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Palaeodepositional Environment of the Cretaceous Hampyeong Basin, Southwestern Korea

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한반도 남서부 중생대 백악기 함평퇴적분지의 고퇴적환경연구

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Abstract: Abstract: The palaeodepositional environment and age of the Cretaceous Hampyeong Basin (southwestern Korea) are reassessed based on new geochemical, lithological, sedimentological, and palaeobotanical data. Results indicate that the Hampyeong Basin was a tectonically active basin comprising predominantly fluvial and lacustrine sediments. Four distinctive facies types have been identified (acidic tuff, black shales/sandstones, red beds, intermediate tuff with tuffaceous conglomerate) and these reflect periods of significant environmental change within the basin and its neighbouring terrains. Volcanism driven by tectonic events provides a source for much of the sediment. The sedimentary sequences compare well with those in the neighbouring Haenam Basin. Sediments of volcanic origin are similar to those of the Neungju Formation of the Yuchon Group. The widespread occurrence of black shales is indicative of extended periods of deposition under anoxic conditions. Measurements of total organic carbon show that the values for the black shales (0.81% to 1.75%) are the average for petroleum source shales. Fossil plants occurred in the black shales and sandstones. The occurrence of platanoid leaves places these sediments in Oishi's angiosperm series, which is consistent with an Aptian/Albian or younger age.

Key words: Hampyeong, environmental change, anoxia, fossil plants, Aptian/Albian

요 약: 중생대 백악기 함평분지의 고퇴적환경과 지질연대를 지화학, 암상 분포, 퇴적암석학 그리고 고식물학 측면에서 재고찰을 시도하였다. 연구 결과는 함평분지가 하성과 호성층으로 구성된 구조적으로 활동적인 분지였음을 시사한다. 이 분지에서는 주변 지형과 관련되어 분명한 환경 변화를 시사하는 산성응회암류, 흑색 셰일/사암상, 적색층, 응회암질 역암을 포함하는 중성응회암류 등 4 가지 암상이 인지되었다. 구조적 운동에 수반하여 일어난 화산활동이 이들 퇴적층을 형성시킨 퇴적물을 주로 제공하였을 것이다. 이들 퇴적층들은 인접한 해남분지와 잘 대비된다. 그리고 화산성 기원의 퇴적물들은 유천층군에 해당하는 능주층의 경우와 유사하다. 분지 내에서 흑색 셰일의 광역적인 분포는 혐기성 환경 하에서 퇴적이 이루어졌음을 지시한다. 이들 암층에 있어서의 유기탄소의 함량(0.81%에서 1.75%)은 석유근원 셰일의 평균치 정도로 나타났다. 식물화석은 흑색셰일과 사암에서 산출된다. Platanoid류 잎 화석의 산출은 이들 퇴적층이 Oishi의 피자식물 계열 지층에 해당하며 시대상 Aptian/Albian 또는 보다 신기 지층임을 시사한다.

주요어: 함평, 환경변화, 혐기성 환경, 식물화석, Aptian/Albian

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INTRODUCTION

Sediments of Cretaceous age are well developed and widespread in the Korean peninsula. The largest contiguous mass occurs in the Gyeongsang Basin, which covers an extensive area (ca 20,000km^2) in the southeast. There are also many other smaller basins in and around the Okcheon Fold Belt, a ca 70km wide geosynclinal zone extending north-eastwards between the Ryeongnam and the Gyeonggi massifs (Figure. 1, Reedman and Um., 1975). These smaller basins have been interpreted as intermontane grabens (Lee, 1987), which are the result of a complex tectonic history culminating in the Daebo Orogeny (Jurassic to Early Cretaceous) (Reedman and Um, 1975). Recent works on the Jinan (Lee, 1992), Haenam (Chun, 1989), and Kongju Basins (Choi *et al.*, 1997) have shown that these are extensional, and that they have developed by sinstral strike-slip faulting. The geology, sedimentology, and palaeontology of these smaller basins and their relationships to the Gyeongsang Supergroup are still comparatively poorly understood. This paper focuses on the Hampyeong Basin (Haenam-Mokpo region; Figure 1), which comprises a sequence of non-marine sediments and volcanics bounded by the north-east to south-west trending Kwangju Fault System. The aim is to document the main facies types in greater detail and to interpret the ancient depositional environment. Stratigraphy and correlation are attempted on the basis of lithology, palaeontology, and geochemistry.

