Evolution of NE Africa and the Greater Caucasus: Common Patterns and Petroleum Potential

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Abstract

Comparative geologic studies are important both to find common patterns in the evolution of distinct regions and to reconsider their petroleum potential. We have attempted a comparison of the Phanerozoic evolution between the Northeastern African basins (NEA) and the Greater Caucasus (GC) (Fig. 1). The latter is nowadays a large elongated structure located within the Alpine Belt to the south of the Russian Platform.

Several tectonic/depositional phases have been distinguished in the evolution of NEA (Table 1): 1) Magmatic Arc Phase (Precambrian-Early Cambrian), 2) Graben Phase (Middle-Late Cambrian), 3) Glacial Phase (Ordovician-Silurian), 4) Tectonic Arches Phase (Devonian-Permian), 5) Mediterranean Phase (Triassic-Early Jurassic), 6) Atlantic Phase (Late Jurassic-Early Cretaceous), 7) Alpine Phase (Late Cretaceous-Eocene), 8) Gulf of Suez Phase (Oligocene-Miocene), and 9) Nile Phase (Pliocene-Recent) (Tawadros, 2001, Tawadros, 2003).

The Magmatic Arc Phase was dominated by the Pan-African Orogeny which led to the formation of Gondwana. Gneisses, granites, migmatites, volcanics, and metasedimentary rocks dominate the Precambrian-Early Cambrian succession.

In the Graben Phase extensional tectonics, accompanied by volcanic activities, formed a series of horsts and graben which were filled by shallow marine sandstones and red beds. The Cambrian fractured quartzites form reservoirs at the Attahaddy Field in Libya and the Hassi Massaoud Field in Algeria.

The Glacial Phase was accompanied by a drop in sea level in the Caradocian that led to the formation of incised valleys. In the Caradocian/Ashgillian, peri-glacial sediments filled these valleys. The rise of sea level in the early Silurian Ruddanian stage and the occurrence of an oceanic anoxic event led to the deposition of “Hot Shales” in West Libya, Tunisia, and Algeria. Peri-glacial reservoirs and Hot Shale source rocks form the hydrocarbon system in a number of oil fields in these three countries.

The Tectonic Arches Phase was dominated by the Hercynian Orogeny and the collision between Africa and Laurussia. Formation of tectonic arches, such as the Sirte, Gargaf, and Helez arches and cratonic sag basins, such as the Kufra, Murzuq, and Ghadames Basins, took place during that time. Sandstones, shales, and carbonates were deposited during a gradual sea level fall. The Devonian rocks form reservoirs in West Libya and the Sirte Basin, and Carboniferous rocks form good reservoirs in West Libya, the Sirte Basin, and the Gulf of Suez. The Frasnian Hot Shales are major source rocks in West Libya and Algeria. Thick Permian sediments were deposited in northwestern Libya, the Permian Basin in Tunisia, and the northern Western Desert of Egypt.

The Mediterranean Phase was a period of extension and rifting in Northeast Africa, related to the opening of the Neotethys. Most of the tectonic arches collapsed at that time. Fluvial, deltaic, and shallow marine sandstones and carbonates were deposited. Thick evaporates dominate the succession in northwest Libya and Tunisia. These sediments constitute major hydrocarbon reservoirs in the eastern Sirte Basin and the El Borma Field in Tunisia.

The Atlantic Phase was dominated by the opening of the Central, Southern, and Northern Atlantic oceans. Shallow marine and continental sandstones dominated the succession. The so-called Lower Cretaceous Nubian Sandstones of the Sarir Formation and the fractured quartzites of the Wadi Formation in the Sirte Basin, the Aptian Alamein Dolomite and the Upper Jurassic coaly sandstones of the Khatatba in the Western Desert of Egypt, form lucrative reservoirs. Source rocks are provided by the coaly sediments of the Upper Jurassic Khatatba Formation and the Neocomian Matruh Shale in the Western Desert and by Aptian shales and marls in the eastern Sirte Basin. Economically exploited coal deposits occur at Gebel Maghara in Sinai.

