PS Inference on the Potential of Hydrocarbon Resources in the Gyeongsang Basin, South Korea, Based on Petroleum System Modeling*

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Search and Discovery Article #10671 (2014)**
Posted November 24, 2014

*Adapted from poster presentation given at AAPG International Conference & Exhibition, Istanbul, Turkey, September 14-17, 2014

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Abstract

Gyeongsang Basin is the largest Mesozoic terrestrial basin covering about 20,000 km^2 with sediment thickness up to 8,000 m in South Korea. Many geological and geochemical studies for hydrocarbon exploration have been carried out in this basin since the 1970s, but any conventional oil or gas reserves have not been discovered yet. Some formations such as the Nakdong and Jinju Formations in this basin, however, show relatively high TOC (> 1 wt%) with maturation of late catagenesis, and thus they appear to be a potential source of shale resources as well as conventional hydrocarbon. We performed 1-D petroleum system modeling to constrain the timing of hydrocarbon generation and the amount of generated and expelled hydrocarbon with an integration of geological, geochemical, and petrophysical results. The maturity of the Nakdong Formation, the lowest formation of the basin with an average thickness of 1,100 m composed mainly of sandstones with shales, shows more than 3.0%Ro in the model. This is in good agreement with the results of measured virtinite reflectance (3~4% Ro) and Tmax (> 590 °C) of outcrop or core samples. Hydrocarbon generation of the Nakdong Formation commenced during Aptian at ~115 Ma and reached maximum oil generation window at ~100 Ma. Total amount of generated hydrocarbon in this formation is ~160 mg/g TOC. Most generated hydrocarbon converted to gas since Cenomanian (~95 Ma), as a result, about 50% of it was expelled from the formation and about 60 mg/g TOC is charged to the formation. The rest (~20 mg/g TOC) is residue of organic matters which no longer produce hydrocarbons. The Jinju Formation also represents high thermal maturation (2~3% Ro), indicated that it has been over-matured. Hydrocarbon generation of the Jinju Formation began at ~102 Ma (Albian) and reached maximum oil generation window at ~94 Ma. After Turonian, most generated hydrocarbons converted to gas, thus about 65% (~105 mg/g TOC) was expelled from the Jinju Formation and ~35 mg/g TOC of gas with some residue preserved in the formation. Since most sandstones in Gyeongsang Basin have low porosities (1~4%) and permeabilities (< 1 md), there is a low probability of discovering conventional hydrocarbon reserves. The petroleum system modeling, however, shows some shale gas potential in this basin.

Selected References

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AAPG International Conference & Exhibition 2014

KIGAM

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ABSTRACT

Gyeongsang Basin is the largest Mesozoic terrestrial basin covering about 20,000 km^2 with sediment thickness of up to 8,000 m in South Korea. Many geological and geochemical studies for hydrocarbon exploration have been carried out in this basin since the 1970s, but any conventional oil or gas reserves have not been discovered yet. Some formations such as Nakdong and Jinju formations in this basin, however, show relatively high TOC (> 1 wt%) with maturation of late catagenesis, and thus they are appeared to be a potential source of shale resources as well as conventional hydrocarbon. We performed 1-D petroleum system modeling to constrain the timing of hydrocarbon generation and the amount of generated and expelled hydrocarbon with an integration of geological, geochemical and petrophysical results. The maturity of Nakdong Formation, the lowest formation of the basin with an average thickness of 1,100 m mainly composed of sandstones with shales, shows more than 3.0%Ro in the model, which is good agreement with the results of measured vitrinite reflectance (3~4%R_o) and T_{max} (> 590 °C) of outcrop or core samples. Hydrocarbon generation of Nakdong Formation commenced during Aptian at ~115 Ma and reached maximum oil generation window at ~100 Ma. Total amount of generated hydrocarbon in this formation is ~160 mg/gTOC. Most generated hydrocarbon converted to gas since Cenomanian (~95 Ma), as a result, about 50% of it was expelled from the formation and about 60 mg/gTOC is charged to the formation. The rest (~20 mg/gTOC) is residue of organic matters which no longer produce hydrocarbons. Jinju Formation also represents high thermal maturation (2~3%R_o), indicated that it has been over-matured. Hydrocarbon generation of Jinju Formation began at ~102 Ma (Albian) and reached maximum oil generation window at ~94 Ma. After Turonian, most generated hydrocarbons converted to gas, thus about its 65% (~105 mg/gTOC) was expelled from the Jinju Formation and ~35 mg/gTOC of gas with some residue preserved in the formation. Since most sandstones in the Gyeongsang Basin have low porosities (1~4%) and permeabilities (< 1 md), there is a low probability of discovering conventional hydrocarbon reserves. The petroleum system modeling, however, shows some shale gas potential in this basin.

