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CRETACEOUS STRATIGRAPHY OF KOREA AND INTERREGIONAL CORRELATIONS

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ABSTRACT

The unconformity-bounded Jasong Synthem (Korea), Itoshiro Subgroup (Japan) and Jehol Group (China) are correlated each other having an age-range astride the Late Jurassic and the Early Cretaceous. In spite of differences in basement, environment and tectono-magmatism, these correlatives appear to form an interregional unconformity-bounded unit suggesting their development under a unified global tectonics. It also appears that the Akaiwa Subgroup (Japan) and the Lower Kyongsang Subsynthem (Korea) form an unconformity-bounded unit. The interregional importance of the mid-Albian unconformity suggests its presence at the boundary between the Nenjiang and the Sifangtai Formations of the Songhuajiang Group (northeast China). The Kuzuryu Subgroup seems unique in that the equivalent is not yet identified in Korea and China. A detailed mapping in future may probably find that the 'Kuwajima Formation' of the paleomagnetic study (Hirooka et al., 2002) is at the base of the Akaiwa Subgroup.

Key words: Upper Mesozoic, Cretaceous, Upper Jurassic, Lower Cenozoic, Unconformity-bounded units, Synthems, Kyongsang Supergroup, Oknyobong Formation, Jehol Group, Songhuajiang Group, Tetori Group

INTRODUCTION

The Kyongsang Basin of southeast Korea lies on the Sino–Korean craton while the Tetori Basin of Inner Zone of southwest Japan lies on the Hida block. The Songliao Basin of northeast China apparently lies on a separate massif, probably a micro-continent of the Central Asian Zone (Wang, 1985). This paper is an attempt at a time-correlation of the basin-fills of these three sedimentary basins. In spite of different continental basements, the apparent correlations of the unconformity-bounded units upon them suggest an influence by an overall tectonics for the development of basins.

The interregional correlation of the Sindong Group of the Kyongsang Basin is based on the common *Trigonioides–Plicatounio–Nippononaia* fauna as well as other geochronological constraints (Chang et al., 2003). A natural consequence is that the Jehol Group of China and its biota should precedes the Sindong Group and its correlatives. According to a recent review (Zhou et al., 2003), however, their 'Jehol biota' was extant in about the Barremian–Aptian interval, which is approximately coeval with the Sindong Group. This contradiction might have been caused by mutually contradictory, still improving radiometric age data. We thus trust that our interregional correlation is valid. For the location of the Jehol area in China, readers are kindly advised to refer the verbal geographic description on Jehol in this paper.

The term 'unconformity-bounded unit' here used should be understood rather loosely due to the nature of an unconformity which may laterally merge into a conformity. The term 'unconformity-related unit' can be a substitute, but the traditional term 'unconformity-bounded unit' is preferred here, which is still good if understood properly.

In this paper, the peri-Cretaceous stratigraphy of Korea is described relatively in detail to compare with the correlatives in the Tetori and the Sungliao Basins. 'Peri-Cretaceous' means the Cretaceous and its adjacency, i.e., Upper Jurassic, Cretaceous and Paleocene together.

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TABLE 1. Upper Mesozoic unconformity-bounded units of Korea with examples from Kyongsang Basin (southeast Korea) and northern Korean basins. **D–J**: Daedonggang–Jaeryonggang; **Y**: Yesonggang.

Unconformity-bounded units (Korean Peninsula)	*Kyongsang Basin (southern Korea)*	*northern Korea*
UPPER KYONGSANG SUBSYNTHEM (mid-Cretaceous -Paleocene)	Yuchon Volcanic Group (U Albian-Paleocene)	Bonghwasan Fm., Y Basin
LOWER KYONGSANG SUBSYNTHEM (L Cret. - mid-Cret.)	Hayang Group(U Aptian-L Albian) Sindong Group (Barrem.-U Aptian)	Hanbongsan Group, D-J Basin
JASONG SYNTHEM (U Jura. - L Cretaceous)	Myogok Formation (Hauterivian) Oknyobong Formation (U Jura.)	Chimchon, Daebosan and Mangyongdae Groups, D-J Basin

PERI-CRETACEOUS UNCONFORMITY-BOUNDED UNITS IN KOREA

Based on unconformities (Chang, 1975b; Chang et al., 2000), the Cretaceous and adjacent strata of the Korean Peninsula, entirely of continental facies, are subdivided into the Late Jurassic–early Early Cretaceous Jasong Synthem and the late Early Cretaceous–Paleocene Kyongsang Synthem. The Jasong Synthem, mainly composed of volcanic rocks of intermediate to felsic, calc-alkaline to alkaline compositions (Filatova, 1995), occurs widely in northern Korea but rarely in southern Korea. Contrastingly, the Kyongsang Synthem occurs mainly in southern Korea though not rare in northern Korea. It is subdivided by the mid-Albian unconformity into the Lower Kyongsang and the Upper Kyongsang Subsynthems (Chang, 1975a, 1975b; Chang et al., 2000). The latter contains prolific volcanic rocks which are intermediate to felsic and notably calc-alkaline (Kim, 1982, 1994).