The Alpine Phase started with the collapse of some of the remaining arches. Plate collision and basin inversion, especially during the Santonian and Oligocene, led to the formation of the Syrian Arc System. Carbonates, shales, sandstones, and evaporites were deposited and form effective reservoirs and cap rocks in North Africa. Pinnacle and shelf edge reefs are common especially in Libya. The OAE during the Cenomanian-Turonian, Coniacian-Santonian, Campanian, and Paleocene led to the formation of significant source rocks in NEA. The Campanian source rocks are particularly important in the Sirte Basin (Sirte Shale) and the Gulf of Suez (Brown Limestone). Sandstones of the Waha, Bahi, Baharia, and Abu Roash formations are among the Cretaceous reservoirs. Reefal limestones of the Zelten (Nasser) and Intisar fields are prolific Paleocene reservoirs. Early Eocene nummulitic shoals and bars form prolific reservoirs in the offshore of Tunisia and Libya. The Middle Eocene carbonates are the main reservoir in the giant Gialo Field, with 4 Bbbls of recoverable oil reserves. Economically exploited iron ores (Cretaceous and Eocene) and phosphates (Campanian) in Egypt belong to that phase.

The Gulf of Suez Phase is characterized by the rifting and the opening of the Red Sea, Gulf of Suez, and the Gulf of Aqaba. Reefal carbonates and dolomites, shales (Globigerina marls), sandstones, and evaporites form a complete hydrocarbon system in the Gulf of Suez. Tilted fault blocks, stratigraphic, and combination traps are common. The closure of the Mediterranean Sea and the isolation of the Gulf of Suez led to the deposition of extensive evaporate deposits during the Messinian Salinity Crisis. Incised Valleys (Sahabi, Nile, and Abu Madi channels) were formed inland during the Messinian period. The collision between the African and Eurasian plates led to the formation of a thrust belt and nappes of the Atlas Mountains in Morocco and northern Tunisia and a foredeep basin in the latter. The Serravallian sandstones form the reservoir in the Birsa Field, offshore Tunisia.

The Nile Phase in NEA witnessed the development of the Nile River and its Delta in Egypt. The Messinian incised valleys were filled with shallow-marine sandstones and shales. Fluvial, deltaic, and turbidite deposits were deposited in the offshore of the Nile Delta and are subjected to extensive exploration activities in that area.

Traditional views of the geologic evolution of the GC should be reconsidered, taking into account the new data and new global paleotectonic models. A key point was the identification of the GC as a Gondwana-derived terrane. The close paleoposition of the GC terrane to the Carnic Alps and Bohemian Massif in the Late Paleozoic is argued by faunal and floral similarity, paleomagnetic constraints, and similarities of the sedimentary successions. Such paleoposition of the GC terrane indicates that it was a part of the Hun Superterrane, which was detached from the Gondwanan margin in the Middle Silurian (Stampfli & Borel, 2002).

Tectonic/depositional phases in the evolution of the GC have been distinguished taking into account this new model (Table 1). The history of the GC included 1) Gondwanan Phase (pre-Ludlow), 2) Hunic Phase (Ludlow-Devonian), 3) Proto-Alpine Phase (Carboniferous-Middle Triassic), 4) Left-Shear Phase (Late Triassic-Earliest Jurassic), 5) Arc Phase (Jurassic-Eocene), 6) Paratethyan Phase (Oligocene-Miocene), and 7) Transcaucasus Phase (Pliocene-Recent).

During the Gondwanan Phase (pre-Ludlow), the GC was a part of the Afro-Arabian margin of Gondwana. Numerous evidences have been obtained for the beginning of the Phanerozoic, while special studies of older rocks are still needed. The Cambrian is represented by quartzites, schists and carbonates. The most of the Ordovician is embraced by a major regional hiatus. The Uppermost Ordovician is composed of clastics, which may be related to a periglacial facies. In the Llandovery-Wenlock, schists, clastics, and volcanics dominate.

During the Hunic Phase (Ludlow-Devonian), the GC was a part of the Hun Superterrane, and it was one of the so-called European Hunic Terranes. The Hun Superterrane was detached from Gondwana and drifted northwards to Laurussia. The Paleotethys Ocean was opened at that time. In the Ludlow-Lochkovian interval, carbonates with “Bohemian-type” fauna were accumulated. Volcanics, schists, and sandstones are common in the Pragian-Frasnian succession. A rimmed carbonate shelf existed in the Famennian. At the end of the Devonian, the GC reached the Laurussian margin.