STRATIGRAPHIC MODEL

GROUP	FORMATION	DEPTH (m)	SCHEMATIC COLUMN[1,2]	LITHOLOGY MIX	BEGIN AGE[3] (Ma)	P. THICKNESS[3] (EROSION)	ΔSUB TECTONIC (m)	BETA (β)	LITHOSPHERE THICKNESS (Km)	POROSITY (φ)[4]	INITIAL TOC(%)[4]	ORGANIC TYPE[4]
YUCHEON	GOSEONG	650		30% SS 10% SILT 58% SH 2% LM	83.6 / 87.0	650	140	1.020	74.2	N/A	0.1	III
HAYANG	JINDONG	1000, 2000, 2150		10% SS 20% SILT 68% SH 2% IGN	97.2	1500	885	1.151	75.7	N/A	1.24	III
HAYANG	GUSANDONG TUFF / HAMAN	3000, 3550		15% SS 15% SILT 68% SH 2% LM	107.0	1400	225	1.036	87.1	7.8	0.17	III
HAYANG	SHILLA CONGLOMERATE	3750		75% SS 10% SILT 10% SH 5% IGN	107.8	200	10	1.001	90.2	5.8	0.1	III
HAYANG	CHILGOK	4000, 4350		15% SS 10% SILT 73% SH 2% LM	111.0	600	240	1.039	90.3	3.9	0.1	III
SHINDONG	JINJU	5000, 5250		25% SS 10% SILT 65% SH	116.0	900	275	1.046	93.9	3.4	1.92	I/III
SHINDONG	HASANDONG	6000, 6250		30% SS 10% SILT 58% SH 2% LM	121.5	1000	240	1.040	98.2	3.3	0.60	III
SHINDONG	NAKDONG	7000, 7350		40% SS 20% SILT 40% SH	125.5	1100	835	1.175	102.1	2.9	1.24	III
BASEMENT		8000		Granite Gneiss	1678 (Precam.)		(-7000)		120.0			

Stratigraphic units and input parameters for the petroleum system modeling at a dummy well in the Gyeongsang Basin (Reference 1: Chough and Sohn, 2010, 2: Paik et al., 2006, 3: Lee et al., 2011, 4: Um et al., 1983, Oh et al., 1995, Son et al., 2000).