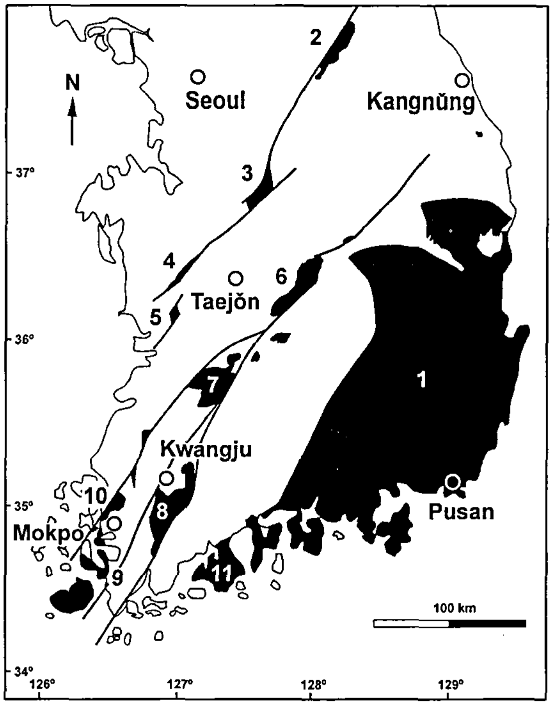

Fig. 1. Distribution of Cretaceous basins in Korea. 1. Gyeongsang, 2. Pungam, 3. Eumseong, 4. Kongju, 5. Buyeo, 6. Yeongdong, 7. Jinan, 8. Neungju, 9. Haenam, 10. Hampyeong, 11. Kohung Basins. 2-10 lie along the Okcheon Orogenic Belt.

GEOLOGICAL SETTING

The Hampyeong Basin is located in the southern part of the Okcheon Fold Belt (Figure 1). This small basin covers an area of ca 520km^2 and is bounded to the north-west by the Kwangju Fault System, to the south-east by an intruded biotite granite of Jurassic age, and to the west and north by a Precambian mica schist and granite gneiss respectively. Throughout the basin, the Cretaceous system rests unconformably on this Precambrian and Jurassic basement. Most of the Cretaceous sequence is in a topographically lower zone between the Okma mountain and the Yeongsan river. The total thickness of sediment is about 500m and comprises in ascending order acidic tuff, black shales with intercalated dark grey sandstones, red beds, pebble conglomerate, and intermediate tuff with intrusive andesite and extrusive rhyloite (Figure 2). Comparisons with similar sequences in the Haenam Basin, 30km to the south, indicate a fluvio-lacustrine depositional environment and an Upper Cretaceous age (Reedman and Um, 1975; Lee and Lee, 1976; Son

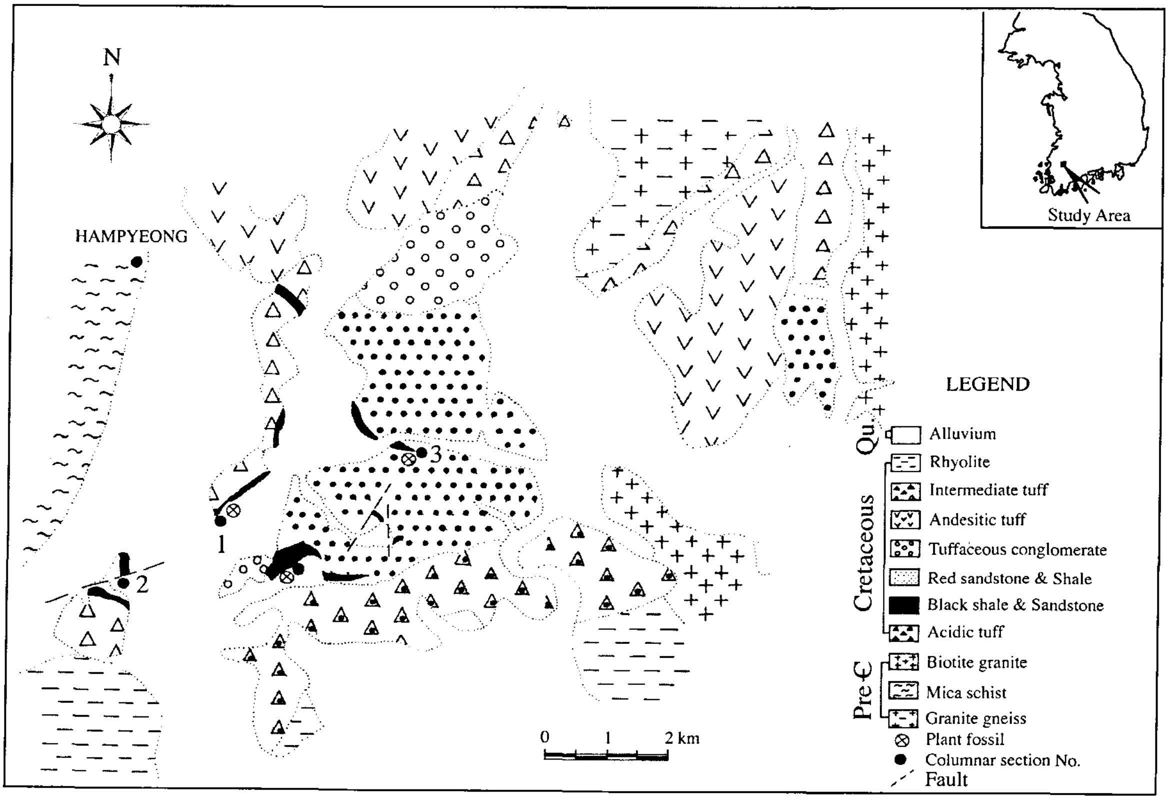

Fig. 2. Geologic map of the Hampyeong area (from Kim *et al.*, 1998)

et al., 1980; Chough and Chun, 1987; Chun, 1989, Chun and Chough, 1995).

