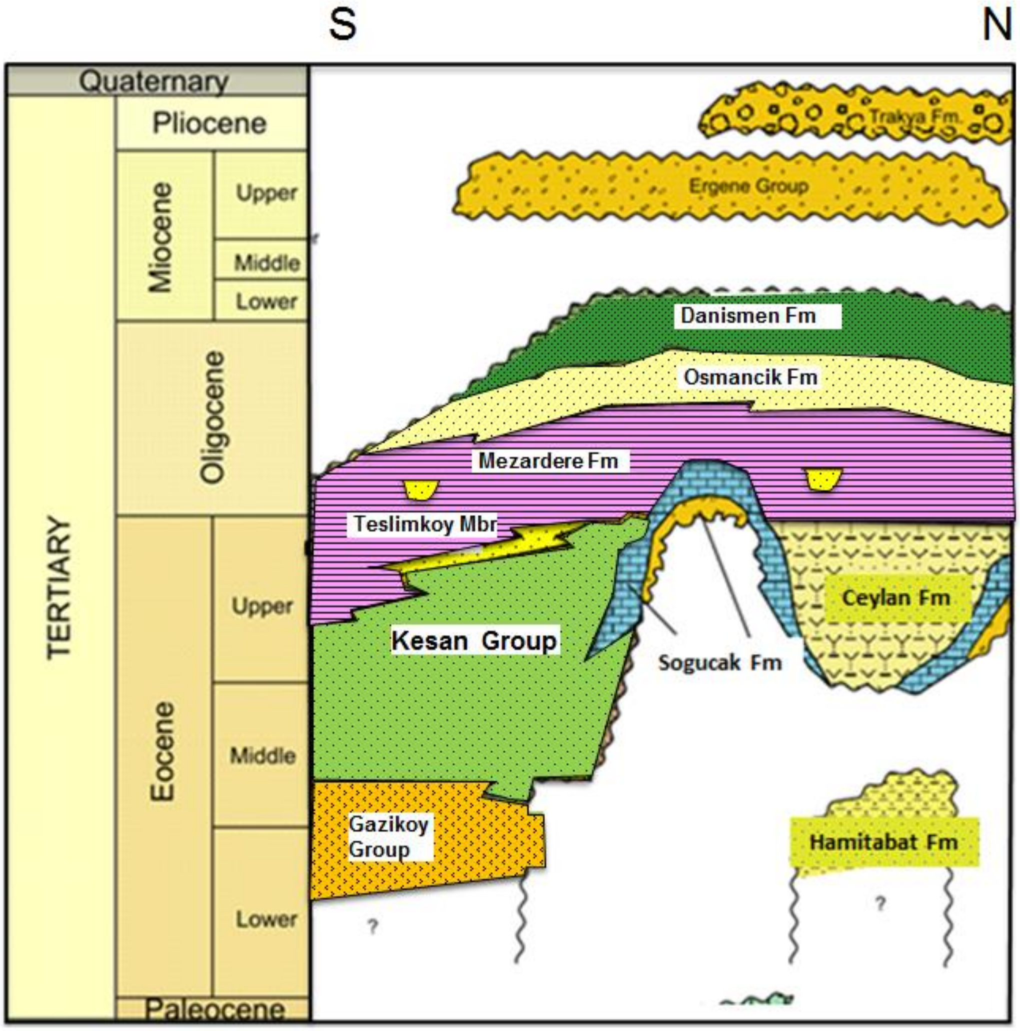

Figure 3. Stratigraphic column showing formations occurring in the outcrop belt and/or subsurface of the Thrace Basin. The Middle to Upper Eocene Kesan Group which reaches thicknesses of greater than 2000m in the southern Thrace is often referred to as the Ceylan Formation in the northern Thrace (modified from Siyako, 2005).