STUDY AREA

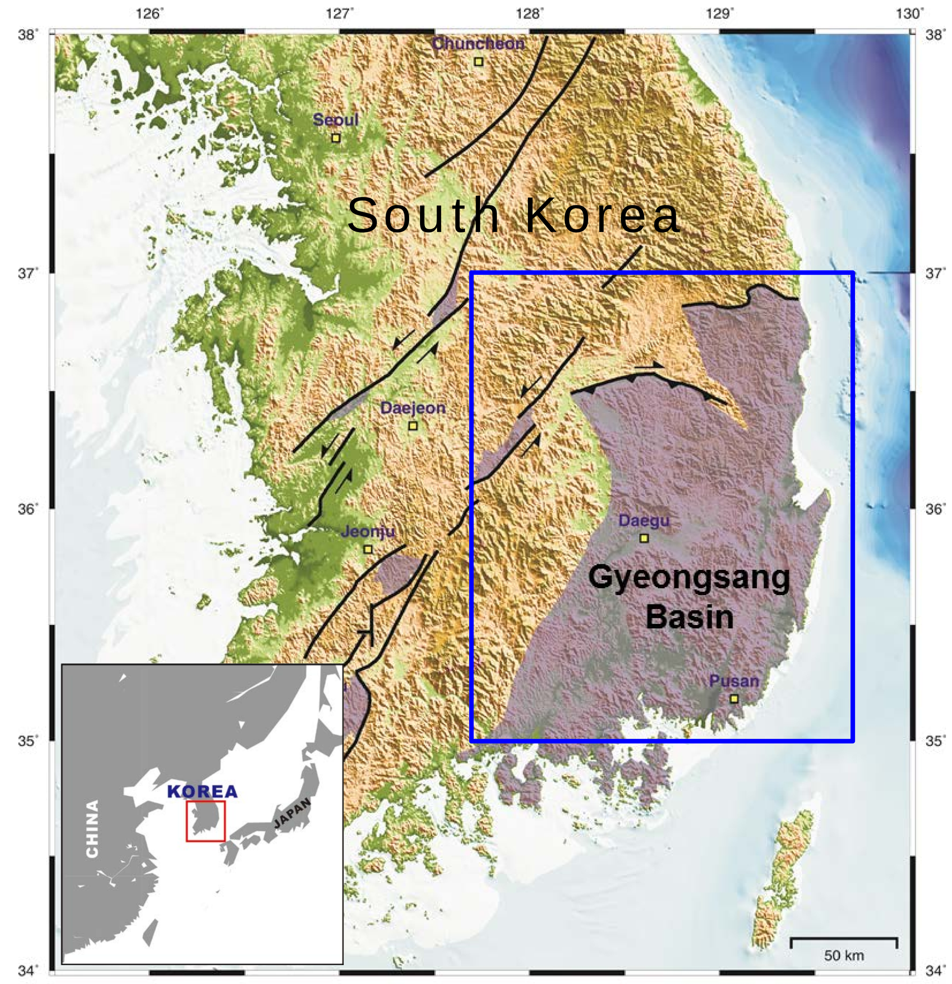

Figure 1. Location of Cretaceous terrestrial basins in South Korea (modified from Chough et al., 2010) .