METHODS

Detailed logs of outcrops by H.S. You were used to produce 5 columnar sections, 3 of which are illustrated in the Figure 3. Samples were taken from horizons indicated in the columnar sections for more detailed lithological, geochemical, and palaeontological analyses. The mineral composition was characterised using standard petrographic thin sections. An attempt to quantify mineral composition of the black shale was undertaken using X ray diffraction analysis (composite of 10 cm thick sample). X-ray diffraction measurements were made by G. Cressy (Mineralogy, NHM) using the rapid phase quantification method (XRD) with a position sensitive detector (PSD) based on the analytical procedure described by Batchelder and Cressey (1998). Chemical analysis of the black shales was undertaken at inter-University Center Natural Science Facilities in the Geology Department of Seoul National University. Fossil plants were described by P. Kenrick (Palaeontology, NHM) using standard palaeobotanical methods. Compression fossils in the black shale were photographed using cross polar illumination (Rowe, 1999). All specimens are stored in the Department of Oceanography, Chonnam National University, Korea.

RESULTS

Stratigraphic Record

A distinctive sequence of lithologies have been

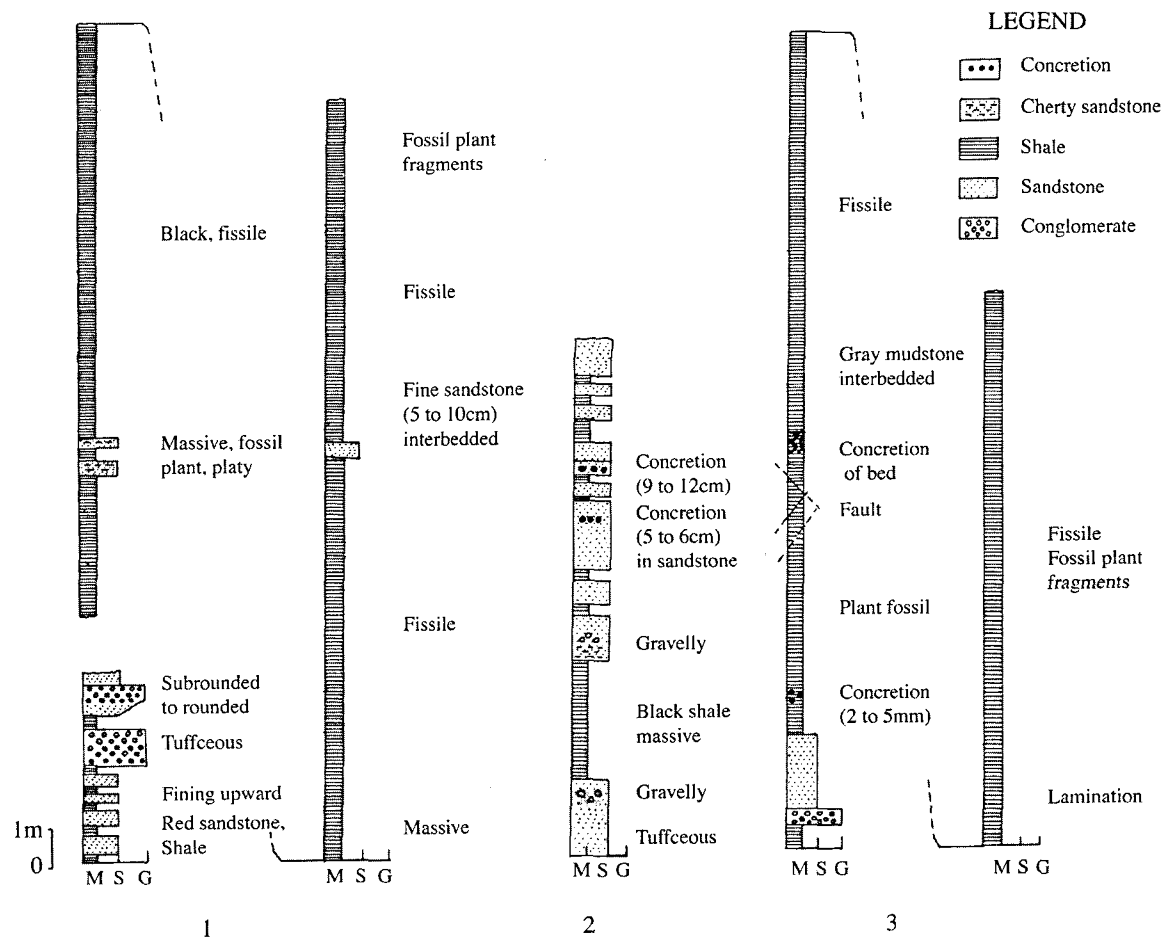

Fig. 3. Columnar sections of the Cretaceous sediments of the Hampyeong Basin.