While over 400 BCF of natural gas has been produced from conventional reservoirs, the focus of exploration currently within the Thrace Basin is on unconventional reservoirs, specifically tight gas sandstones (Sadownyk, 2013). To date, most efforts have targeted the turbidite and prodelta deposits of the Kesan Group and Mezardere Formation within the southern part of the basin. Initial production rates from single and multi-stage fracs in both vertical and horizontal wells has ranged from 0.5 to 5.0MMcf/d.

Sedimentary Facies and Facies Associations

A graphic log depicting the bedding characteristics and vertical associations of sedimentary facies in the Baglik-1 Kesan Group core is shown in Figure 4. An 11.5m thick turbidite channel- margin facies association extends from 1119m to 1130.5m and consists primarily of poorly sorted, very fine- to fine-grained sandstone interbedded with shaley fine- to- coarse- grained

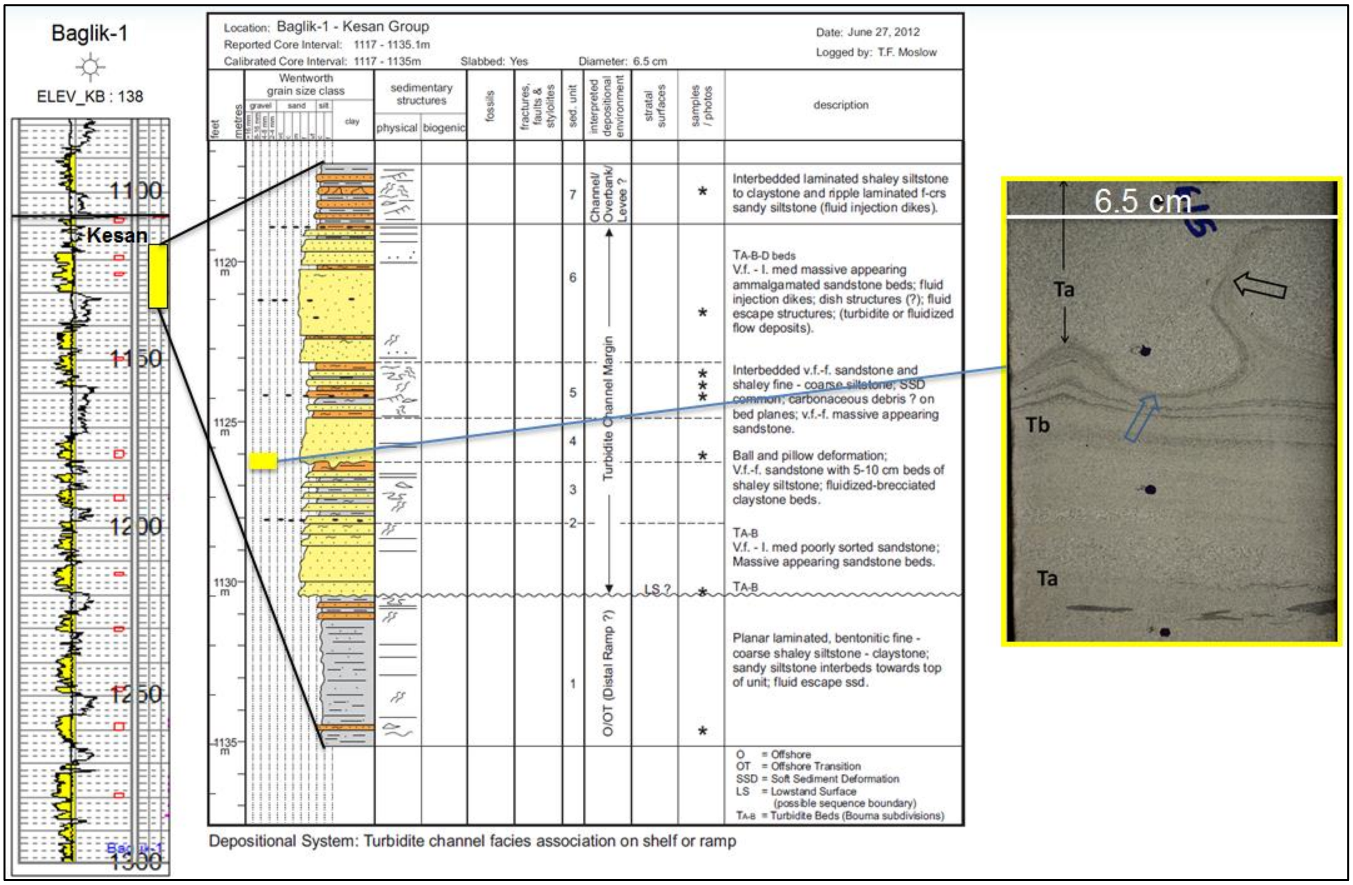

Figure 4: Graphic log calibrated to the downhole gamma ray log for the Kesan Group core in the Baglik-1 well identifying sedimentary characteristics, detailed description and interpreted environments of deposition. A legend of abbreviations used in the graphic log is provided in the lower right. The close-up core photograph to the right shows a ball and pillow structure at the bounding surface of two beds at 1126.2m within the turbidite channel-margin facies association.

siltstone and infrequently occurring brecciated claystones. Sandstone beds are commonly amalgamated and massive –appearing with respect to sedimentary structures. Less frequently, individual beds up to 30cm in thickness display Bouma sequences of Ta-b or Ta-b-d subdivisions. Fluid injection dikes, flame structures and dish structures are observed within the Ta subdivision of individual turbidite sandstone beds (Figure 5A). The observed sedimentary structures infer episodic sedimentation by sediment gravity flows, specifically turbidity currents, and less commonly debris flows (Figure 5B).

