Nyalga PSC XVI, Mongolia:
Structural Interpretation and Sequence Stratigraphy and Correlation

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October 2010

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SUMMARY

The tectono-sedimentary development of the China-Mongolia Border Region (CMBR) is reported to provide the larger context of the history of the Nyalga basin. The CMBR was assembled by the amalgamation of island arcs at the end of the Permian. It comprises several lacustrine basins that developed during Late Jurassic/Early Cretaceous transtension: Nyalga, Choibalsan, South/East Gobi, Tamtsag, Yingen, and Erlian. These basins and their subbasins were inverted during transpression in the Late Cretaceous. Five characteristic stratigraphic megasequences are associated with these tectonic events. While the CMBR basins have very similar tectono-sedimentary histories, their detailed stratigraphies may vary significantly even from one sub-basin to the next. Rigorous analysis is therefore required when correlating reservoir rocks between sub-basins and basins.

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1. Introduction

This report covers the tectono-sedimentary history of the China-Mongolia Border Region (CMBR) and established the larger context of the Nyalga basin. A detailed history of the Nyalga basin is given in a companion report (Kraus, 2010b).

Southeast Asia contains a multitude of oil and gas basins of differing rigidity, built on different types of crust (Figs 1 & 2) (e.g. Li 1995, 1996; Okada, 2000; Cunningham, 2005; Dai, 2008; Zhao, 2008).

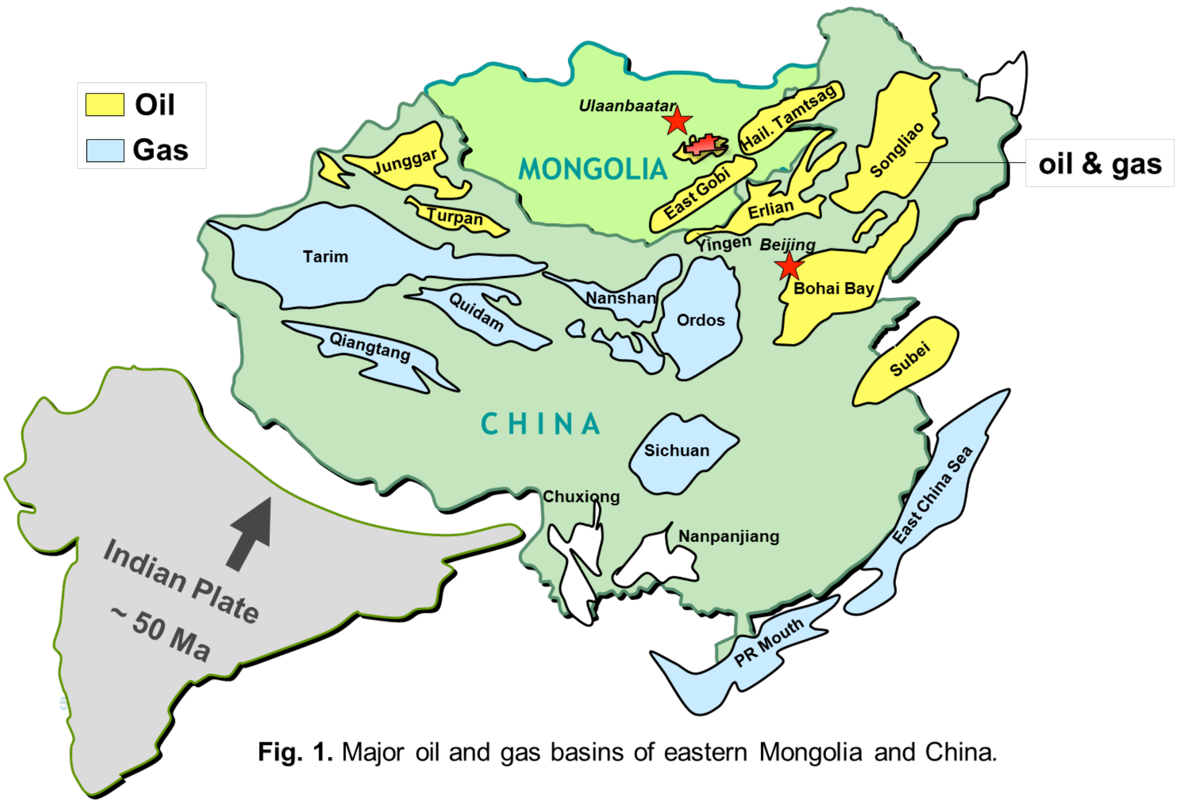

Fig. 1. Major oil and gas basins of eastern Mongolia and China.