recognized in the Hampyeong Basin. In ascending order these comprise acidic tuff, black shale with intercalated dark grey sandstone (20~35 m thick), red beds with intercalated gravel bearing sandstone and shales, conglomerate and intermediate tuff, all of which is overlain by andesite and tuff. The transition between black shale and red beds is maybe paraconformable. The black shale beds dip 10 to 45 and are interbedded in a lenticular form with the overlying red beds and underlying tuff and exhibit lateral facies change over a distance of 200~500 m between outcrops 1 and 5. The black shale bed thins towards the western edge of the section. Fossil plants occur mainly in the black shales and sandstones (Figure 3). The plant bearing shales bear ripple marks on a few horizons intercalated with siltstone and are overlain by a 30 cm thick cherty sandstone. In outcrop 3, minor post depositional faulting and folding have been observed.

Sedimentary Structures

On the sedimentary structures of sandstone and shale, we present a description in terms of primary and secondary structures based on field observations and microscopic work in laboratory (Allen, 1982; Collinson and Thompson, 1982).

Primary structures: Primary structures observed in the black shale, dark grey sandstone, and red beds include cross lamination, mud cracks, micro ripple marks, scouring and splitting, and platy, fissile, and papery laminations (Plate 1.1). In the intercalated layer of black shale and dark grey sandstone, fissile laminations (1 mm~5 mm thick) occur in the middle part of columnar sections 1 and 3. Platy laminations occur in sections 2 and 3. These are enhanced by weathering but are probably caused by an increase in clay and organic matter. Parting lamination probably indicates the traction transport of sand and silt in the flatbed mode. In addition to the primary structures listed above, graded bedding was also observed in the red beds.

Secondary structures: These include micro-faults, convolute beds, and concretions. Minor faults and fold structures were observed at outcrop 3 at the back of Hampyeong High School. More or less spherical concretions (9 cm~12 cm diameter) were observed at outcrops in columnar section 2 in a sandstone layer (40 cm~50 cm thick). Oval and spherical concretions (1 cm~2 cm diameter) occur in the black shale at outcrops in columnar section 5. Microscopic observation shows that the concretions are connected with vienlets of calcite and that they are filled with calcite and organic material (Plate 1.2). These concretion bearing sandstones and black shales can be used as marker horizons because the concretions are restricted to these layers. As diagenetic structures, concretions indicate local and usually early cementation in a defined layer. The concretions formed around an organic nucleus without major displacement of the mud matrix. The interconnection of concretions with vienlets of calcite is suggestive of replacement by hydrothermal solution flowing through pores in a selective layer bearing organic material (Plate 1.3).

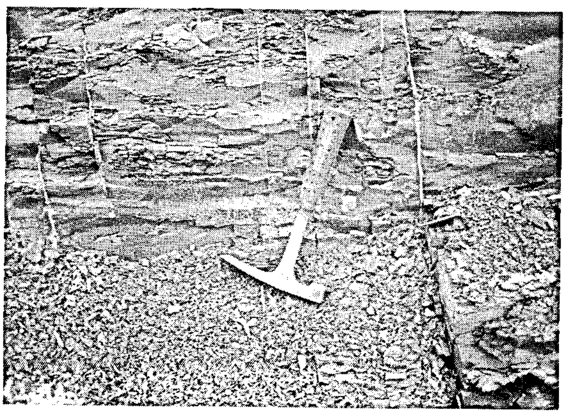

Plate 1.1 Papery laminations and faults.

Lithology

Sandstones: These are mainly red to dark grey and medium-, fine-, and very fine- grained. The medium grained sandstone of the red beds consist of angular to subangular shaped grains that are poorly sorted. This most closely resembles litharenite (Pettijohn, 1975), which consists predomiantly of rock fragments

Plate 1.2 Calcite vein and carbonaceous matter in shale (X40).