Four diastrophisms causing these unconformable boundaries are: (1) the middle Jurassic Daebo Orogeny, (2) the early Early Cretaceous Jaeryonggang Disturbance, (3) mid-Albian Yuchon Disturbance, and (4) an end-Paleocene disturbance.

The Cretaceous–Paleocene Kyongsang Supergroup of the Kyongsang Basin is the stratotype of the Kyongsang Synthem, an unconformity-bounded unit applicable over the Korean Peninsula. The unconformity at the base of the Yuchon (Volcanic) Group is a local expression of the interregionally recognizable mid-Albian tectonism (Filatova, 1996, 1998; Kirillova, 1999, 2000).

The volcanism of the Yuchon Group was declining by the end of the Cretaceous, but continued till the Paleocene. The Eocene volcanic group in the coastal area of southeast Korea is the product of a separate geologic regime (Chang, 1985). The Eocene unconformity-bounded unit, the Gokgang Synthem, is distinct particularly because an Oligocene stratigraphic gap is salient in the Korean Peninsula.

JASONG SYNTHEM

The Late Jurassic–early Early Cretaceous Jasong Synthem (unconformity-bounded unit) (Table 1) occurs widely in northern Korea (Paek et al., 1996) while it rarely occurs in southern Korea represented only by the early Early Cretaceous Myogok Formation at the northern periphery of the Kyongsang Basin and the latest Jurassic Oknyobong Formation of the Mungyong area, Southern Korea (Chang et al., 2000, 2003) (Table 1).

Jasong Synthem in Northern Korea

Notable is the relative abundance in northern Korea of the Jasong Synthem (Table 1) with Upper Jurassic–Neocomian plant fossils (Chang et al., 1999). It also contains the Upper Jurassic–Lower Cretaceous *Eosestheria middendorfii–Lycoptera middendorfii–Ephemeropsis trisetalis* fauna.

The Jasong Synthem occurs in the following major localities in northern Korea (Fig. 1):

(1) Daedonggang Basin (4 in Fig. 1): The Jasong Synthem, about 1,550 m thick, is subdivided into 3 groups, in ascending order as follows:

The Chimchon Group, about 300–400 m thick, is composed of sedimentary and pyroclastic rocks: conglomerates, sandstones, siltstones, tuffaceous sandstones and tuffs. The tuffs of intermediate composition predominate with basaltic, andesitic, and andesite-dacitic pyroclasts ranging in size several mm to 2–3 cm across. Subordinately, acidic tuffs also occur.

The Daebosan Group, conformable on the Chimchon Group, is a volcanic association, about 800 m thick. Near Pyongyang, 5–10 dark-grey andesitic lava flows (130–170 m thick) occur at the base of the Daebosan Group. Overlying are intercalated medium- to coarse-grained tuff layers mainly of andesitic composition with subordinate amount of dacitic tuffs. The upper part of the Daebosan Group consists of the rhyolitic lava-