The western/central Chinese gas basins are young foreland basins, mainly related to the collision of India into China and the resulting indentation in the Eocene. The oil basins are related to rifting and transpressional/transtensional deformation, whereby some eastern Chinese basins (Bohai Bay, Subei) have a distinct Cenozoic history. In contrast, the eastern Mongolian basins (Nyalga, Choibalsan, South and East Gobi, and Tamtsag) and the northeastern Chinese basins (Yingen, Hailar, Erlian, and to some extent Songoliao) developed owing to Jurassic and Early Cretaceous rifting, which reversed to compressional deformation in the Late Cretaceous. The eastern Mongolian basins and the northeastern Chinese basins share much of their tectono-sedimentary development (Meng *et al.*, 2003). They therefore have similar geometries, stratigraphies, and petroleum systems, and are collectively referred to as China-Mongolia border region (CMBR) [also as China-Mongolia tract or NCT]. It is attempted in this report to establish a correlation between the rather underexplored Nyalga Block XVI and the better explored, and producing CMBR basins.

2. GEOLOGICAL SETTING

The crust in central/southern Mongolia is part of the Central Asian Orogenic Belt, a vast accretionary orogen that records the opening and closure of the Mongol-Okhotsk ocean in the late Proterozoic to Paleozoic (Zorin, 1999; Kravinksy *et al.*, 2002; Meng *et al.*, 2003). The crustal evolution of the region is revealed in basement inliers, which constitute Devonian-Carboniferous segments of island arcs.

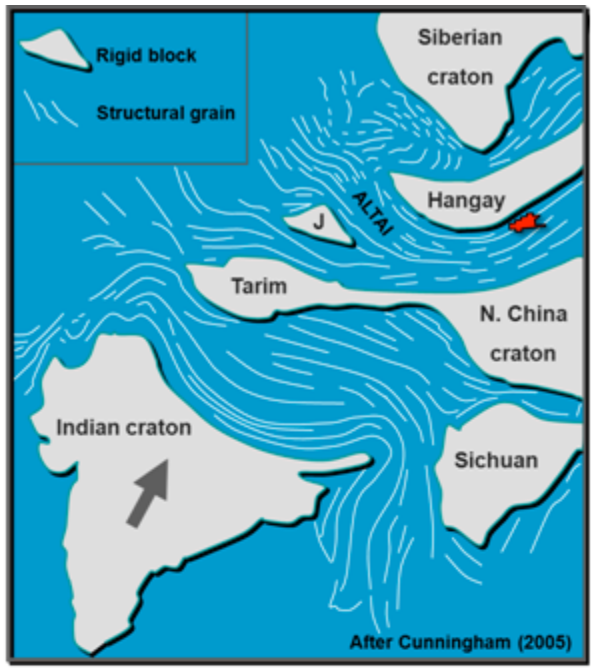

Fig. 2. Southeastern Asian crustal blocks of different rigidity. Red box is Nyalga Block XVI. After Cunningham (2005).

Nyalga Block XVI is located in the Middle Gobi belt, immediately south of the Mongol-Okhotsk suture, which is approximately delineated by the southern margin of the Hangay-Hentey dome (Figs. 1, 2 & 3). It sits along strike with the small Choibalsan basin, a possible correlative, about which no useful published geological data exist. South of this panel, and thus farther away from the suture, is another panel consisting of the South and East Gobi basins and the Hailar-Tamtsag basins (e.g. Johnson, 2004; Prost, 2004). Farther south, in China, there is yet another panel consisting of the Yingen and Erlian basins. These three panels form the CMBR and are draping like concentric ring segements around the Hangay-Hentey dome.