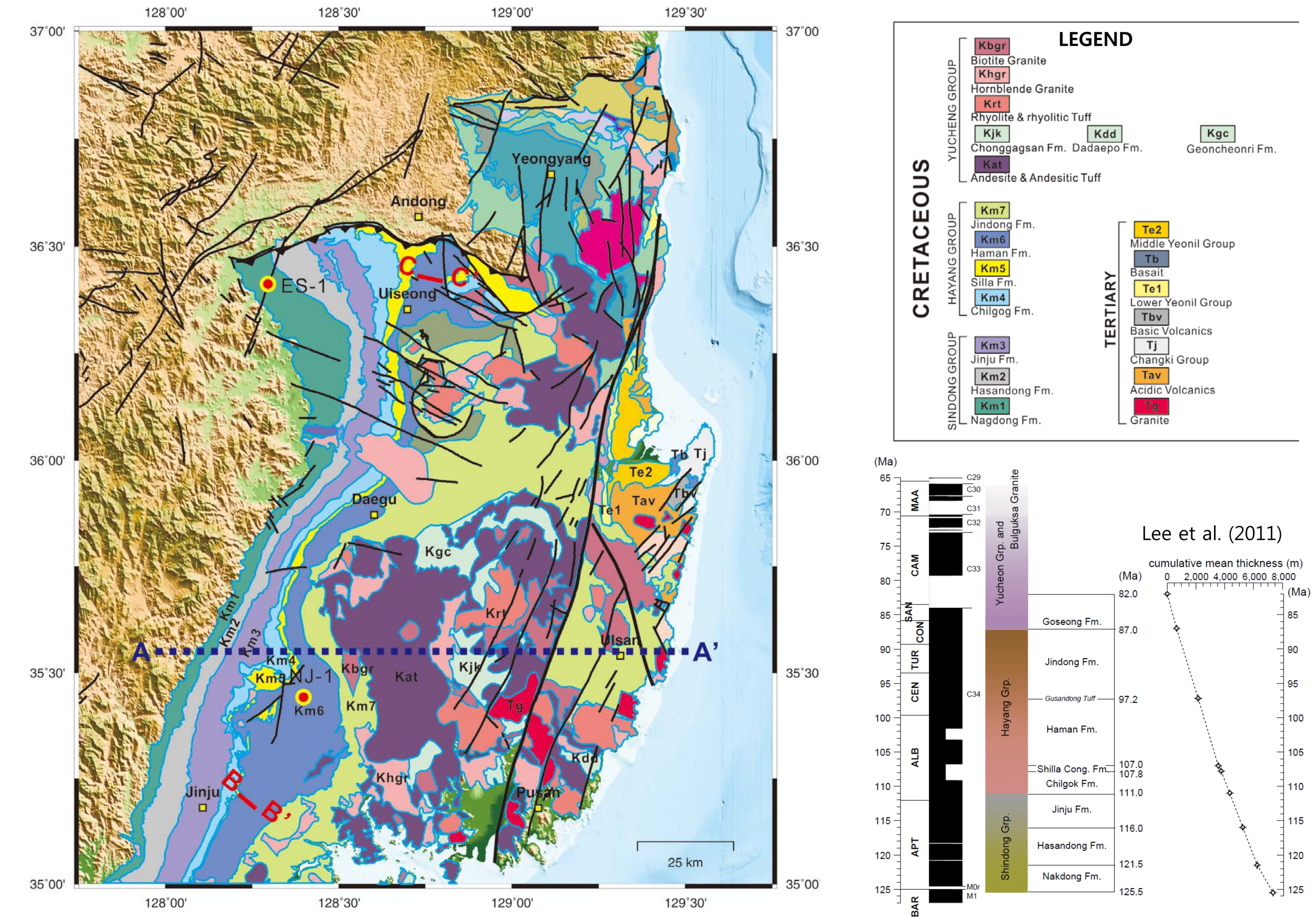

Figure 2. Geological map of the Gyeongsang Basin (KIGAM, 1996, 1998). Red circles with annotation represent hydrocarbon exploration wells. ES-1 : Euiseong drilling well (TD : 1,536 m), NJ-1 : Namji drilling well (TD : 800 m).

