Tectonics, sedimentation, and magmatism of the Cretaceous Gyeongsang (Kyongsang) Basin, Korea: Integrated approach to defining basin history and event mineralization

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ABSTRACT

During the past decade, integrated stratigraphy has been effectively applied to many sedimentary basins to analyze stratigraphic response to tectonic evolution. This application has been beneficial to hydrocarbon exploration in the basins because it provides a better understanding of temporal and spatial relationships of hydrocarbon source and reservoir rocks as a function of basin evolution. Like the maturation, migration, and trapping of hydrocarbons, ore-forming processes in hydrothermal deposits may be causally linked to particular phases of basin evolution. Consequently, applying integrated stratigraphy to mineral exploration may be a logical and helpful approach to understanding ore-forming processes and predicting their occurrence, location, and origin.

The Cretaceous Gyeongsang Basin in the southeastern Korean Peninsula comprises more than 9,000 m of siliciclastic and volcanic strata, which were deposited in a continental rift setting. At present more than 600 hydrothermal, metallic, vein type Au/Au-Cu-Pb/Zn and clay mineral deposits have been discovered in the basin. Despite of continued effort for searching new mineral deposits in the basin, no additional discovery has been made so far. This might be due to the lack of comprehensive understanding on stratigraphic response to tectonic evolution of the basin. Furthermore, the recent discovery of gold-silver deposits (i.e., the Eunsan and Moisan mines) in

Cretaceous rocks at Haenam in the southwestern Korean Peninsula sparked renewed interest in mineral exploration of Cretaceous rocks throughout South Korea. This discovery prompted the need for a better understanding of the Cretaceous geology throughout the area. Thus, it is imperative to make a more sophisticated understanding on the Cretaceous geology in the Korean Peninsula.

Detailed stratigraphic, sedimentologic, and paleontologic data are integrated with the broader scaled correlation to understand tectonics and sedimentation of the Cretaceous Gyeongsang (Kyongsang) Basin, Korea. Based on integrated stratigraphy approach, four distinct units are recognized in the basin: Late Jurassic-Early Cretaceous (?Tithonian-Berriasian), Early Cretaceous (Barremian-Albian), Late Cretaceous (Campanian-early Maastrichtian), and late Late Cretaceous-Early Paleocene (middle Maastrichtian-Danian). The oldest unit I (?Tithonian-Berriasian) includes the Myogog and Oknyobong formations that were deposited between the Daebo and Nagdong disturbances. The unit is attributed to the pre-rifting sequence that was locally developed before the major extension of the basin. The overlying unit II (Barremian-Albian) encompasses the Sindong and Hayang groups as well as the lowermost part of the Yuchon Group. The unit II represents a syn-rift sequence that was deposited during the major E-W extension of the basin. Overlying the unit II are calc-alkalic volcanic rocks of the Yuchon Group that is, in turn, separated into two units (III and IV) by a distinct break at 69 Ma (with ca. 1 Ma pause of volcanism and plutonism). These two units are considered as an inversion sequence that was deposited during the NW- and E-W compression in the basin. Each unit defined in this study represents a functioning tectonic unit that provides time-sliced information on basin-forming tectonics, sedimentation, and basin-modifying tectonics of the Cretaceous Gyeongsang Basin.

In the Late Jurassic (?Tithonian), northeastward movement of the Izanagi Plate beneath the Eurasia Plate probably produced a number of small-scaled strike-slip (dextral sense?) extensional basins in the southeastern margin of the Korean Peninsula. These basins were infilled by arkosic sediments with intermittent volcanic flows (trachyte and rhyolite), forming a pre-rifting sequence (the unit I). This basin-forming tectonic event is characterized by the N-S extension and E-W compression. During the Early Cretaceous, however, the pre-rifting sequence was once uplifted and deformed due to the Nagdong disturbance, when the Izanagi Plate began to change the movement direction toward the northwest.

In the Early Cretaceous (Barremina-Albian), the Izanagi Plate was moving northward so that oblique convergence and sinistral strike-slip contemporaneously occurred along the margin. The sinistral strike-slip wrenching resulted in the NE-trending Gongju (Kongju) and Gwangju (Kwangju) fault systems in the mid-southwestern part of the peninsula, which was causally linked to development of strike-slip basins (i.e., proto-Gyeongsang Basin and a series of small-scale pull-apart basins along the Gongju and Gwangju fault systems). With the interaction of these fault systems as well as a NE-trending subduction zone, continued sinistral movement of these fault systems until the Albian resulted in an E-W crustal extension in the southeastern Korean Peninsula, forming a large-scale pull-apart basin (i.e., the Gyeongsang Basin). Alluvial fans and fluvial channel networks formed along the basin margin and were transitional to ephemeral lacustrine system into basin center. Accompanied with the intermittent alkaline volcanism, siliciclastic sediments of the Sindong and Hayang groups were deposited, forming a syn-rifting sequence (the unit II) in the basin. The second basin-forming tectonic event represents the marked E-W extension in the basin during the Albian to Aptian.