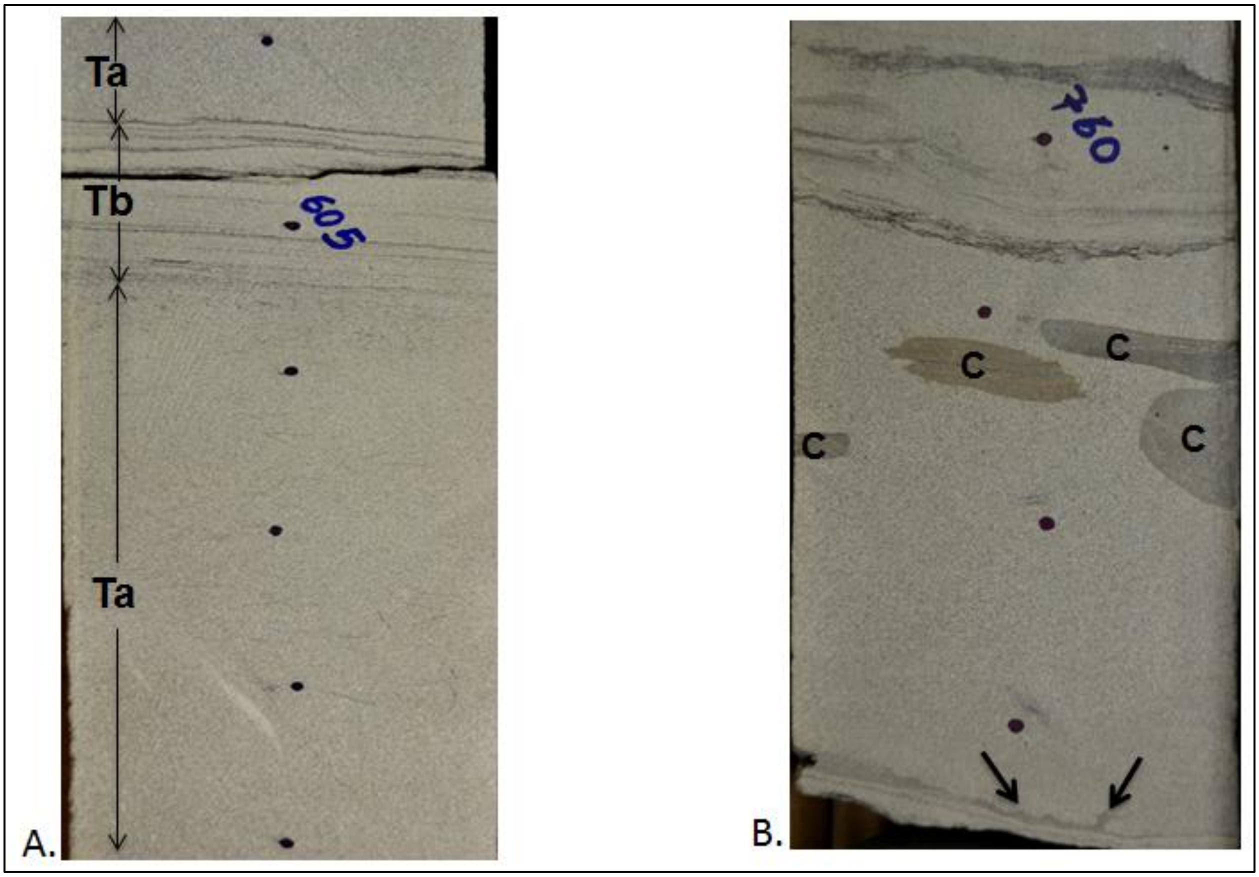

Figure 5. Turbidite channel margin facies association. A.) Close-up core photograph of amalgamated vf-m turbidite sandstones displaying massive- appearing (Ta) and planar laminated (Tb) subdivisions of a Bouma sequence. The Ta subdivision of the lower turbidite bed is characterized by discrete soft-sediment deformation features known as "dish structures" that are the product of rapid interstitial pore water evacuation in a fluidized sand bed as a product of rapid and/or differential deposition. Core diameter is 6.5cm. Baglik-1: 1120.5m. B. Debris flow deposit near base of turbidite channel-margin facies association. Note inverse grading of cm scale subangular to subrounded siltstone clasts (C) in upper half of massive-appearing vf-m sandstone bed. Base of bed displays small-scale flame structures (arrows), evidence of rapid sedimentation. Overlying siltstone bed at top of photo displays contorted laminations likely due to pore water evacuation. Core diameter is 6.5cm. Baglik-1, 1128.3m.

A listing of the sedimentary structures, bedding characteristics and inferred depositional processes for the facies observed in the Baglik-1 core of the Kesan Group is provided in Table 1.

Table 1. Baglik-1 KESAN GROUP Sedimentary Facies

Lithology/ Grain Size	Bedding	Physical Sedimentary Structures	Process of Deposition	Reservoir Quality	Depositional Environment