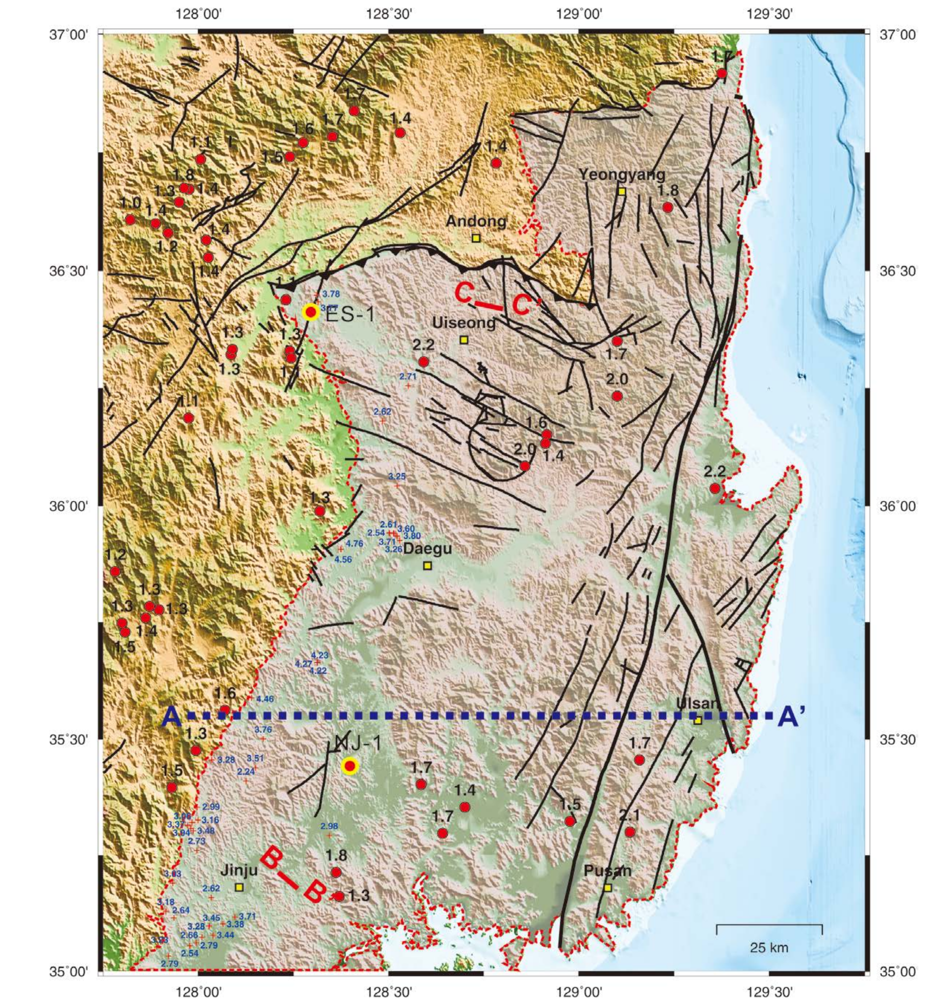

Figure 3. Distribution of heat flow and Vitrinite Reflectance around the Gyeongsang Basin. Red circles with number denote heat flow in HFU (1 HFU = 41.84 mW/m^2). Crosses with numbers represent Vitrinite Reflectance (%R_o).

GEOLOGICAL, GEOCHEMICAL & PETROPHYSICAL CONSTRAINTS

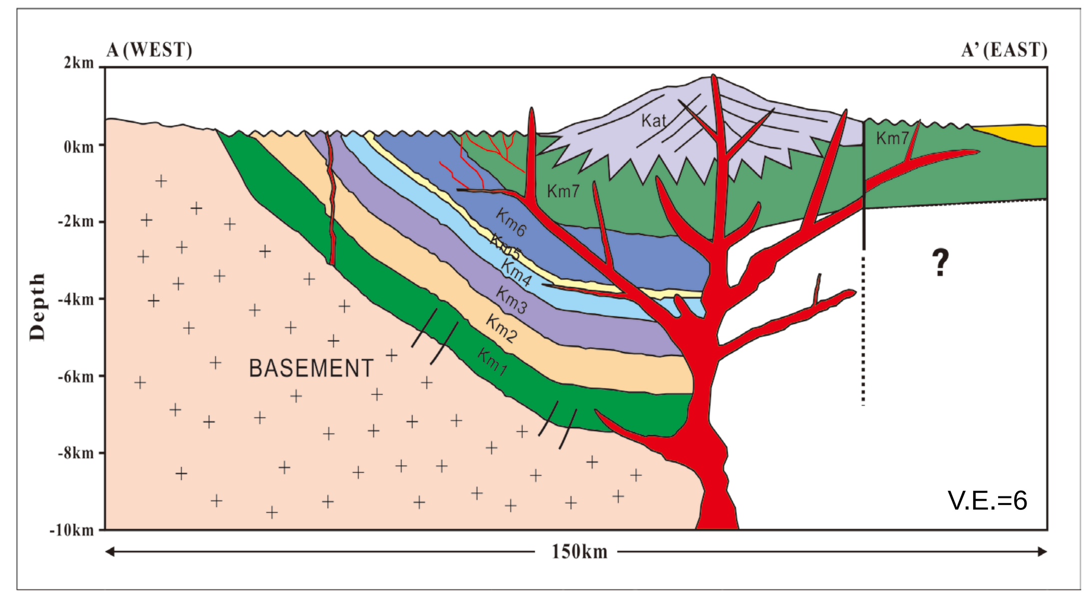

Figure 4. Schematic geological cross-section of the Gyeongsang Basin. See Figures 2 and 3 for the location.