Beginning the Cenomanian, the E-W extension was gradually replaced by the N-S compression due to the Yuchon disturbance. As a result, the syn-rifting sequence was uplifted and deformed, recording an angular unconformity at the top of the unit II. The N-S compression continued in the basin until the Santonian, when the Izanagi Plate completely changed the movement direction to the northwest. The N-S compression during the Cenomanian-Santonian is recognized in the Andong Fault that is the northern boundary fault of the Uiseong Block. The fault separates the Cretaceous Gyeongsang Basin (the Uiseong Block) to the south from the Precambrian-Jurassic basement to the north, displaying an E-W trending and northward convex pattern. The Andong Fault was a transfer fault at a time of the E-W extension and then changed to a top-up-to-the-south reverse fault due to the N-S compression during the Late Cretaceous. Continued N-S compression resulted in three different types of motion in the Andong Fault: sinistral motion in the western segment, reverse motion in the central segment, and dextral motion in the eastern segment. Conceivably, a similar deformation history may be envisioned in the Jaesan Fault that is the northern boundary of the Yongyang Block. The Jaesan Fault is bounded on north by the Precambrian-Jurassic basement and on south by the northern boundary of the Cretaceous Gyeongsang Basin. In addition, the N-S compression during the Cenomanian-Santonian documents the open folds with a wavelength of 2 Km and east-trending fold axes in the northern part of the basin near

Uiseong. It is envisaged, however, that the southern part of the basin experienced more severe N-S compression due to the proximity of a NE-trending subduction zone. Thus, the proximal type hydrothermal deposits (Au-Ag and Cu dominated) are common in the southern mineralized area near Haman, Gunbug, and Goseung because of severe uplift and erosion during the Cenomanian-Santonian.

Since the Campanian, when the Izanagi Plate underwent orthogonal subduction beneath the Eurasia Plate, extensive calc-alkaline volcanism was initiated in the basin. Volcanisms continued throughout the Maastrichtian until the Paleocene. The resultant volcanic rocks are the Yuchon Group that is unconformably overlain by the Middle Eocene volcanic rocks of the Wangsan Formation (ca. 44.7 Ma). During the Yuchon volcanism, co-magmatic granitoids were emplaced in the sub-volcanic crust. These volcanic and plutonic rocks are deformed by the NW-compression, suggesting the NW-compression be dominated from the Cenomanian to the Paleocene. Although the Yuchon volcanism and the associated plutonism appear to be continuous, two distinct pauses of magmatism are recognized in the basin: middle Maastrichtian (69 Ma) and Selandian (59-61 Ma). On the basis of the middle Maastrichtian break, the Yuchon Group is divided into two units: III and IV. The middle Maastrichtian pause is termed here as the *"Tongri disturbance"* that is related to the basin-forming tectonics of the Tongri Basin near the Samcheog-Dogye coalfield, Gangwon Province. During the Cenomanian-early Maastrichtian, the Gyeongsang Basin experienced the crustal deformation due to the NW-compression. The NW-compression is evidenced by several NW-trending tear faults that dissect the Andong Fault. Continued NW-compression until the middle Maastrichtian eventually resulted in the polymetallic hydrothermal deposits (Au-Ag-Cu-Pb-Zn) in the Uiseong-Milyang mineralized area. As well, the crustal deformation in the basin is accompanied with anticlockwise rotation of the Uiseong and Yongyang blocks. Previous paleomagnetic studies indicate that, since these times, the Uiseong and Yongyang blocks were rotated 7° and 30° anticlockwise, respectively. Differential rotation between two blocks suggests that the Yongyang Block moved ca. 60 km toward the north along a NW-trending tear fault (proto-Ulsan Fault?) that demarcates the western boundary of the block.

The northward protrusion of the Yongyang Block probably commenced at a time corresponding approximately to the initial volcanism in the Tongri Basin (ca. 69 Ma). Due to the abrupt release of accumulated strain, the Izanagi Plate began to change the movement direction toward the east so that the E-W compression has been dominated in the basin. The E-W compression, since the middle Maastrichtian, resulted in the WNW-trending sinistral strike-slip faults (e.g., the Gaum Fault) as well as the open folds with an N-S axis in the basin. As a result, polymetallic hydrothermal deposits (Cu-Pb-Zn and Fe-Mo-W) were developed in the Uiseong and Gyungju-Ulsan mineralized areas during the middle Maastrichtian-Danian. This mineralization event was, in turn followed by another polymetallic mineralization during the Thanetian, forming the Ulsan-Weolseung mineralized area.

In this study, an integrated stratigraphy is beautifully applied to the Cretaceous Gyeongsang Basin, providing strikingly different interpretations of the basin evolution. The integrated stratigaphy approach is now able to defining event mineralization in the basin, when combined with magmatic and mineralization ages. The event mineralization is particularly useful for synthesizing temporal and spatial correlation of the hydrothermal deposits in the basin. This study gave us a valuable lesson that the integrated stratigraphy approach fundamentally vivifies the creativity and imagination of exploration geologists. As like ***oil is first found in the mind***, we can figure it out in the mind where new additional hydrothermal deposits are. When no one any longer believes more precious mineral is left to be found, no more precious mineral deposits will be discovered in Korea.

Key words: integrated stratigraphy; basin history; event mineralization; Cretaceous basin; Korea