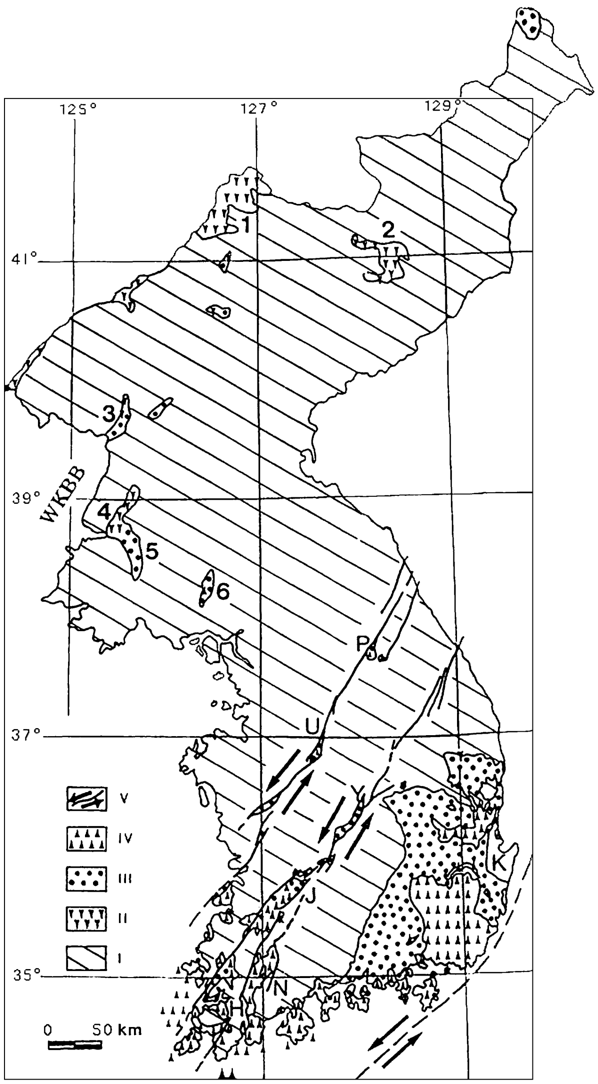

FIGURE 1. Peri-Cretaceous sedimentary basins in Korean Peninsula. **I**: basement (Precambrian–Jurassic); **II**: Late Jurassic–Early Cretaceous Jasong Synthem; **III**: Barremian–early Albian Lower Kyongsang Subsynthem; **IV**: late Albian–Cretaceous–Paleocene Upper Kyongsang Subsynthem; **V**: Cretaceous faults with arrows showing sinistral motions. **K**: Kyongsang Basin; **Y**: Yongdong Basin; **J**: Jinan Basin; **N**: Nungju Basin; **H**: Haenam Basin; **P**: Pungam Basin; **U**: Umsong Basin. **1**: Amnokgang Basin; **2**: Hochongang Basin; **3**; Daeryonggang–Chongchongang Basin; **4**: Daedonggang Basin; **5**: Jaeryonggang Basin; **6**: Yesonggang Basin; **WKBB**: West Korea Bay Basin.

flows and numerous extrusive domes with rhyolitic breccia.

The Mangyongdae Group, about 350 m thick, consists of tuffaceous sandstones, acidic tuffs and conglomerates.

(2) Jaeryonggang Basin (5 in Fig. 1): The Chimchon Group is missing here, and the Daebosan Group composed of lavas and tuffs rests unconformably on the Lower Jurassic Songnimsan Series. The Daebosan Group here includes the volcanic association ranging from basalt to rhyolite, dominated by andesites and dacites. The volcanic bombs and tuffs of basaltic and andesitic composition prevail in the basal part, and the lapilli of dacitic composition are widespread in the top of the sequence. The youngest acidic shallow intrusive bodies and extrusive domes occupy the central and peripheric parts of the cauldrons. Thus, the Daebosan Group here shows a typical volcanic compositional sequence as in the Pyongyang area. The overlying sedimentary (partly tuffaceous) sequence, a correlative of the Mangyongdae Group, has a very limited distribution here.

(3) Daeryonggang Basin along the Daeryonggang fault zone near Anju city (3 in Fig. 1): Containing distinctly mafic volcanic rocks, the Bongsu Group, 600–900 m thick, corresponds to the Chimchon, Daebosan and Mangyongdae Groups together. The lower part of the Bongsu Group consists of conglomerates, sandstones and mudstones with pyroclastic admixtures. The middle part is composed of dark-green and grey violet basalts and andesitic basalt as well as basic tuffs. The basalts contain the phenocrysts of plagioclase, olivine, clinopyroxene, rare hornblende and ore minerals. The upper part of the group consists of sedimentary (partly tuffaceous) rocks including acidic tuff layers.

(4) Amnokgang Basin near Unbong and Jasong cities (1 in Fig. 1): The Sinuiju Group, about 2,000 m thick, consists of sedimentary and effusive rocks. The group shows numerous ring-shaped volcanic structures of the central type having different size (up to 20 km in diameter). The lower and upper parts of the Sinuiju Group are (tuffaceous-) sedimentary rocks while the middle part is volcanic rocks. The lower part of the group includes red, grey and green conglomerates, sandstones, mudstones and sometimes thin coal beds. The pyroclastic component is predominantly andesitic. The middle volcanic part forms a sequence from andesitic basalts and andesites in the lower part to dacites and rhyolites (lava-flows and massive bodies) at top. The upper part of the Sinuiju Group consists of alternated grey, green, rarely reddish sandstones, mudstones and conglomerates with coal layers and acidic pyroclasts.

(5) The Hochongang Basin near Kapsan city (2 in Fig. 1): A volcanic sequence from andesites, dacites to rhyolites occurs here.

Jasong Synthem in Southern Korea

The age of the Myogok Formation (Cheong and Lee, 1966) was known as either Early Cretaceous (Chang and Yang, 1970; Chun et al., 1991) or Late Jurassic (Yang, 1984). But, recently, Kozai et al. (2001) concluded the Hauterivian age of the Myogok Formation on the basis of its gastropods akin to the Tatsukawa-type fauna (Japan) and also of species akin to *Trigonioides* which, in Japan, is limited to the Lower Cretaceous.

Recently, the Oknyobong Formation is known as another example of the Jasong Synthem. A few hundred meters thick, it occurs as pre-Cretaceous post-Ordovician volcanic strata near the Unsong coal-mine, near Mungyong. Its trachyte sample with a ca. 139 Ma K–Ar whole-rock age suggested the basal Cretaceous, or a little older, age of the Oknyobong Formation (Chang, 1985). Its Jasong age has recently been reinforced by an U–Pb CHIME isochron date, 187±35 Ma, of a zircon grain derived from a rhyolite sample of the same formation (Chang et al., 2003): the grain is notable in being subrounded due to erosional abrasion implying its derivation from an Early Jurassic felsic igneous rock, i.e. the Jurassic Daebo Granite.