Interbedded VF-M/ VF-F poorly sorted sandstone and fine-coarse siltstone	normal grading; brecciated claystone beds	Amalgamated Bouma A-B/A-B-D beds or massive appearing; fluid injection dikes; dish structures	episodic sedimentation by sediment gravity flows (i.e. turbidites); overbank deposition	mean porosity of 10.1%; range of 2.5-15%; vertical and lateral heterogeneity	Turbidite Channel-Margin
Interbedded shale siltstone and fine - coarse sandy siltstone	Interbedded to inter-laminated	Ripple and planar laminated; brecciated claystone clasts; soft-sediment deformation	rapid-episodic sedimentation; overbank and suspension deposition	mean porosity of 6.18%; range of 3.0-9.0%	Turbidite Channel Overbank/ Levee
Bentonitic fine - coarse shaley siltstone and claystone	Laminated	Planar laminations; rare lenticular beds; convoluted laminations	suspension deposition; low velocity storm-generated current transport	mean porosity 8.4%; range 7.5-9.3% (coarse siltstone beds); very low matrix porosity	Offshore/ Offshore Transition

The turbidite channel margin facies association erosionally overlies a 4.5m thick interval of planar laminated, bentonitic, fine-to coarse- grained shaley siltstone to claystone, interpreted to have been deposited in an offshore to offshore transition environment of deposition. The erosional contact bounding these two facies associations at 1130.5m is interpreted as a sequence boundary/lowstand surface induced by a relative or eustatic drop in sea level and across which there is observed a rapid basinward shift in sedimentary facies (Figure 4).