The Proto-Alpine Phase is characterized by strike-slip activity along the Northern Paleotethyan Shear Zone, which was extended westwards as the Intra-Pangaean Shear Zone. Dynamics of these shear zones was caused by the rotations of Africa. In the Carboniferous-Middle Triassic, anticlockwise rotation of Africa caused the right-shear deformations (Swanson, 1982; Rapalini & Vizán, 1993; Ruban & Yoshioka, 2005). At the same time, Hercynian and then Early Cimmerian orogenic events took place in the Proto-Alpine Region, which included the GC. The Mississippian deposits of the GC are schists, clastics, volcanics and carbonates. The Pennsylvanian deposits were continental coal-bearing strata. The Lower-?Middle Permian is a typical red-bed Molasse up to 25,000 m in thickness. A remarkable transgression and a short-lived rimmed carbonate shelf characterized the Late Permian. In the Early-Middle Triassic, carbonates, shales, and sandstones were accumulated.

During the Left-Shear Phase (Late Triassic-Earliest Jurassic) Africa was rotated clockwise, which caused the change of shear-motion direction. The GC moved along the shear zone to its present position to the south of the Russian Platform. In the Norian-Rhaetian, a rimmed carbonate shelf evolved in the GC, while in some areas shales were deposited. The Upper Rhaetian-Lower Sinemurian interval is embraced by a major regional hiatus.

The Arc Phase (Jurassic-Eocene) of the GC evolution comprises the time when island arcs existed at the active margin of the Neotethys (Lordkipanidze et al., 1984). Shales and clastics were accumulated in the Early-Middle Jurassic, but a very large rimmed carbonate shelf existed in the Late Jurassic. In this epoch a regional salinity crisis occurred, and salt was deposited at the same time when reefs existed. Flysch basins evolved during the Cretaceous-Paleogene, and their depth reached its maximum in the Maastrichtian-Danian.

The Paratethyan Phase (Oligocene-Miocene) is characterized by the growth of the Caucasus Orogen. Orogenic chains separated the relatively shallow basin of the Paratethys Sea from the Mediterranean. The salinity crisis, which affected the latter in the Messinian, did not appear in the GC.

During the Transcaucasus Phase (Pliocene-Recent) the principal feature of the GC became the subsiding Transcaucasus Depressions, such as the Rioni Depression and Kura Depression, which are tectonically connected with the Black Sea Depression and the Caspian Depression (Ruban, 2003).

As a result of the comparison of the Phanerozoic evolution between NEA and the GC common patterns for these regions have been established: a) in the Cambrian-Ludlow both NEA and the GC were included in the Gondwanan margin; b) in the Carboniferous-Early Jurassic both studied regions were affected by the major shear zone; c) in the Jurassic-Eocene NEA and the GC were dominated by the development of the Neotethyan structures (Fig. 2).

In NEA, source rocks range in age from the Silurian to the Pliocene and are related to global oceanic anoxic events, except for the Jurassic coals and Miocene marls (Tawadros, 2001). Proven oil reserves of Egypt, Libya, and Algeria are approximately 54 billion barrels.

The proven petroleum reserves of the Azerbaijanian Hydrocarbon Province of the GC are 7-13 billion barrels of oil. They were generated principally by the Majkopian (Oligocene-Early Miocene) source rocks, which were accumulated in locally dysoxic and anoxic environments in the subsiding basins. The Majkopian Group comprises organic-rich shales with interbeds of sandstones (Ali-Zadeh, 1945; Efendiyeva, 2004). Oil was generated from them and stored in the Pliocene Productive Group (traditionally called "Productive Series"), which is the principal exploited reservoir. Depositional environments in the Majkopian Basin were similar to those which existed in the Miocene Gulf of Suez, which generated proven reserves of 1.1 billion barrels of oil. All possible, including minor, petroleum reservoirs in the Azerbaijanian Hydrocarbon Province are shown in Table 2.

The common patterns in the geologic evolution of NEA and the GC suggest that special attention should be paid in the latter to those sedimentary complexes, which are considered as source rocks in NEA (in particular the Silurian, Cenomanian, and Campanian sediments). This suggests that new perspectives in the petroleum exploitation and reserves growth in this region, where the petroleum industry started more than a century ago, still exist.