These isotope dates strongly suggest that the Oknyobong Formation belongs to the Jasong Synthem of Korea, whose age is astride the Jurassic and the Cretacecous Periods. The volcanics-dominant Oknyobong Formation is highly deformed while the black-shale-dominant Myogok Formation is only mildly deformed; they are mutually isolated. Such differences support the presumption that they are the products of two different tectonic phases, not a single 'Jaeryonggang Movement' (Paek et al., 1996). In southern Korea, the Nakdong Disturbance (Cheong and Lee, 1966) appeared to correspond the 'Jaeryonggang Movement' of northern Korea. But, the concept of the Oknyobong Disturbance appears necessary. These disturbances are seen as two different tectonic phases of the Jaeryonggang 'Movement.' Supposedly, the Oknyobong Formation was tectonized by a pre-Myogok Oknyobong Disturbance (Valanginian). The age of the Nakdong Disturbance of the Myogok Formation may be late Hauterivian–early Barremian.

KYONGSANG SUPERGROUP OF KYONGSANG BASIN

The Kyongsang Supergroup of the Kyongsang Basin, southeast Korea, is the stratotype of the Kyongsang Synthem of the Korean Peninsula. It consists of the Sindong, Hayang and Yuchon Groups, all entirely of continental facies.

In a central part of the Kyongsang Basin Tateiwa (1929) divided the sedimentary–volcanic sequence into the Nakdong and Silla Series. As mapping expanded over the whole Kyongsang Basin in the 1960s, the absence (due to discontinuity) of the Silla Conglomerate there did not allow such a division. Massive efforts in mapping compelled the senior author (1975a) to propose the Sindong, Hayang and Yuchon Groups, a triple division of the Kyongsang Supergroup, which is now widely accepted. The Sindong–Hayang boundary, significant in basin history of the Kyongsang Basin, is useful in mapping within the basin and serves a reference horizon for the Cretaceous stratigraphy in Korea. The significance of the sub-Yuchon unconformity, which was not recognized by Tateiwa, is now realized over a wide area including the Korean Peninsula (Chang et al., 2000).

Sindong and Hayang Groups (Barremian–early Albian)

In mid-Early Cretaceous time, a NNE trending Nakdong Trough was formed in the western Kyongsang Basin, in which the Sindong Group, 2,000 to 3,000 m thick, composed of sandstone, shale, conglomerate and marl was deposited. The Sindong Group is developed almost exclusively in the Nakdong Trough (Chang, 1975a) which appears an intermontane post-orogenic semi-graben. The major source area in WNW as indicated by paleocurrent analyses (Chang, 1988) was intermittently rising as recorded in sedimentary megacycles

The Sindong Group consists of the Nakdong (non-red), Hasandong (red-banded) and Jinju (non-red) Formations. The upper part of the Nakdong Formation contains *Clypeator jiuquanensis* (Seo, 1985), a charophyte known to range Hauterivian to early Barremian (Wang and Lu, 1982). Choi (1989) also studied charophytes from the upper part of the same formation with a conclusion that they indicate a Barremian age. Recently, the Barremian age of the Nakdong Formation was reinforced by Kozai et al. (2001), who correlated the Sindong Group with the Kitadani Formation of the Tetori Group, Japan, based on their common Barremian–Aptian Sebayashi-type bivalve faunas comprising *Nippononaia ryosekiana*, *Nagdongia soni*, *Plicatounio naktongensis* and *Pseudohyria matsumotoi*. The Sindong Group is correlated by the common *Trigonioides–Plicatounio* assemblage with the Wakino Subgroup, the lower part of the Kanmon Group, the Inner Zone of SW Japan (Kobayashi and Suzuki, 1936; Yang, 1974). The present writers judge that the lower part of the Sindong Group is of the Barremian age following Choi (1989) and Kozai et al. (2001). It is thus constrained that the age of the Nakdong Disturbance prior to the Nakdong Formation is about the earliest Barremian.

The Hayang Group sedimentation after the Sindong Group witnessed an abrupt eastward expansion of the depositional area or an eastward migration of the depocenter. The Hayang Group, 1,000 to 5,000 m thick, is composed of shale, sandstone, conglomerate and intra-basinal volcanic rocks. Paleocurrent and facies analyses indicate a dominant clastic source area to the east: somewhere in the present East Sea (Japan Sea) (Chang, 1988; Chang et al., 1990). The abrupt eastward basin migration from the Nakdong Trough to the whole Kyongsang Basin in the Aptian may have been related with a sinistral strike-slip pull-apart due to the Korea–Taiwan Strait Fault, one of several paralleling major Cretaceous sinistral faults (Xu et al., 1987; Chang, 1994).