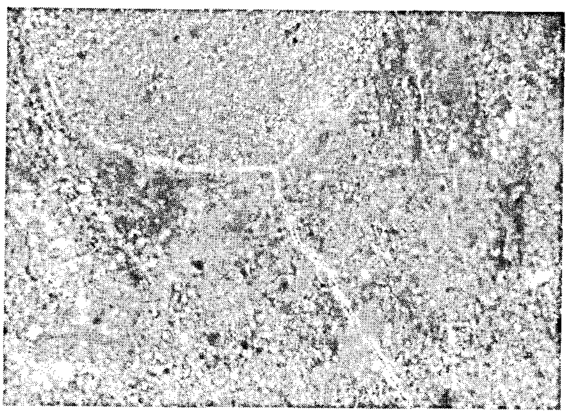

Plate 1.3 Concretions in shale(X40).

from shales and sandstone, K-feldspar, and plagioclase containing albite twin which has sericitized due to thermal alteration. Some exhibit concave-convex contact, but there is an absence of grains in contact along the long axis. Quartz grains are well-rounded and volcanic ash was observed. On the basis of grain composition, this belongs to feldspathic litharenite (McBride, 1963; Folk, 1968).

Fine grained sandstone is more abundant in the red beds than medium grained sandstone. Sand grains are arranged by point contact along the long axis, are very poorly sorted, are angular to subangular, and have a compact texture. Quartz grains appear to be unaltered, whereas feldspar is sericitized by alteration and weathering. Rock fragments consists mainly of volcanics including andesite and sedimentary rock. This lithology most closely resembles the graywacke of Pettijohn (1975).

Fine to very fine grained sandstone comprises angular to subangular grains with point contacts. The grains are poorly sorted. Most quartz exhibits instant extinction but some show wave extinction. Aggregates of quartz are composed of polycrystallized micro-quartz and are probably derived from a metamorphic source. The higher feldspar content is sericitized along twin plane and clevage plane by weathering and hydrothermal alteration. Due to their finer nature, these sediments contain a smaller number of rock fragments. Patch forming calcite is probably a replacement or pore filling of existing feldspar. This lithology most closely resembles the feldspathic graywacke of Pettijohn (1975) and the arkose of McBride (1963) and Folk (1968) (Table 1, Plate 1.3).

Black Shale: The black shale has alternating light and dark laminations. Clay particles are clearly oriented along the plane of lamination, a phenomenon of post depositional origin. The comparatively small amounts of quartz and feldspar have angular clay minerals as well as oval or spherical patches of calcite that have filled voids or replaced pre-existing minerals. Results from X-ray diffraction on a sample from columnar section 3 indicate that the black shale contains 23% quartz, 4% calcite, and 73% clay mineral, which is composed of 38% illite and 35% smectite (Table 2).

The smectite is of volcanic origin and the illite is derived from smectite by weathering during burial and diagenesis. But the relatively higher contents of smectite in the black shale is exceptional, which imply a special diagenetic condition of the shale. The oval or spherical concretions within the black shale are arranged as waveforms along the bedding planes and also cut bedding planes irregularly. Thus, the

Table 1. The composition of sandstones in the study area.

Sandstone type	Quartz			Feldspars		Chert	Rock Fragments			Matrix	Carbo-nate
	Undul-atory	Non-undul-atory	Poly-cryst alline	K-feld-spar	Pla-gio-clase		Vol.	Met.	Sed.		
Medium grained sandstone	2.27	0.55	0.91	11.82	13.63	6.45	16.09	8.18	34.73	5.36	-
Fine grained sandstone	0.80	6.40	1.50	11.40	10.80	5.50	24.30	2.00	14.30	23.00	-
Fine to very fine grained sandstone	4.90	7.60	4.00	24.50	25.00	2.00	0.00	0.00	3.50	15.60	12.90

Table 2. X-ray diffraction data of shale specimens

Sediment	Pattern fit %	Mass absorption coefficient	Weight %
quartz	20	36.6	23
calcite	7	74.5	4
illite	40	44.4	38
i/s smectite	33	38.9	35

Table 3. Chemical composition of shale as weight %

Sample Number	*	1	2	3	4	5
SiO_2	58.10	67.56	67.15	65.29	66.81	64.86
Al_2O_3	15.40	15.08	13.81	13.64	12.94	8.22
Fe_2O_3	4.02	4.38	3.92	4.49	3.51	3.52
MgO	2.44	1.88	2.16	2.33	1.49	1.27
CaO	3.11	5.12	6.88	10.24	9.75	18.01
Na_2O	1.30	0.74	1.11	1.12	0.73	0.62
K_2O	3.24	3.42	3.55	2.77	4.23	2.01
OC	0.80	1.04	1.51	1.75	1.81	0.93
OM	2.20	2.39	3.29	3.72	2.08	2.33

* average for shale from Pettijohn(1975)
OC=organic carbon; OM=organic matter

concretions appear to fill pores or replace pre-existing minerals and organic matter selectively. The presence of calcite concretions agrees well with the results of chemical analysis, which found 18.01% CaO and 2.33% organic matter.

Tuff: Acidic tuff occurs at the base of the Hampyeong Formation, where it is underlain unconformably by basement rocks and overlain unconformably by alternating layers of black shale and dark grey sandstone. Intermediate tuff occurs in the upper part of the Hampyeong Formation (Table 4), where it is underlain unconformably by red beds and conglomerate. Both tuff layers comprise predominantly volcanic ash. The intermediate tuff has a very compact texture. Small grains of clastic quartz and feldspar were observed and weak laminations have developed.