Offshore transition to offshore facies, observed at the base of the Balgik-1 core, are characterized by indistinct parallel laminations, with sharp based 5-7cm thick coarse siltstone beds that are planar laminated with rare lenticular beds and convoluted laminations. There were no macroscopic biogenic sedimentary structures observed. Inferred processes of deposition include an alteration of low-velocity storm generated current transport in alteration with suspension sedimentation.

At the top of the core a 2.0m thick channel overbank/ levee facies is observed conformably overlying the turbidite channel-margin facies association. The channel overbank facies is a laminated shaley siltstone to claystone interbedded with ripple laminated fine-to coarse-grained siltstone beds. Soft sediment deformation features are observed mostly in the form of fluid injection dikes. Brecciated claystone clasts occur at the base of this facies where it is in contact with the top of the underlying turbidite channel-margin facies association (Fig. 4). Inferred processes of deposition are rapid and episodic sedimentation, local scour from traction and/or turbidity currents and suspension deposition.

Depositional Model

The vertical association of facies and facies contacts observed in the Baglik 1 provided the basis for interpreting the Kesan Group cored interval as having been deposited along the flank or margin of a turbidite channel (Figure 6).

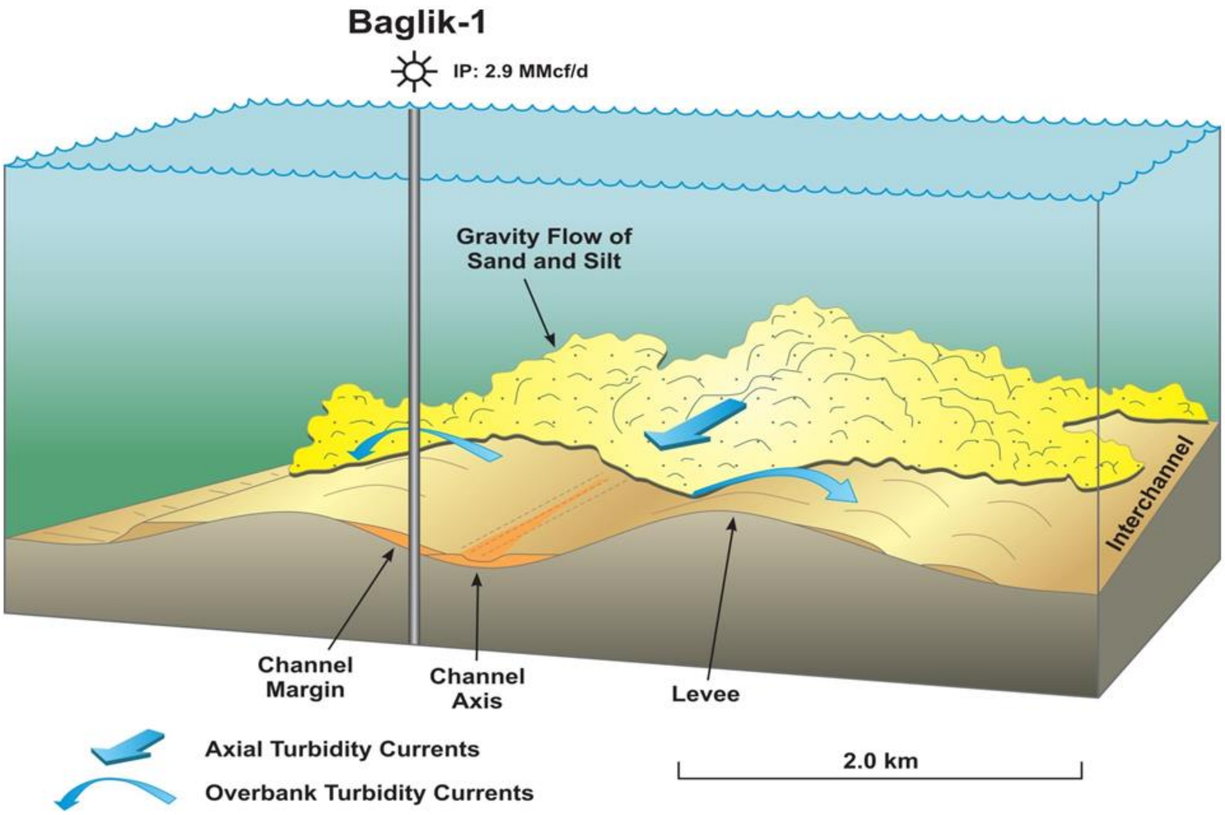

Figure 6. Three-dimensional block diagram depicting a depositional model for the Kesan Group core in Baglik-1 showing the interpreted location of the well and cored interval on the flank or margin of a turbidite channel. Blue arrows refer to the orientation and nature of turbidity currents that deposited sediment on the flank or levee of the turbidite channel (modified after Shanmugan et al, 1993).