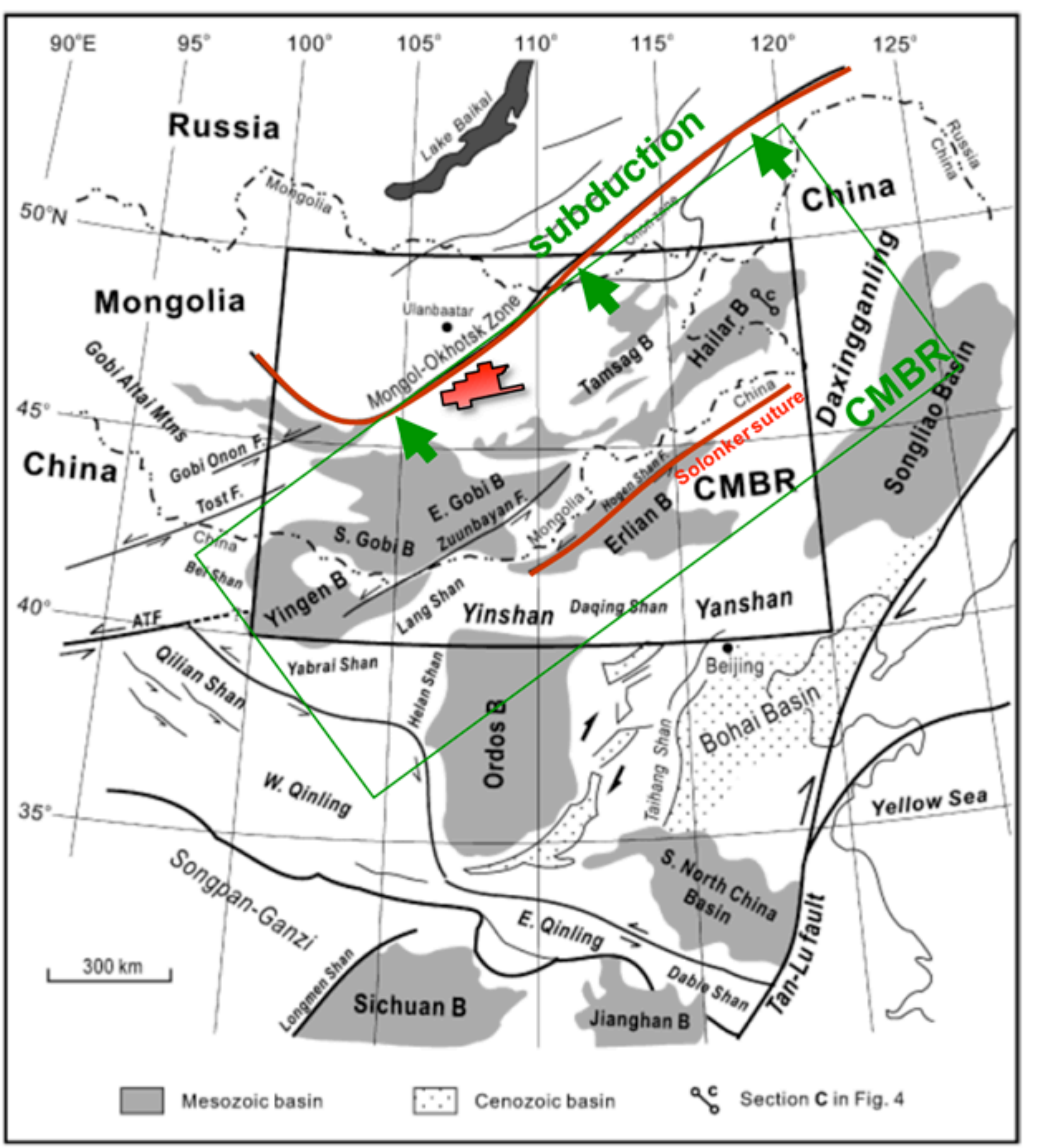

Fig. 3. Tectonic map showing the distribution of the Mesozoic sedimentary basins in North China and southern and eastern Mongolia. Green box delineates the China-Mongolia border region (CMBR) Nyalga Block XVI is yellow and the red line tracks the oceanic suture. Modified from Meng *et al.* (2003).

3. CHINA MONGOLIA BORDER REGION STRUCTURAL EVOLUTION

It was mentioned above that the Nyalga basin belongs to the CMBR that also hosts these main petroleum basins: the Hailar-Tamtsag, East/South Gobi, Erlian, and Yingen basins (Meng, 2003, Meng *et al.*, 2003). The areas occupied by these basins have independent pre-Permian, oecanic developments but share a common tectonostratigraphic, petroleum-related, intracontinental history since the Late Mesozoic.