Conglomerate: The conglomerate comprises rounded to subrounded cobbles and pebbles in a tuffaceous matrix. The cobbles and pebbles, mainly ranging 4 to 12cm in size, are composed mainly of granite gneiss, quartzite, shale, sandstone, andesite, rhyolite, chert, and quartz.

MINERALOGY AND GEOCHEMISTRY OF BLACK SHALE

The black shale contains a wide range of minerals including quartz, feldspar, zeolites (usually present as an alteration product of volcanic glass), and clay minerals such as kaolinite, smectite, illite, muscovite, chlorite, as well as other constituents including carbonates, oxides, hydroxides, and organic material. The relative proportions of the major constituents are 23% quartz, 73% clay minerals, and 4% organics (Table 2). The breakdown for clay minerals is 38% illite and 35% smectite.

The chemical composition of the shale was measured for a range of oxides and organic matter (Table 3). The contribution of most measured inorganics falls within the normal range for sandstones (Pettijohn, 1975). The SiO_2 content is significantly higher than the average for shales and it corresponds to levels found in graywacke sandstone. The high CaO content of columnar section 3 is probably related to the presence of calcite concretions. The organic carbon content responsible for the dark colour of the shale is typical of that in black shales elsewhere. For the Hampyeong Basin, organic carbon ranges from 0.81 to 1.75%. Total organic matter ranges from 2.08 to 3.72%; the highest values were observed in outcrops 2 and 3.

PALAEOBOTANY

Fossil plants are most abundant in the black shales and the dark sandstones. But they are fossil fragments in most cases for poor preservation. Identifiable plant fossils are not going beyond two forms at most. Most