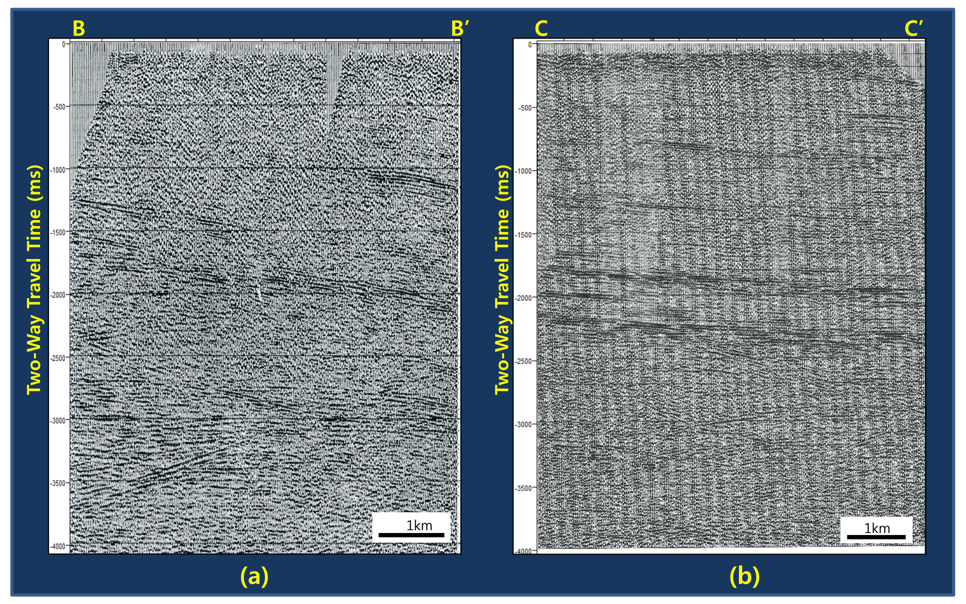

Figure 5. 2D seismic profiles acquired in the Gyeongsang Basin. (a) southern part of the Gyeongsang Basin(Cho et al., 1979), (b) northern part of the Gyeongsang Basin(Choi et al., 1982). The seismic reflectors in both sections show a general eastward dip. See Figures 2 and 3 for the locations.

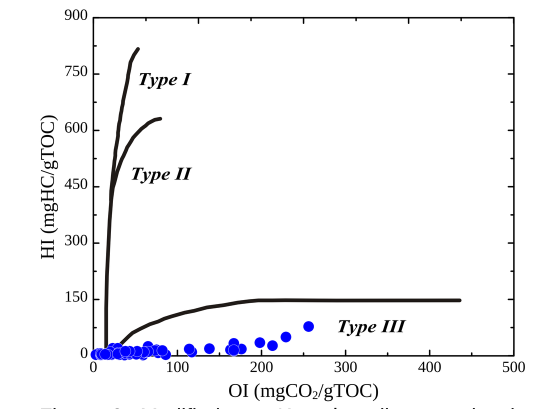

Figure 6. Modified van Krevelen diagram showing the kerogen type of the Gyeongsang Basin (KIGAM, 2014)

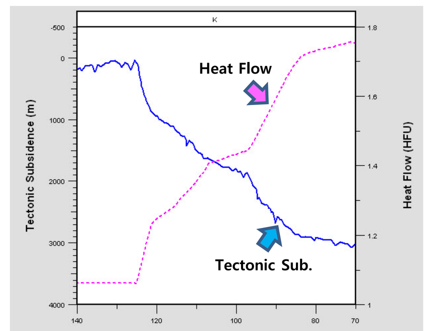

Figure 7. Tectonic subsidence and heat flow history of the Gyeongsang Basin.

Table 1. Total Organic Carbon (TOC) contents of each formation in the Gyeongsang Basin (KIGAM, 2013).

Formation	TOC (%) Min	TOC (%) Max	TOC (%) Avg	No. of sample	% of samples TOC < 0.5	% of samples 0.5≦ TOC <1	% of samples TOC ≧ 1
Nakdong	0.01	3.60	0.50	57	66.7	21.1	12.3
Hasandong	0.03	1.32	0.25	54	85.2	9.3	5.6
Jinju	0.04	3.02	0.58	209	46.4	37.8	15.8
Chilgok	0.02	0.04	0.03	4	100.0	0.0	0.0
Haman	0.01	0.17	0.04	56	100.0	0.0	0.0
Jindong	0.03	1.24	0.29	38	84.2	13.2	2.6

Table 2. Petrophysical properties of sandstones from drillings cores in the Gyeongsang Basin (Cheong et al., 1992). See Figures 2 and 3 for the well locations.

Well	Depth (m)	Formation	Porosity (%)	Permeability (md)	Density (g/cm^3)
NJ-1	45.50	Chilgok	1.65	< 1	2.69
	330.37	Jinju	1.50	< 1	2.71
	408.90	Jinju	2.04	< 1	2.72
ES-1	245.12	Nakdong	5.24	< 1	2.62
	422.66	Nakdong	1.94	< 1	2.67
	556.85	Nakdong	2.88	< 1	2.64
	802.95	Nakdong	1.53	< 1	2.71
	1050.26	Nakdong	1.31	< 1	2.67
	1431.73	Nakdong	7.33	< 1	2.64