During the sedimentation of the Hayang Group, the Kyongsang Basin was ruled by WNW-trending growth faults that divided the basement of the basin into smaller crustal blocks or subbasins such as the Milyang and Uisong Subbasins (Table 2). Syndepositional block movements and related sedimentation yielded abrupt lateral lithologic and thickness changes causing difficulties in intra-basinal correlation (Chang, 1975a, 1987; Chang and Park, 1995).

TABLE 2. The formations of Hayang Group in three subbasins of Kyongsang Basin. **V**.: Volcanic; **Fm**.: Formation; **Mb**.: Member.

<table>
<tr><th>Yongyang Subbasin</th><th>Uisong Subbasin</th><th colspan="2">Milyang Subbasin</th></tr>
<tr><td colspan="2">Sinyangdong Formation</td><td>Konchonri Fm.</td><td rowspan="3">Jindong Formation</td></tr>
<tr><td rowspan="2">Kisadong Fm.</td><td rowspan="2">Chunsan Fm.</td><td>Chaeyaksan V. Fm.</td></tr>
<tr><td>(Songnaedong Mb.)
Lower Jindong Fm.</td></tr>
<tr><td>Dogyedong Fm.</td><td colspan="3">Haman Formation</td></tr>
<tr><td>Osipbong Fm.</td><td></td><td colspan="2">Hakbong Volcanic Fm.</td></tr>
<tr><td>Chongryangsan Fm.</td><td>Jomgok Fm.</td><td colspan="2">Silla Conglomerate Fm.</td></tr>
<tr><td>Kasongdong Fm.</td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="2">Donghwachi Fm.</td><td>Kugyedong Fm.</td><td colspan="2" rowspan="2">Chilgok Formation</td></tr>
<tr><td>Kumidong Fm.</td></tr>
<tr><td>Ullyonsan Fm.</td><td>Ilgik Fm.</td><td colspan="2"></td></tr>
</table>

Recently, an U–Pb CHIME isochron, about 113.6 Ma, has been obtained from the zircon grains of the Kusandong Tuff in the top Haman Formation of the Hayang Group (Chang et al., 1998). It now appears that the boundary between the Haman and the Jindong Formations roughly corresponds to the Aptian–Albian transition, ca. 112 Ma. The Jindong Formation, a dark-gray silty lacustrine facies 1,500 m or more thick, is the last of the Hayang sedimentation.

In the northern part of the Kyongsang Basin, the Kumidong and Kisadong Formations of the Hayang Group bear conglomerates containing the pebbles of the Permian, Triassic, Jurassic and Early Cretaceous cherts. The cherts of the pebbles are in lithology and fossil content very similar with the cherts of the Tamba–Mino–Ashio and Chichibu belts of Japan (Chang et al., 1990), the latters being accretionary belts that must have been located adjacent to the Kyongsang Basin in the Cretaceous.

Volcanism was rare in the Sindong time. Only some felsic tuff beds are observed in the upper part of the Sindong Group (Choi, 1986). But volcanisms were numerous and rather active in the Hayang time though not so vigorous as in the Yuchon time.

In the Hayang Group (Aptian–lower Albian), the following volcanics are found as here described in ascending order:

(1) andesitic pebbles and a lava of alkalic basalt in the upper part of the Chilgok Formation,

(2) pebbles/cobbles of andesite, rhyolite etc. in the Silla Conglomerate,

(3) basalt layers of the Hakbong Volcanic Formation,

(4) two copper-bearing basalt layers (in the lower Dogyedong Formation, which is correlated with the Haman Formation),

(5) felsic crystal tuff, the Kusandong Tuff,

(6) Haman Andesite [(5) and (6) are almost synchronous], and

(7) andesite-basalt of the Chaeyaksan Volcanic Formation.

Among the above, (4) appears a few hundred meters below (5). A copper-bearing basalt layer similar to (4) was drilled below the Yellow Sea; its K–Ar ages of 107 Ma and 114 Ma (Jin et al., 1991) are comparable with U–Pb age of the Kusandong Tuff, 113.6 Ma. These on-land and submarine copper-bearing basalts appear to be correlated.

Yuchon Volcanic Group (late Albian–Paleocene)

Composed of mainly volcanic rocks and also clastic rocks, this unit unconformably overlies the Hayang and Sindong Groups and the basement rocks, and is subdivided into the andesitic lower part (Jusasan Intermediate-Volcanic Subgroup) and the felsic upper part (Unmunsa Acidic-Volcanic Subgroup). In the most parts of the Kyongsang Basin, the sub-Yuchon unconformity at the base of the Yuchon Volcanic Group shows an angular discordance caused by the mid-Albian Yuchon Disturbance (Chang et al., 1984, 2000). It was a brief crustal disturbance that mildly folded earlier strata not only in the Kyongsang Basin but all over Korea, where the event was generally coincident with a transition from a clastics-dominant to a volcanics-dominant sedimentary phase. And also, it was coincident with a change from moderate, alkaline, volcanisms of the Hayang Group (Aptian–early Albian) into abundant calk-alkaline volcanism of the Yuchon Volcanic Group (Kim, 1982, 1994), though the lower part of the Yuchon Group does contain some alkaline rocks (Jin, 1998). The Yuchon volcanics and the comagmatic plutonic rocks are distinctly calc-alkaline, suggesting its belonging to the subduction-related continental marginal volcanic belt (Chang et al., 1984).