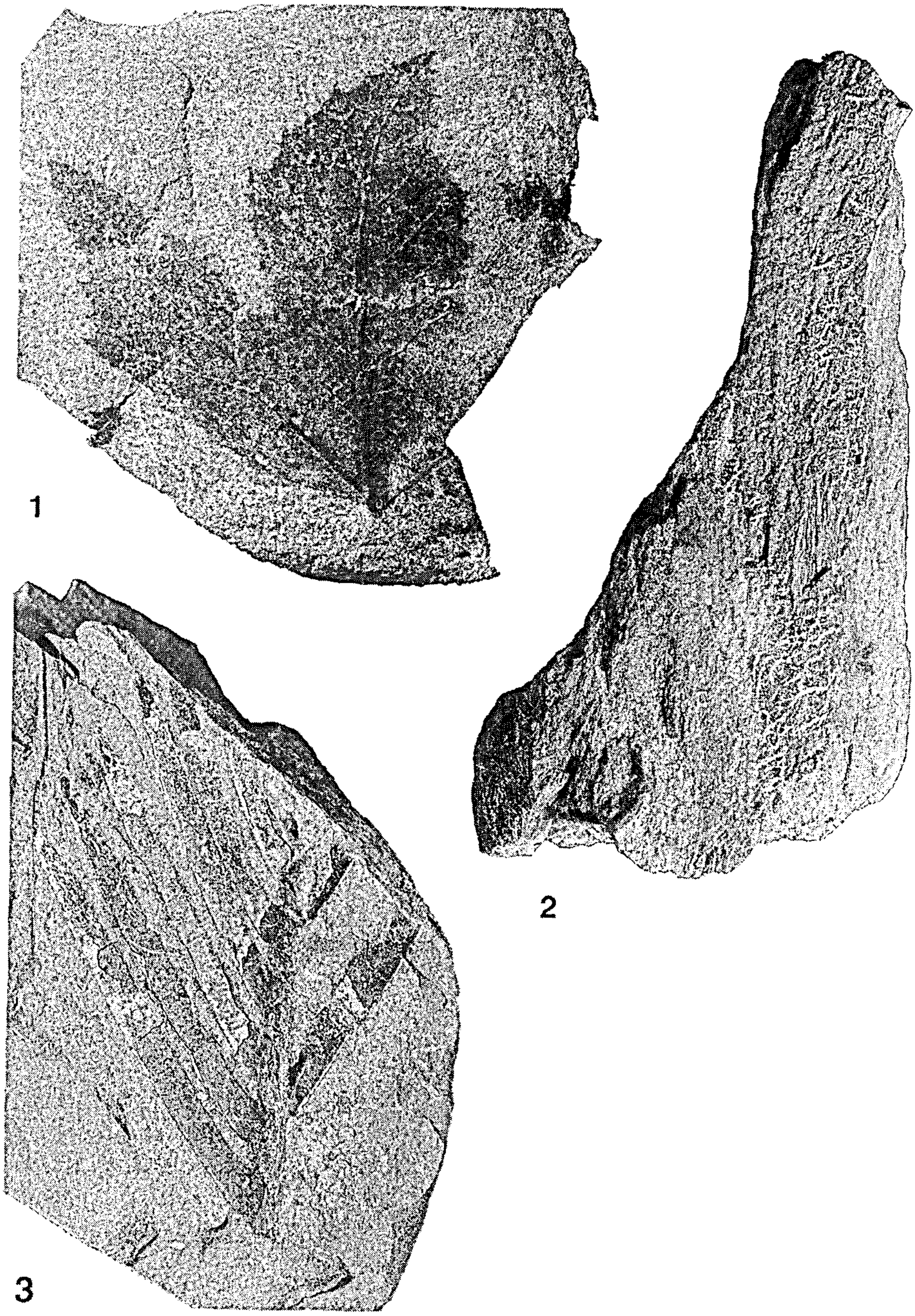

Plate 2. 1. *Platanus(?) aceroides* Göppert, Incomplete leaf fragment from black shale, Contrast enhanced with cross-polarized filters, CHU-HH0003. X1.0; 2. Petrified wood, CHU-HH0002, X0.8; 3. *Ptilophyllum* Morris, Incomplete leaf fragments from gray sandstone, CHU-HH0001, X1.4

fossils are compressions of leaves, but fragments of permineralized wood occur in the sandstones. Some wood fragments are sizeable trunks or branches (Plate 2, Fig. 2), but none has yet yielded good anatomical information.

SYSTEMATIC DESCRIPTION

Bennettitales

Ptilophyllum Morris

Ptilophyllum sp.

Specimen: CHU- HH0001 (Plate 2, Fig. 3)

Description: Pinnate leaf fragment (6.3cm long) is incomplete at distal and proximal ends. Rachis is 4mm width at base. Pinnae alternate, attached to upper surface of rachis, borne half leaf width apart, set at angle of $\sim$30 to rachis. Basiscopic junction is decurrent; acroscopic junction is slightly contracted. Pinnae is narrow, elongate, parallel sided (3.5mm wide; at least 42 mm long), with acute to sub-acute apex. Venation is indeterminable.

Occurrence: Specimen collected from black shale at Outcrop No. 1

Remarks: Tateiwa(1929) reported 2 species of *Ptilophyllum* from the Cretaceous Jinju Formation, the Nagdong Series. The taxa was also reported from the Sansudong Formation, the Jinan Series by Shimamura (1926). It is implied that the present formation is correlated with the Gyeongsang Supergroup.

Specimen: CHU-HH0003

Platanus (?) *aceroides* Göppert (Plate 2, Fig. 1)

Description: Large palmately trilobate leaf (incomplete) (7.3cm long; ca 10cm wide). Dentate: teeth large, acute. Prominent main veins are in each lobe; lateral veins are more or less equally spaced and parallel.

Occurrence: Specimen collected from black shale at Outcrop No. 3

Remarks: *Platanus* was reportd as a questionable specimen from the Jinan Series (Shimamura, 1926) and P. heeri from the Gubongsan group, Hwasun (Ichimura, 1927).

DISCUSSION AND CONCLUSIONS

Depositional Environment

Our interpretation of the depositional environment of the Hampyeong Basin is based on the structural geology, and on new evidence on the geochemistry of the sediments, lithology, and plant fossils. These data are supplemented by field observations on the bounding contact, position, and geometry of the basin. Results are consistent with a small but tectonically active basin comprising predominantly nonmarine sediments. Four distinctive lithological types have been identified (acidic tuff, black shales/sandstones, red beds, intermediate tuff with tuffaceous conglomerate) and these reflect periods of significant environmental change within the basin and its neighbouring terrains.

The sedimentary sequences identified in the Hampyeong Basin compare well with sequences in the neighbouring Haenam Basin (Table 4). The stratigraphy of the Haenam Basin has been studied and characterised in greater detail (Kinosaki, 1929; Lee and Lee, 1976; Son *et al.*, 1980; Park, 1984; Chough and Chun, 1987; Chun, 1987, 1989; Chun and Chough, 1995). Here the sequence of the Haenam Group has been subdivided into 3 formations: the Jindo Rhyolite (volcanic complex), the Hwangsan Tuff (tuff), and the Uhangri Formation (black shale, grey sandstone, cherty sandstone) in descending order. These formations have been correlated with the Yucheon Group of the Gyeongsang Basin, which is of Upper Cretaceous age (Lee and Lee, 1976; Kim *et al.*, 1998).