PETROLEUM SYSTEM MODELING

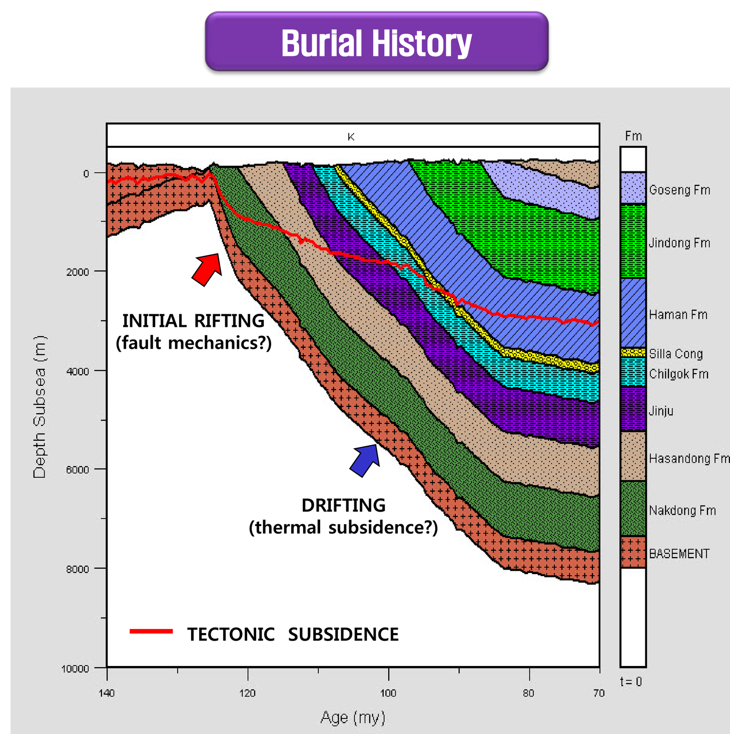

Figure 8. Non-steady state burial history profile of the Gyeongsang Basin.

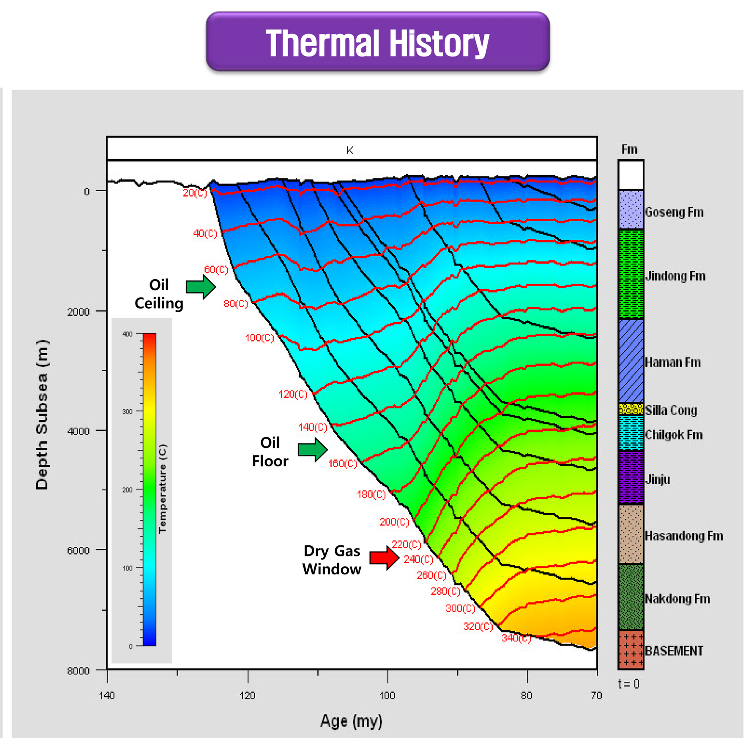

Figure 9. Thermal history profile of the Gyeongsang Basin.