Such a chemical change was coincident with an interregional crustal disturbance recognized in adjacent countries. According to Kirillova (1999, 2000), the mid-Albian was the time of tectonism, volcanism, unconformity and transgression in northeast Russia, when the late Albian–Senonian Okhotsk–Chukotka continental marginal volcanic belt began to form. Filatova (1996, 1998) interpreted the interval of 120–100 Ma (mid-Cretaceous; Aptian–Albian) as a period of intense orogeny over the peri-Pacific and Tethyan continental margins caused by an accelerated rate of spreading due to a Pacific Superplume; the succeeding interval of 100–80 Ma (the early Late Cretaceous) underwent an intense volcanism due to normalized subduction following its previous cessation.

The mid-Albian tectonism is reminiscent of the ‘mid-Cretaceous’ (Albian–Coniacian) pulse in the rate of sea-floor spreading (Larson and Pitman, 1972) and the ‘mid-Cretaceous’ (Aptian–Albian) pulses of peri-Pacific deformation, metamorphism, uplift and hiatus in sedimentation (Vaughan, 1995). According to Engebretson et al. (1985), the Izanagi plate was spreading during the Aptian–Albian age toward the north almost parallel with the Asian continental margin. Apparently, the alkaline volcanism of the Aptian–Albian interval was of intra-plate origin during the cessation of the subduction, which was succeeded by a rapid subduction resulting in the vigorous calk-alkaline volcanism of the Late Cretaceous.

The Upper Kyongsang Synthem (late Albian–Paleocene) was succeeded by the Kokgang Synthem of the Eocene age.

TABLE 3. Jurassic-Cretaceous unconformity-bounded units of Japan, Korea and China and their correlations.

Geochronology (Ma)				Northeast CHINA	Southern KOREA	Southwest JAPAN
		Danian				
65			65			
70	CRETACEOUS	Maastrichtian	71	SONGHUAJIANG GROUP	KYONGSANG SYNTHEM	
75, 80		Campanian	83.5	Mingshui Fm.	YUCHON VOLCANIC GROUP	
85		Santonian	86	Sifangtai Fm.		
		Coniacian	89			
90		Turonian	93.5			
95		Cenomanian	99			
100, 105, 110		Albian	112	~~~~~~~~ Nenjiang Fm. Yaojia Fm.	~~~~~~~~~~ HAYANG GROUP	mid-Cret. igneous rocks ~~~~~~~~~~~~ TETORI GROUP (absence of strata: non-depostion)
115, 120		Aptian	121	Qingshankou Fm. Quantou Fm.	---------------- SINDONG GROUP	AKAIWA SUBGROUP
125		Barremian	127	Denglouku Fm. ~~~~~~~~~~	~~~~~~~~~~~~	? 'Kuwajima Fm.' ~~~~~~~~~~~~
130		Hauterivian	132	JEHOL GROUP: Fuxin Fm.	JASONG SYNTHEM: Myogok Fm. ~~~~~~~~~	Kuwajima Fm. ~~~~~~~~ ?
135		Valanginian	137	Jiufotang Fm.		
140		Berriasian	145	Yixian Fm.		ITOSHIRO SUBGROUP
145, 150	JURASSIC	Tithonian	151	Dabeigou Fm.	Oknyobong Fm.	
155		Kimmeridgian	156.6	Zhangjiakou Fm. ~~~~ ? ~~~~~	~~~~~ ? ~~~~~	~~~~~~~~~~~~ KUZURYU SUBGROUP

JEHOL AND SONGHUAJIANG GROUPS, CHINA

In northeast China the Late Jurassic–Early Cretaceous Jehol Group in Yan–Liao area and the Cretaceous Songhuajiang Group in the Songliao Basin are comparable respectively with the Jasong and the Kyongsang Synthems of Korea (Table 3).

The Jehol (Rehe) Group

The name Jehol ('Johol' by Grabau, 1928; most recently 'Rehe') derives from the former Jehol Province, now the northeast part of the Hubei Province. The Jehol area is in the northeast of Beijing astride the Yanshan Mountain and the Liaoning Province; hence the name 'Yan–Liao' area, an approximate equivalent of the Jehol area.

The 'Johol Series' of Grabau (1928) was a clastic unit 50–100 m thick, its upper part being rich in fish fauna of larger-sized *Lycoptera joholensis* Grabau and smaller-sized *L. joholensis* var. *minor* Grabau. It lies between the 'Lower Porphyry Beds' and the 'Upper Porphyry Beds,' both volcanic rocks. Grabau wrote: the plant fossils, insects and molluscs suggest an Early Cretaceous age.