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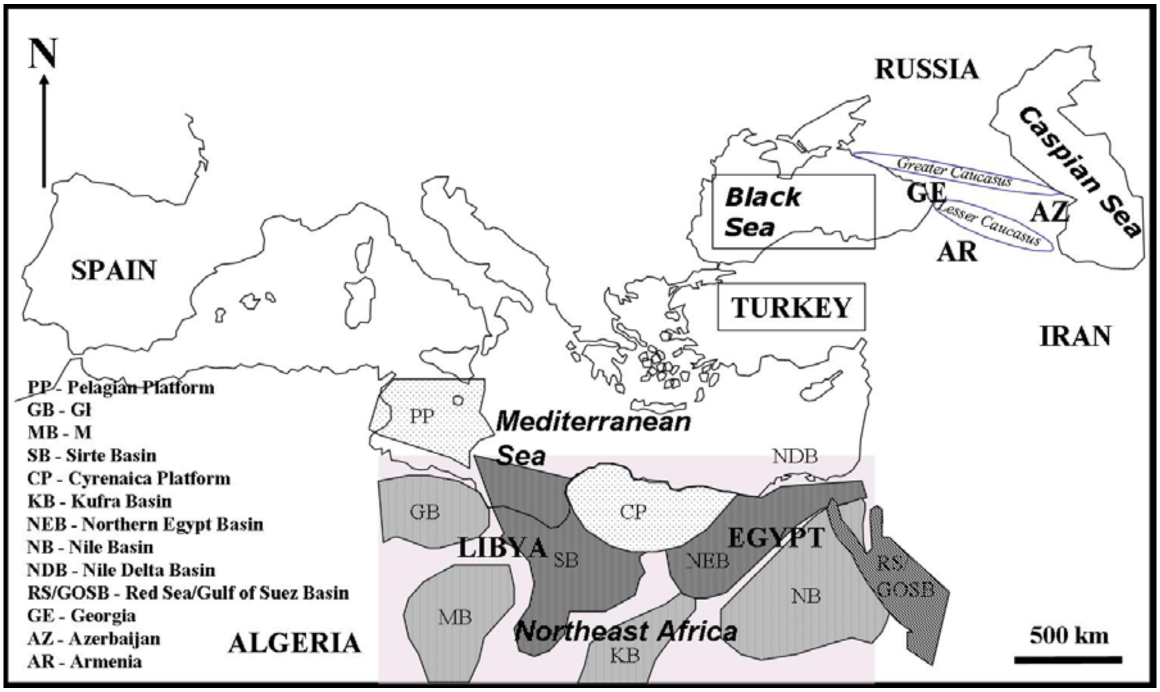

Figure 1. Geographical location of the studied regions (chronostratigraphy and absolute ages after Gradstein et al., 2004).

Table 1. A comparison of the tectonic/depositional phases between NEA and the GC.

Eras	Periods	Ages, Ma	Northeastern Africa	source rocks	Greater Caucasus	source rocks
Cenozoic	Neogene	23	*Nile Phase* *Gulf of Suez Phase*		*Transcaucasus Phase* *Paratethyan Phase*	
	Paleogene	65.5	*Alpine Phase*			
Mesozoic	Cretaceous	145.5			*Arc Phase*	
	Jurassic	200	*Atlantic Phase*			
	Triassic	251	*Mediterranean Phase*		*Left-Shear Phase*	
Paleozoic	Permian	299			*Proto-Alpine Phase*	
	Carboniferous	359	*Tectonic Arches Phase*			
	Devonian	416			*Hunic Phase*	
	Silurian	444				
	Ordovician	488	*Glacial Phase*			
	Cambrian	542	*Graben Phase*		*Gondwanan Phase*	
	Precambrian		*Magmatic Arc Phase*			