The early history of the CMBR is dominated by convergence. The CMBR originates as a group of island arcs and other oceanic assemblages in the Devonian. In the Carboniferous, another (=successor) arc system is built onto the earlier one and the arcs are amalgamated to the Mongolian collage during continental collision by the end of the Permian. Voluminous subduction-related granitic intrusions generate continental crust and prominent porphyry copper-gold mineralizations such as Ivanhoe Mines' Oyu Tolgoi deposit. The Mongolian collage is docked onto the North-China craton to the south by northward subduction along the Solonker suture (Fig. 3), somewhere between the Early Permian (294 Ma) and the Mid Triassic (234 Ma) (Chen *et al.*, 2009; Jian *et al.*, 2010). The combined Mongolia collage/North China craton is converging with the Siberian continent in the north by northward subduction, which leads to the closure of the Mongol-Okhotsk ocean. Final collision along the Mongoal-Okhotsk suture is completed at the Early/Middle Jurassic boundary (Zorin, 1999; Kravinksy *et al.*, 2002; Meng *et al.*, 2003). The suture appears to straddle the northwestern boundary of Nyalga PSC XVI.

During terminal collision with Siberia, the Mongolia collage experiences north-south directed compression, significant shortening and thickening until the final closure in the Mid to late Early Jurassic), and the formation of a high-standing plateau. The viscosity of the overthickened crust is greatly reduced by pre- and syn extensional voluminous granitic magmatism (Blight *et al.*, 2010). Contractional deformation in the Mid to Late Jurassic is registered by the regional unconformity 1 at the base of the Upper Jurassic (Fig. 4; Meng *et al.*, 2003).

Following collision, a period of widespread extension in the CMBR leads to the formation of rift basins, exhumation of metamorphic core complexes, rift-related volcanism, and sedimentation from the latest Late Jurassic to the late Early Cretaceous (the age of the Tsagaantsav fm) (Traynor & Sladen, 1995; Meng *et al.*, 2003). Lithospheric extension is triggered by the breakoff of the north-dipping, subducting slab (or backarc spreading by slab rollback or channel flow in the lower to middle crust underneath an extending upper crust) (Meng *et al.*, 2003). Slab breakoff results in mantle lithosphere stretching in CMBR with subsequence ascent of hot asthenosphere and magmatic underplating at the base of the crust. Collectively, these features cause gravitational collapse of the previously thickened crust – and thus extension.

Island arc stage	Devonian to Carboniferous
Amalgamation of arcs	End of Permian
Closure of Paleo-Asian ocean	Early Permian (294 Ma) to Mid Triassic (234 Ma)
Closure of Mongol-Okhotsk ocean	Early-Middle Jurassic
Intracontinental rifting	Late Jurassic - Early Cretaceous
Tectonic subsidence	Early Cretaceous
Intracontinental compressional deformation	Late Cretaceous - Tertiary

Table 1. Summary of CMBR tectonic events. After Meng *et al.* (2003) and Chen *et al.* (2009).

The onset of rifting is recorded by bimodal volcanism (basalt, andesite, rhyolite) whereby the flood basalts floor many of the sub-basis, including East Gobi and Nyalga. The alkaline nature of the Triassic volcanism indicates a rift setting. After plate readjustment, renewed compression at the end of the Cretaceous leads to crustal shortening, basin inversion, and uplift in the CMBR. This compression is manifested by another regional unconformity 2 separating Lower and Upper Cretaceous rocks (Fig. 4).

Cenozoic deformation of the CMBR is compressional however mild, and mainly related to the collision of Indian into Asia and the resulting indentation of Asia around the rigid indentor. The CMBR is indirectly affected in that is is draped around the rigid Hangay-Hentey passive indentor on the northern site of the Mongol-Okhotsk suture (Cunningham 2001, 2005). The sequence of tectonic events if summarized in Table 1.

4. SEDIMENTATION AND SEQUENCE STRATIGRAPHY

The sedimentation and depositional environments of the CMBR basins are strongly influenced by the temporal varations of compression and extension.