Stratigraphically extended Jehol biota and Jehol Group have proved useful for the Late Jurassic–Early Cretaceous continental facies of northeast China. A currently popular 'standard' Jehol Group of the Yan-Liao area consists, in ascending order, of the Zhangjiakou, Dabeigou, Yixian, Jiufotang and Fuxin Formations (Stratigraphical Group, Institute of Geology, Chinese Academy of Sciences, 1989).

The Zhangjiakou Formation, ca. 2,500 m thick, consists of rhyolitic rocks (often with quartz phenocrysts), trachyte, minor andesite and sandstone. The Dabeigou Formation, ca. 150 m thick, consists of sandstone and shale with a basal conglomerate; contains the Jehol Fauna. Famous with excellently preserved birds and other vertebrate fossils, the Yixian Formation, 100s to 1,000s m thick, consists of andesite, basalt and clastics with *Lycoptera–Eosestheria–Ephemeropsis* (L–E–E) Assemblage, a typical Jehol Fauna; a species similar to *Nakamuranaia* occurs. The Jiufotang Formation, one to two thousands m thick, consists of lacustrine clastics with L–E–E Assemblage. The Fuxin Formation, ca. 1,000 m thick, is a coal-bearing formation of sandstone and shale with the Early Cretaceous *Ruffordia–Onychiopsis* Flora; A *Nippononaia* sp. and *Viviparus* sp. cf. *V. onogoensis* occur.

According to the Stratigraphical Group (1989), the bulk of the Jehol Group is Late Jurassic except the uppermost formation which may be Cretaceous. But recent references advocate the Early Cretaceous age for the bulk of the Jehol Group except the Late Jurassic lower part. Recently Ar–Ar and K–Ar dates, about 145 Ma, of the volcanic minerals from the lower part of the Yixian Formation proved the Late Jurassic age of the formation (Lo et al., 1999). It is, thus, certain that the age of the Jehol Group is the Late Jurassic–Early Cretaceous.

The Songhuajiang Group

The Cretaceous Songhuajiang (Sungari) Group in the Songliao Basin, northeast China, is an oil-bearing clastic formation, which represents a new depositional regime after the volcanics-dominant Jehol Group. Their unconformable relation is manifest in their different locations of sedimentation.

The Songhuajiang Group has been divided into seven formations (Stratigraphical Group, 1989): (in ascending order) the Denglouku (440+ m; conglomerate, sandstone, mudstone; gray), Quantou (1,019 m; mudstone, sandstone, conglomerate, tuff; red), Qingshankou (614 m; mudstone, oil shale; gray), Yaojia (208 m; mudstone; red), Nenjiang (828 m; mudstone, oil shale, andesite, basalt; gray), Sifangtai (394 m; mudstone, sandstone; red) and Mingshui Formations (597 m; shale, sandstone; gray). The Sifangtai Formation lies disconformably upon the Nenjiang Formation.

Among these formations, the Denglouku–Yaojia interval forms the zone of the *Trigonioides–Plicatounio* Assemblage. And, the Sifangtai–Mingshui interval forms the zone of the *Pseudohyria–Sphaerium* Assemblage. Comparing with the Korean strata with molluscs, the Denglouku–Nenjiang interval may be correlated with the Sindong and Hayang Groups; then, the Sifangtai–Mingsui interval is correlated with the Yuchon Group. Generally, the Songhuajiang Group corresponds to the Kyongsang Supergoup of the Kyongsang Basin, Korea.

TETORI GROUP, JAPAN

In spite of structural complexity of the Tetori Group and a general feature that unconformities may locally include conformable parts, Maeda (1961) could recognize unconformities within the Tetori Group that enable us to interpret the subgroups of the Tetori Group as unconformity-bounded units (Table 3).

Kuzuryu Subgroup deposited on the Hida gneiss, granites, and Paleozoic formations, is intercalated with some fossiliferous marine strata astride in age the Middle and Late Jurassic, spanning Bajocian–Oxfordian. The Kimmeridgian/Oxfordian upper-bounding unconformity was called the Umagadani unconformity that reflects a tectonism (Maeda, 1961).

Itoshiro Subgroup was deposited either on the Kuzuryu Subgroup or the Hida gneiss often with basal conglomerates. Both fresh- and brackish-water molluscs occur implying an mixed environment. The age of the Itoshiro Subgroup is astride late Jurassic and early Cretaceous.

Akaiwa Subgroup appears to conformably overlie the Itoshiro Subgroup (Fujita, 2002). But, a ‘Valanginian Okura Unconformity’ was recognized at the base of the Akaiwa Subgroup by Maeda (1961) who also observed the basal conglomerates: Okura and Okurodani conglomerates. The Okura Unconformity might go up in age till the Barremian because a ‘Hauterivian-Barremian’ molluscs was found in the upper part of the Itoshiro Subgroup (Fujita, 2002). The Akaiwa Subgroup, unconformably overlain by the mid-Cretaceous igneous rocks, is of the late Barremian–Aptian age. According to Kozai et al. (2001), the uppermost part of the Akaiwa Subgroup is correlated with the Sindong Group of Korea based on the Sebayashi-type fauna. Relying on this correlation, we recognize a hiatal part above the Akaiwa Sungroup, which is correlated with the Hayang Group of Korea.