Sediment gravity flows of fine grained sand and silt were transported basinward, likely by up-dip mass wasting events. The subsequent erosion, scour and deposition from these events are believed to be responsible for the origin of a turbidite channel on a ramp or basin-floor fan setting. If this interpretation is correct, it is likely that the axis of the turbidite channel would be represented by an amalgamation of thicker and higher net: gross sandstone beds, with minimal siltstone interbeds, in contrast to what is observed in the Baglik-1 core. Overbank turbidity currents depicted in the depositional model were responsible for the deposition of the fine grained overbank/ levee facies interval that is observed to overly the turbidite channel- margin facies association at the top of the core. The downhole gamma-ray log signature for the turbidite facies in the Baglik 1 displays a serrated nature reflecting the interbedding of sandstones and more clay rich siltstones, and very abrupt base coincident with an erosional contact 1130.5m as observed in the core. Based on its similarity in gamma-ray log character and shape (Figure 4), it is likely that the turbidite facies observed in the cored interval are just one of several turbidite channel or channel-margin facies associations of similar origin. This would imply a relatively rapid degree of compaction or tectonic subsidence during Kesan Group deposition.

Petrography and Reservoir Properties

Petrographic analysis including the point counting of 9 thin sections from sandstone beds in the Baglik-1 Kesan Group core are shown in Figure 7A.