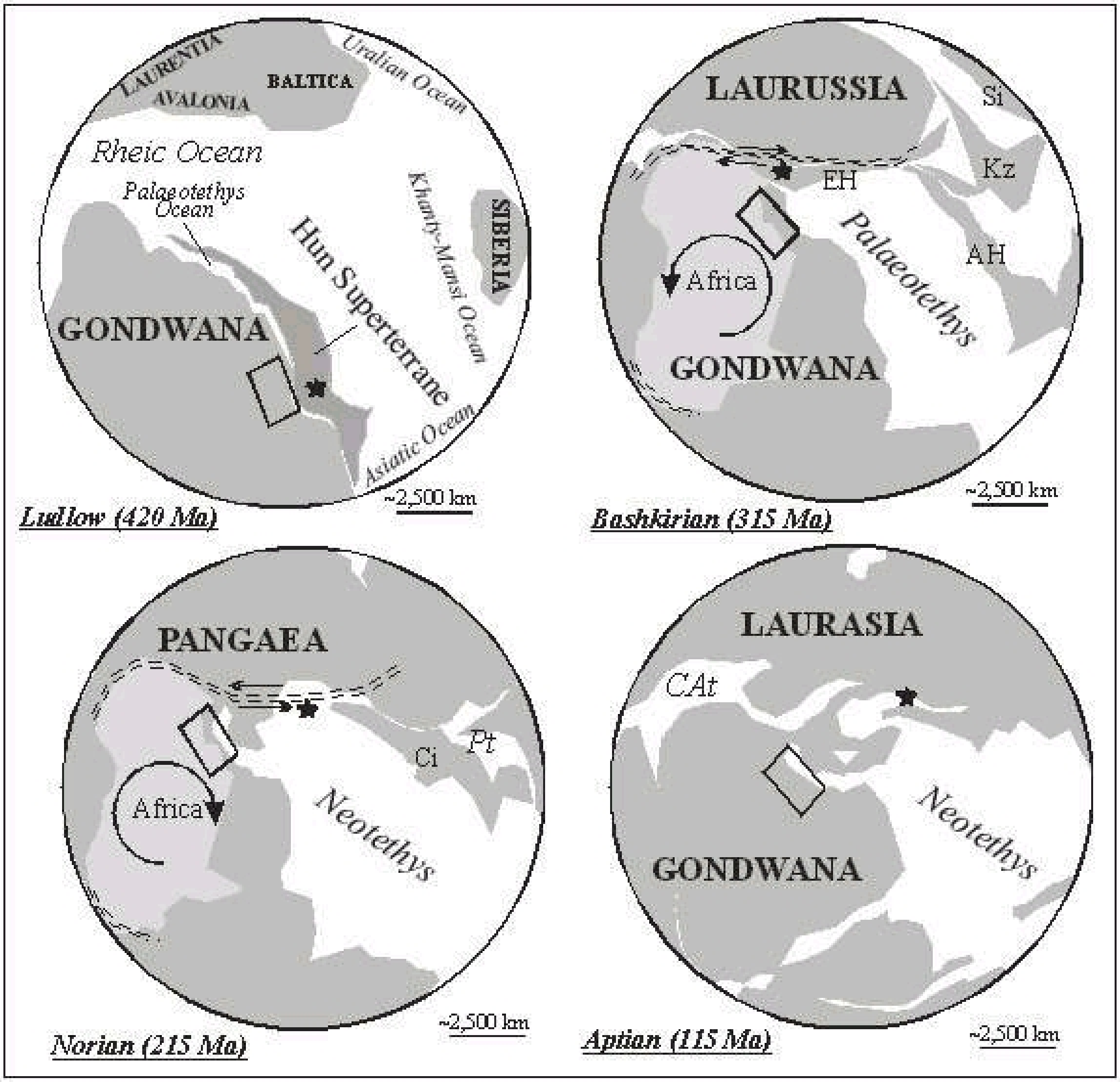

Figure 2. Paleotectonic sketch-maps (modified from Stampfli & Borel, 2002). Rectangle marks NEA, asterisk marks the GC. Abbreviations: EH – European Hunic Terranes, AH – Asiatic Hunic Terranes, Ci – Cimmerian Terranes, Si – Siberia, KZ – Kazakhstan, Pt – Palaeotethys, CAn – Central Atlantics.

Table 2. Possible petroleum reservoirs in the Azerbaijanian Hydrocarbon Province.

Stratigraphy	Region	Outcrop/well Area
Middle Jurassic (Aalenian, Bajocian)	Pri-Caspian-Guba	
Lower Cretaceous (Valanginian, Hauterivian, Albian)	Pri-Caspian-Guba	Sovetobad, Gyadysu, Kurkachidag
Upper Cretaceous-Lower Paleogene (Maastrichian-Danian)	Pri-Caspian-Guba Schamakha-Gobustan, Gyanja	Astrachanka
Paleocene	Pri-Caspian-Guba	Siazan monocline
Eocene	West Azerbaijan	Tarsdallyar, Gyrzundag
Majkop	entire province	Umbaki, Naftalan, Kalamaddyn, Shorbulag, etc.
Chokrak (Middle Miocene)	Gobustan, Apsheron	Umbaki, Duvanny
Diatom Beds (Miocene)	West Apsheron, Shamakha-Gobustan	Binagady, Shabandag, Garadag
Productive Group	Apsheron Peninsula, Apsheron and Baku Archipelagos	40 oil/gas fields