Based on the common Hauterivian Tatsukawa-type fresh-water molluscs, the Izuki, Kuwajima and Okurodani Formations (‘the upper part’ of the Itoshiro Subgroup) appear roughly correlated mutually and also correlated with the Myogok Formation, southern Korea (Kozai et al., 2001). According to a paleomagnetic study, however, the sedimentary basin of the Itoshiro Subgroup was in low latitude until the deposition of the Izuki Formation while the deposition of the Kuwajima Formation took place in a higher latitude together with the Akaiwa Subgroup (Hirooka et al., 2002).

Relying on the paleomagnetic study, the present writers dare suppose two ‘Kuwajima Formations’ for the present, preliminary, stage of mapping: A Kuwajima Formation with *Viviparus onogoensis* must be correlated with the Izuki Formation, while another ‘Kuwajima Formation’ belongs to the Akaiwa Subgroup; the studied paleomagnetic sample was supposedly taken from the ‘Kuwajima Formation’ which should hence be studied to find out *Trigonioides–Plicatounio* Assemblage typical to the Akaiwa Subgroup.

DISCUSSION AND SUMMARY

The Late Jurassic–early Early Cretaceous volcanic belt of northern Korea extends to northeast China (Wang, 1985). In the Inner zone of southwest Japan, the Late Jurassic–Early Cretaceous sedimentary sequences of West Chugoku (Toyonishi Group) and central Honshu (Itoshiro Subgroup of Tetori Group) show no volcanisms but regressive phases from shallow-marine or brackish facies below to fluvio-lacustrine ones above (Kimura et al., 1991; Sakai and Okada, 1997).

The unconformity-bounded Jasong Synthem (Korea), Itoshiro Subgroup (Japan) and the Jehol Group (China) have an age that ranges astride the Late Jurassic and the Early Cretaceous. The Barremian/Hauterivian age of the upper-bounding unconformity of these units is constrained by the Barremian–Aptian *Trigonioides–Nippononaia* Zone in the lower part of the Songhuajiang Group, the Kyongsang Synthem and the Akaiwa Subgroup (Table 3). The age of the basal unconformity of the Jehol Group (China) and the Oknyobong Formation (Korea) appears roughly correlated with the Umagadani Unconformity at the base of the Itoshiro Subgroup, a Kimmeridgian/Oxfordian age based on marine intercalated fossils (Maeda, 1961).

The Jasong Synthem and the Jehol Group, both entirely non-marine, are dominated by volcanic rocks, but the Itoshiro Subgroup (Japan), non-volcanic, is intercalated with marine strata. In spite of such environmental and tectono-magmatic differences, the Jasong Synthem and the correlatives appear to form an interregional unconformity-bounded unit suggesting their development under a unified global tectonic regime.

In Korea including the Kyongsang Basin, volcanic activity becomes abruptly and active the mid-Cretaceous time forming the Yuchon Volcanic Group and its intrusive equivalents. The mid-Cretaceous igneous rocks on Table 3 (Tanase et al., 1994) appear to be correlated with the lower part of the Yuchon Group. Then, we have to recognize a hiatal part between the 'mid-Cretaceous igneous rocks' and the Akaiwa Sungroup, which is correlated with the Hayang Group of the Kyongsang Basin. But, the Akaiwa Subgroup (Japan) should be correlated with the Lower Kyongsang Subsynthem (Korea).

The mid-Albian unconformity, important in various parts of East Asia, might have left a stratal break in northeast China: it may probably divide the Songhuajiang Group into the Denglouku–Nenjiang interval and the Sifangtai–Mingshui interval (see Table 3). The uniqueness of the Kuzuryu Subgroup implies an earlier development of the Tetori Basin compared to the Kyongsang Basin.

The samples for the paleomagnetic study (Hirooka et al., 2002) may have been taken from a 'Kuwajima Formation' without *Viviparus onogoensis* but possibly with *Trigonioides–Plicatounio* Assemblage typical to the Akaiwa Subgroup. If this conjecture is valid, the 'Kuwajima Formation' is only a homonym of the Kuwajima Formation. A detailed mapping is desirable for the clarification.

In southern Korea, the Myogok Foramtion and the Oknyobong Formation, both of the Jasong Synthem, appear mutually unconformable. The unconformity representing the Oknyobong Disturbance is shown on Table 3. A hypothetical unconformity is conjectured in the upper part of the Itoshiro Subgroup which may be correlated with the pre-Myogok unconformity representing the Oknyobong Disturbance (top Valanginian) in Korea (Table 3).

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