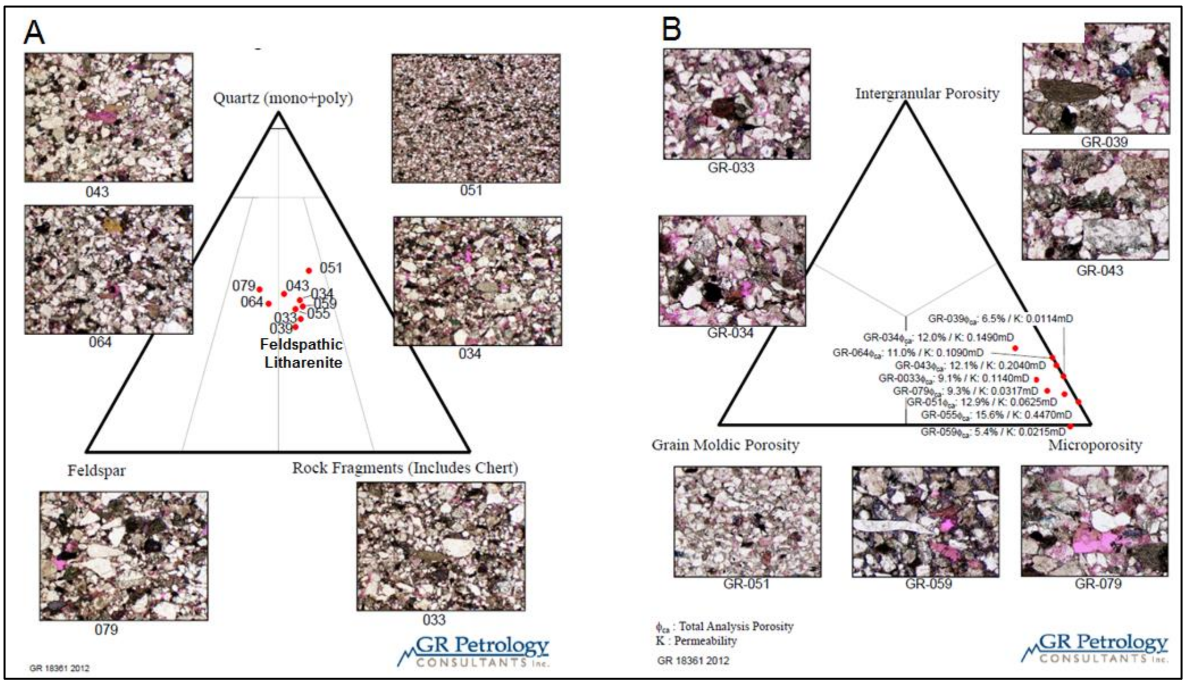

Figure 7. A. Ternary classification (Q, F, R) diagram for the Kesan Group core in Baglik 1 showing results from 9 samples from which thin sections were prepared. Point counting identified the Kesan Group core sandstones as feldspathic litharenites. Thin section photomicrographs are number-coded and correspond to sample id's within the QFL diagram. B. Porosity sandstone classification diagram for the Kesan Group core in Baglik-1 showing that the majority of observed thin section porosity is microporosity, most likely attributable to detrital and authigenic clays. Effective porosity is intergranular in nature.

Seven of the samples identify the sandstones as feldspathic litharenites and two samples are lithic arkoses. Samples contain a roughly even mixture of quartz, feldspar and sedimentary rock fragments, thus plotting near the center of the QFL ternary diagram. Mono and polycrystalline quartz and rock fragments are slightly more common than feldspar in seven of the nine samples. Rock fragments include chert, sedimentary, volcanic, igneous and metamorphic clasts. Sediment composition is both mineralogically and texturally immature as can be readily observed in the thin section photomicrographs in Figure 7A and infers localized proximal sediment derivation from igneous, metamorphic and/or volcanic terrains.

The vast majority of the observed thin section porosity in Kesan Group sandstones is microporosity with a minor component of intergranular and grain moldic porosity (Fig. 7B). The microporosity attributes its origin to the dissolution of feldspar and volcanic rock fragments. Most primary porosity has been occluded by compaction of labile grains, carbonate cementation and grain rimming clays. Microporosity is mainly responsible for the disproportionately high core porosity relative to permeability. The arithmetic mean core porosity from approximately 42 samples is 10.1% (Figure 8).