Table 4. Correlation of stratigraphic sequences

Haenam Basin (Lee and Lee, 1976)			Hampyeong Basin (the present study)	
Haenam Group	Jindo Tuff		andesite, rhyolite	
	Hwangsan Tuff		andesitic tuff	
	Uhangri Formation	tuffaceous sandstone cherty sandstone black shale sandstone tuff	Hampyeong Formation	tuffaceous conglomerate red bed chert sandstone black shale(fossil plants) sandstone(fossil plants) acidic tuff

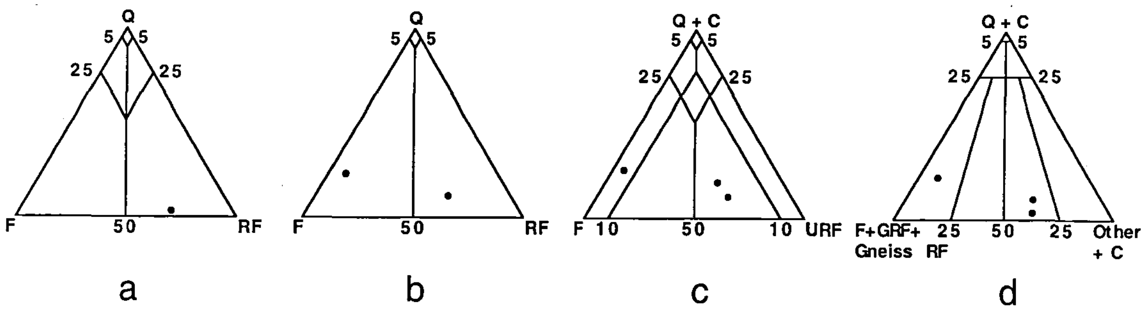

Fig. 4. Triangular diagrams showing the classification of sandstones.
(a, Pettijohn, 1975, matrix<15%; b, Pettijohn, 1975, matrix>15%; c, McBride, 1963; d, Folk, 1968)

Volcanism

The widespread occurrence of acidic tuff, intermediate tuff, andesite, and rhyolite is indicative of volcanism. Much of the sediment within the basin is derived from local volcanic terrains and is probably of intraformational origin. Sediments of volcanic origin occur throughout the sequence but are most well developed in the lowermost and uppermost parts. Grain size characteristics are consistent with volcanic ash transport in small rivers. The well-developed and thick tuffaceous conglomerate indicates at least one period of much higher energy transport. The volcanic sequences of the Hampyeong Basin are very similar to those of other smaller basins (Kongju, Choi *et al.*, 1997; Eumseong, Chun *et al.*, 1994; Haenam, Chun and Chough, 1995) and to the Neungju Formation of the Yucheon Group. These sediments are a product of volcanism. Volcanic activity appears to have been most active during the Cretaceous Period and at the closure phase of basin formation (Lee and Lee, 1976; Choi *et al.*, 1997).

Anoxia

Black shales and dark grey sandstones are widespread in the Hampyeong Basin where they are interrupted by a thick sequence of red beds with intercalated gravel bearing sandstones and shales. This sedimentary sequence is indicative of two major periods of deposition under anoxic conditions (black shales) separated by an extended period of deposition in an oxidising environment. Plant fossils are common in the black shales and sandstones but are rare or absent in the red beds. The black shales and sandstones are intercalated with the acidic tuffs. Here, the presence of cherts and evidence from wave forms indicates a low energy environment. We suggest that this depositional environment is associated with a nonmarine (possibly lacustrine) deposit.

Age of plant-bearing sediments

Only a handful of fossil plants have yet been collected from the black shales and sandstones of the Hampyeong Basin. Here we document the presence of cycadophyte leaves, which are known to be widespread in other Cretaceous sediments of South Korea (Kenrick *et al.*, 2000; Oishi, 1940) and neighbouring areas (Kimura *et al.*, 1992; Kimura and Ohana, 1997; Ohana and Kimura, 1995; Son *et al.*, 1995). The fossil plants of the Hampyeong Basin differ significantly in one respect to those of the Kohung Basin. In the Hampyeong Basin we have documented unequivocally the presence of angiosperm leaves. Angiosperms have not yet been recorded from the Kohung Basin (Kenrick *et al.*, 2000). However, angiosperms reported from Jinan and Hwasun areas (Shimamura, 1926; Ichimura, 1927). The presence of leaves of Platanaceae places these sediments within the angiosperm series of Oishi (1940). From these results, the Hampyeong Formation corresponds to the

Hayang or Yuchon groups of the Gyeongsang Basin.

Petroleum Source

The potential of the black shales and sandstones as sources for petroleum was investigated by analysing total organic carbon. The minimum amount of organic carbon necessary for the generation of significant amounts of hydrocarbon is in the region of 0.5%, known source shales average about 1.0%. Measurements from black shales in the Hampyeong Basin show this average value in the range of 0.81% to 1.75% organic carbon. In the neighbouring Haenam Basin, similar values for organic carbon were obtained from the black shales, but a material with grease-like properties, composed of microscopic spherical grains in an oily matrix, was observed in these sequences (Lee and Lee, 1976). We cannot therefore rule out the black shales as a possible petroleum source.

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