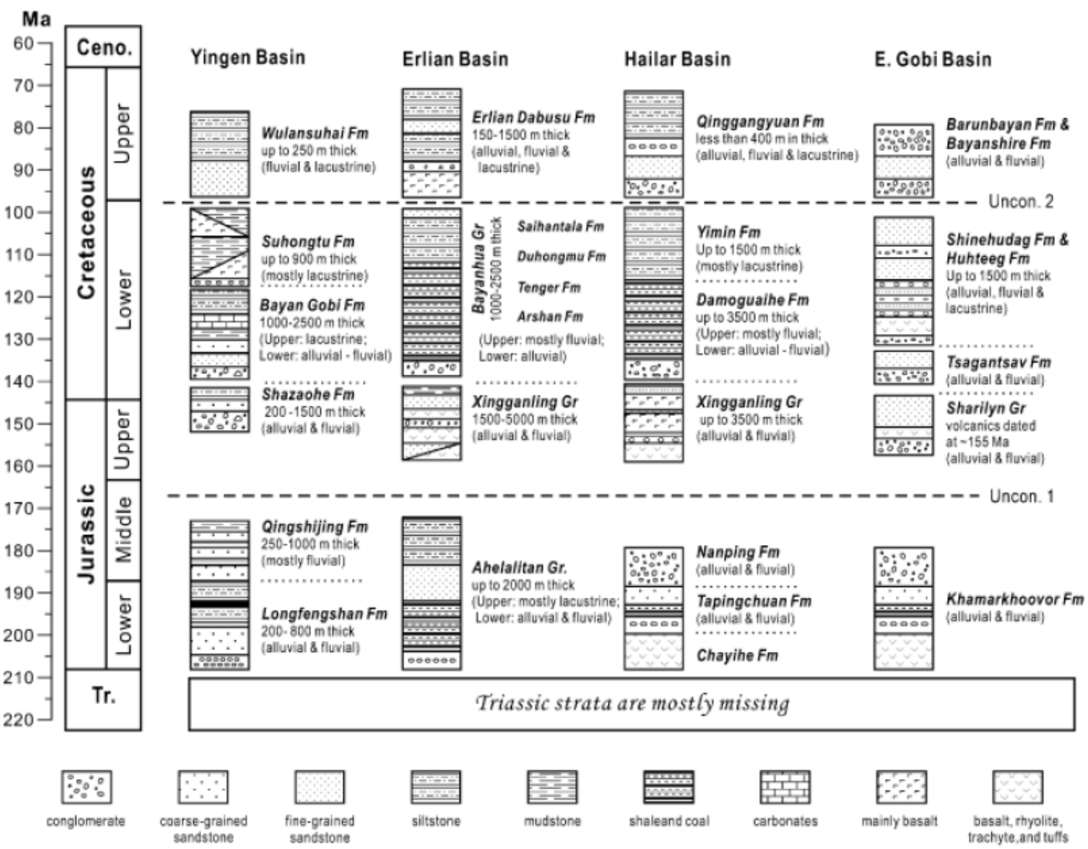

Fig. 4. Generalized Mesozoic stratigraphy and lithology of the Yingen, Erlian, Hailar, and East Gobi basins. From Meng *et al.* (2003).

Meng *et al.* (2003) report that, following final collision with the Siberian craton, the Lower to Middle Jurassic is characterized by fluvial deposits with intercalations of coal measures. The Upper Jurassic to Lower Cretaceous successions show dramatic spatial variations in facies associations between these basins. Conglomerates and coarse sandstones constitute most of the Upper Jurassic of the Yingen basin, whereas voluminous volcanic rocks with sedimentary interbeds are predominant in Erlian and Hailar basins, and similar in East Gobi. The Kherulen subbasin of the Nyalga basin is dominated by basic and intermediate volcanics and their tuffs, with intercalated sediments. Lower Cretaceous sequences are developed in all these basins and usually begin with alluvial and fluvial conglomerates passing upwards into lacustrine deposits like siltstones and mudstones that are major petroleum source rocks in the Erlian, Yingen, East Gobi basins, and Nyalga basins. Lower Cretaceous sequences can be complex and vary from sub-basin to sub-basin. The Upper Cretaceous is again characterized by fluvial environments following the reversal from extension to compression. A correlation of the Cretaceous stratigraphy across the basins has been performed by Khand *et al.* (2000).

Applying the concepts of sequence stratigraphy, five megasequences have been identified (Traynor & Sladen, 1995; Graham *et al.*, 2001). Megasequence 1 (Precambrian – Silurian) records the amalgamation of a 'Caledonian' fold belt in western Mongolia. Megasequence 2 (Devonian – Permian) is the most complex one, with a variety of active margin collisions. It eventually leads to the amalgamation of island arcs to a collage by the end of the Permian. Megasequence 3 (Triassic – Early Jurassic) is characterized by widespread erosion and limited deposition. Megasequence 4 (Mid Jurassic – Cretaceous) records extension across the partially eroded fold belt with the development of transtensional rift basins and tectonic subsidence leading to a widespread lacustrine environment. These rift basins later experience uplift in a transpressional during megasequence 5 (Late Cretaceous – Tertiary), which constitutes . The five megasequences are summarized in Table 2.