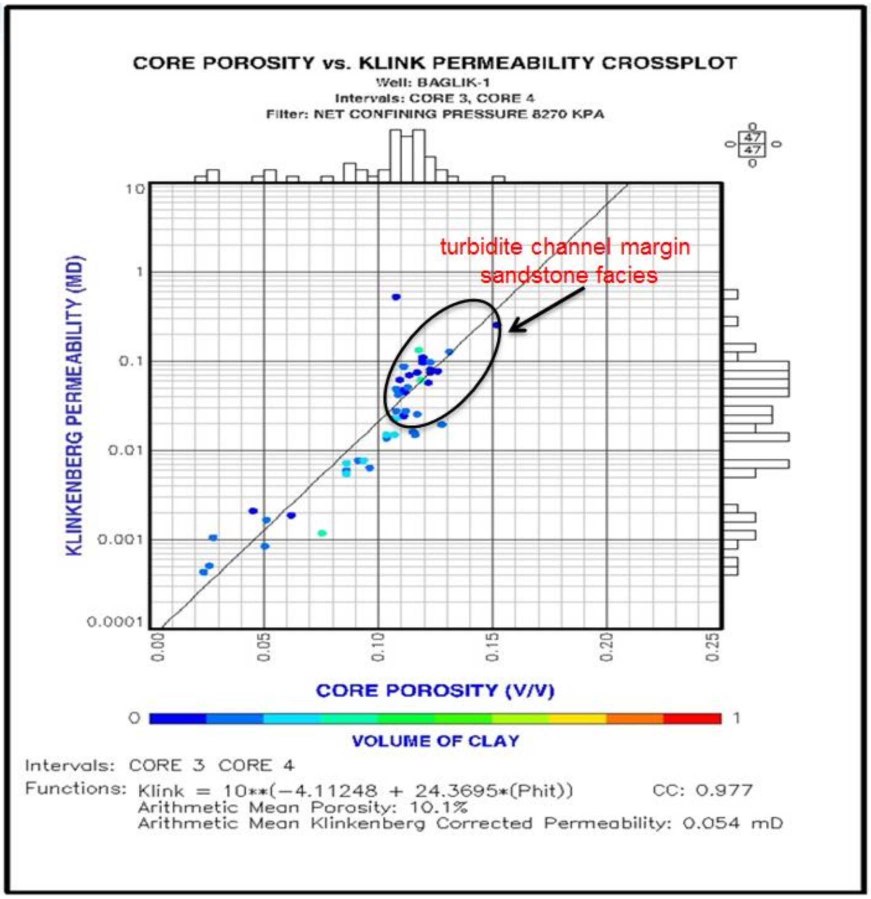

Figure 8. Core porosity vs. Klinkenberg permeability cross-plot for the Kesan Group core. Individual samples are color coded to Vshale and show that the highest porosity (10-15%) occurs where Vshale is lowest (dark blue). The ellipse superimposed onto the diagram outlines the turbidite channel-margin facies sandstone samples.

In contrast, the mean Klinkenberg corrected permeability is 0.054md with a range from .0004 to 0.5md. A petrophysical calibration of clay volume (V shale) to core analysis porosity shows a strong correlation between higher net: gross sandstones and porosity. These sandstones occur within the turbidite channel margin facies association which is the interval of highest inferred reservoir quality within the core. Based on these observations and analyses it is likely that reservoir quality would improve in a thicker and higher net: gross sandstone succession as would be expected in the axis of a turbidite channel. Such a succession is interpreted to be in close proximity to the Baglik-1 (Figure 6).

Conclusions

Full diameter core from the Eocene Kesan Group in Baglik-1 provides an excellent example of fine grained turbidite facies that exemplify one of the principal reservoir targets in the Thrace Basin of N.W. Turkey. The core displays a 13.5m thick turbidite channel margin and levee/overbank facies association eroded into bentonitic fine-coarse grained mudstones deposited in an offshore transition environment of deposition. The lower bounding surface of the turbidite facies association is interpreted as a lowstand surface of sequence stratigraphic significance marking an abrupt basinward shift in facies associated with a fall in relative sea level. Turbidite channel margin facies are interbedded very fine- to fine- grained sandstones and fine- to coarse- grained siltstones characterized by amalgamated Bouma A-B (Ta-b) and A-B-D (Ta-b-d) beds. The overlying turbidite channel overbank facies is an interbedded shaley siltstone and fine- to coarse- grained sandy siltstone with ripple and planar laminations, brecciated claystone beds and soft-sediment deformation inferring rapid episodic sedimentation along with overbank and suspension deposition.

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