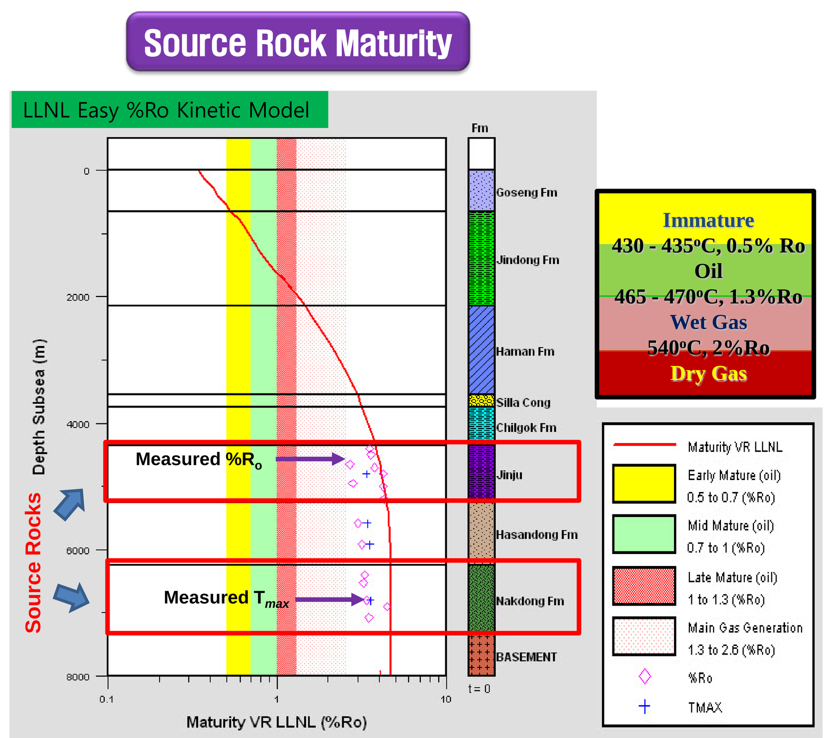

Figure 10. Source rock maturity modeling using LLNL Easy %R_o Kinetic model in the Gyeongsang Basin.

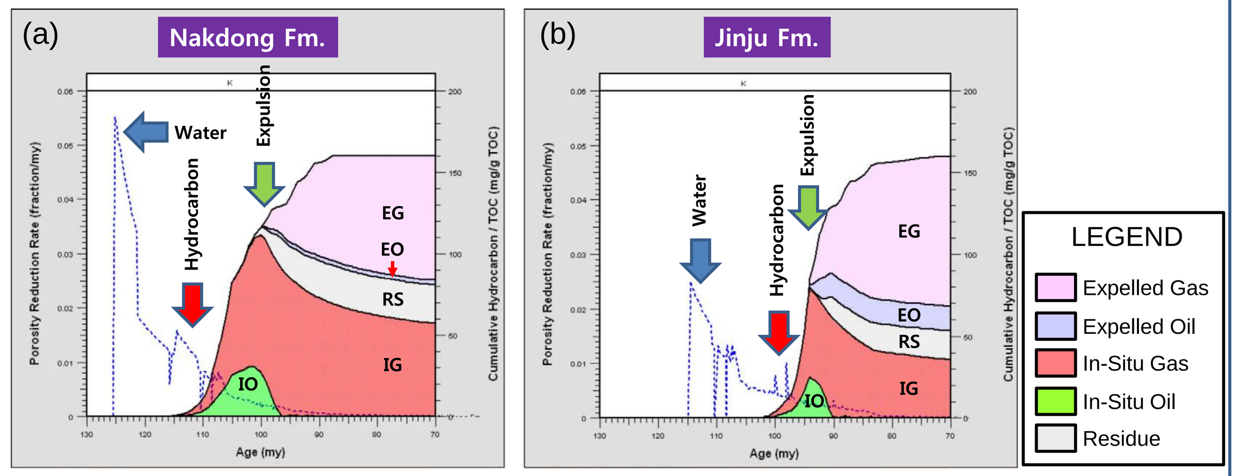

Figure 11. Cumulative hydrocarbon generation and expulsion of (a) Nakdong and (b) Jinju formations in the Gyeongsang Basin. EG: Expelled Gas, EO: Expelled Oil, IG: In-Situ Gas, IO: In-Situ Oil, RS : Residue.

CONCLUSION

- By the result of the petroleum system modeling in the Gyeongsang Basin, source rocks in the basin have reached extremely high degrees of thermal maturity (over mature) and most of the generated hydrocarbons were expelled during the basin evolution in the Cretaceous.
- Since most sandstones in the basin have low porosities and permeabilities, there is a low probability of discovering conventional hydrocarbon reserves in the basin.