Megasequence 5	Late Cretaceous – Tertiary	Transpression; inversion; fluv. sedimentation
Megasequence 4	Mid Jurassic – Cretaceous	Transtension; rifting; volcanism; tectonic subsidence; lacustrine sedimentation
Megasequence 3	Triassic – Early Jurassic	Pre-rift: limited deposition; erosion
Megasequence 2	Devonian – Permian	Amalgamation of island arcs
Megasequence 1	Precambrian – Silurian	Oceanic: amalgamation of Caledon. fold belt

Table 2: CMBR megasequences. After Traynor & Sladen. (1995) and Graham *et al.* (2001).

Megasequence 4 is the most important from an economic aspect, as it contains most elements of the Upper Jurassic-Lower Cretaceous petroleum system. It is discussed here in more detail and the concepts of marine sequence stratigraphy are applied to the nonmarine closed basins *sensu* Keighley *et al.* (2003). The Upper Jurassic-Lower Cretaceous of the CMBR is characterized by volcanic and fluvial-alluvial rocks in a lowstand systems tract that becomes increasingly transgressive towards its top. Basalts of the J3-K1 Tsagaantsav fm at the base are indicative of initial rifting, and they occupy large areas. For example, the vesicular and amygdaloidal basalts of the East Gobi and Nyalga basins, ca. 450 km apart, look identical, and may belong to the same sheet. Other examples of large rift-related basalt flows exist in India and Siberia (Mid Jurassic Gondwana breakup), and in Bavaria/Czech Republic (Tertiary Eger rift). In southeastern Mongolia, the basalts are overlain by andesites and their tuffs, with intercalated siltstones, mudstones, and minor freshwater limestones (all J3-K1 Tsagaantsav fm). They are locally topped by conglomerates and mudstones, which constitute a late lowstand regressive systems tract. A maximum flooding surface sequence boundary separates the top of the J3-K1 sequence from the overlying Lower Cretaceous highstand systems tract defined by lacustrine strata (K1dz1 Lower Zuunbayan fm), which developed in response to fast tectonic subsidence. An erosional surface within the Lower Cretaceous surface separates the lacustrine rocks from overlying, regressive, lowstand fluvial-alluvial rocks (K1dz2 Upper Zuunbayan fm). Limited accommodation space and greater reworking amount in little preservation of muds (as possible seals). The erosional top of the Lower Cretaceous constitutes another erosional sequence boundary and is overlain by a lowstand systems tract of high-energy, fluvial sandstones (K2 Sainshand fm).

5. MAGMATISM

Meng *et al.* (2003) report vigorous and extensive volcanism during Late Jurassic into the Early Cretaceous for the CMBR. Many basins are floored by alkaline volcanic rocks, which indicate the onset of rifting prior to the subsidence phase that resulted in tectonic lakes. I observed basalts with vesicular and amygdaloidal textures in uplifts of the East Gobi and Nyalga basins. In Nyalga, these basalts may form the basin floor and are overlain by andesites and their tuffs, with minor rhyolite and intercalated sediments, including freshwater limestone. Granitic plutonism was active from the Late Jurassic to the Early Cretaceous (Wu *et al.*, 1999). Granite plutons are geochemically similar to the volcanic rocks and pertain to basalt underplating in conjunction with large-scale lithospheric extension, owing to subduction and breakoff of the north-dipping Paleo-Okhotsk slab (e.g. Meng *et al.*, 2003).

6. CORRELATION OF BASINS

The CMBR basins exhibit similar histories of sedimentation suggesting a similar tectonic evolution following their amalgamation at the end of the Permian. Two regional unconformities are developed throughout the CMBR, separating the Upper Jurassic–Lower Cretaceous successions from the underlying and overlying successions (Fig. 4). Upper Jurassic volcanism is ubiquitous in the CMBR basins indicating the onset of rifting. This is followed by tectonic subsidence that initially creates first a fluvial-alluvial environment in the latest Jurassic and earliest Cretaceous (J3-K1), followed by a lacustrine environment in the Early Cretaceous (K1dz1). K1dz1 is considered to constitute an intraformational source, reservoir, and seal, and the underlying J3-K1 is considered to constitute reservoir only. Lower Cretaceous sequences, however can be complex and vary from sub-basin to sub-basin (Meng *et al.*, 2003). For example, J3-K1 is considered to be the primary reservoir in the Tamtsag basin by PetroMatad. In contrast, BP regards K1dz1 as the prime reservoir for Nyalga. Caution is therefore advised when correlating potential reservoir rocks between basins and even sub-basins.

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