Detrital Zircon U-Pb Geochronology and Petrography Analysis of the Haenam Basin

Lujia Pan

Department of Energy and Resources Engineering, Chosun University, Gwangju, 61452, South Korea

Abstract: *The detrital zircons of the Cretaceous Haenam basin were examined to determine how they responded to the subduction of the oceanic plate to the eastern Asian continental margin during the Cretaceous. A sinistral strike-slip movement caused by the oblique subduction of the Paleo-Pacific plate created these two nonmarine subbasins in the northern marginal Okcheon Belt of the Korean Peninsula. In the late Cretaceous, due to the orthogonal subduction of the oceanic plate, sediments were deposited in terrestrial environments with associated volcanism. A total of 247 ages obtained from 300 zircon grains reveal that the maximum depositional ages of the Haenam basin is ca. 79.5 0.17 Ma, respectively. The detrital zircon age spectra indicate that their basin fills were mainly derived from the adjacent basement rocks comprising Paleoproterozoic metamorphic rocks and Jurassic granitoids with a minor supply from the Paleozoic metasedimentary rocks in the western Gyeonggi Massif and Okcheon Metamorphic Belt.*

Keywords: *LA-MC-ICPMS, Haenam Basin, detrital zircon age, U-Pb dating, Cretaceous*

1. Introduction

The evolution of the Cretaceous basins in the East Asian continental margin is known as a response to the paleo-Pacific plate subduction beneath the Eurasian continent, on account of crustal deformation (Daebo event) under contractional setting and dextral ductile shearing due to orthogonal (northwestward) subduction of the Izanagi Plate began to subduct northward, caused the formation of the Haenam basin occurred with associated volcanism in retroarc setting [1-3]. The development of Haenam basin was well studied by various studies [1, 4-13], while their closings in the late Cretaceous time were not. The event is supposed to be caused by tectonic event.

Even though detrital zircons are minor constituents in sedimentary rocks, their chemical resistance and high concentrations of trace elements make them an important component in studies of crustal evolution and sedimentary provenance [14-16]. As a result of LA-MC-ICPMS, we were able to estimate the deposition period of Haenam basins based on the U-Pb content in detrital zircons. As a result of zircon age data, we examined the deposition history and sedimentary provenance of sediments found in Haenam basins, as well as how volcanic activity led to the closure of sedimentary basins.

Detrital zircon grains have essentially stable U-Pb isotope systems, and they resist chemical and physical degradation. Sediment transport also survives detrital zircon grains [14]. As a result, zircon age populations can be used to reconstruct paleotectonic evolution from sedimentary rocks [16, 17]. In this paper, U-Pb age dating and petrographic analysis are used to determine the provenance of rocks from Haenam basin.

2. Geological setting

Haenam basin (including Jindo island), the basement rocks are Precambrian gneiss and is intruded by massive and relatively undeformed Daebo Series granitoid and foliated Triassic plutons [9, 10]. They are unconformably overlain by Hwawon, Uhangri, Hwangsan tuff and Jindo tuff [9, 11, 12]. In the Hwawon Formation, fine-grained trachyandesite, basalt, and andesite lavas, and a red-brown siltstone are interlayered in an andesitic lappilli tuff sequence [8]. Weighted mean age through SHRIMP U-Pb dating of andesitic tuff from the Hwawon Formation shows 85.08 ± 0.79 Ma (n=14 of 16) [13]. In addition to black shale, laminated siltstones and mudstones, tuffaceous sandstone, chert and calcareous siltstone, the Uhangri Formation also contains minor intercalated volcanogens [9, 10]. Zircon grains from a tuff in the Uhangri Formation showed slightly variable ages range in 79.4~86.0 Ma (n=15) [13]. The formation

ISSN 2663-1563 Vol. 4, Issue 2: 53-59, DOI: 10.25236/AJAGE.2022.040209

locally contains plant fossils [11] as well as trace fossils of dinosaurs, pterosaurs, birds and arthropods [5], We interpret the arthropod trackway-bearing unit to have been deposited in a lake margin setting, and we infer that the lake waters at the time of the Haenam arthropod trackway-bearing unit were alkaline and saturated with dissolved silica from the nearby volcanoes (Chun and Chough, 1995). The Hwangsan tuff conformably overlies the Uhangri formation, the youngest age yielded a weighted mean age of 83.81 ± 0.82 Ma (20 of 21) through SHRIMP U-Pb dating [13]. The uppermost part of the Haenam Group, Jindo tuff and rhyolite, is found mostly along southern coastal areas. Most rhyolites exhibit flow and perlitic structures [11], $^{40}K/^{40}Ar$ of Jindo rhyolite from 72.5 Ma to 75.4 Ma [7].

3. Method

Three clastic sedimentary rocks from the Haenam basin were collected. Detrital zircon grains were collected from the samples by conventional heavy mineral separation. Zircon Cathodoluminescence (CL) images were obtained using an Analytical Scanning Electron Microscope (JSM-IT300) connected to a Delmic sparc system. The imaging condition was 0.5-30 kV voltage of electric field and 72 μA current of tungsten filament.

4. Results

4.1. Petrographic analysis

4.1.1. HN-211201-2 (Andesitic lithic-crystal tuff)

The rock is mainly composed of a large amount of crystal debris and some volcanic debris and cement (Figure 1).The crystal chips are mainly plagioclase (varying degrees of sericitization, a small number of carbonation, most of the particles remain in tabular form, which is phenocrysts from magmatic origin, and polysynthetic twins can be seen), with some altered dark minerals (complete serpentinization, partial sliding and precipitation of iron along the edge or cleavage), The particle size is less than 1.9mm, accounting for 75% of the total. The cuttings are andesitic cuttings (composed of microcrystalline plagioclase and a small amount of plagioclase phenocryst, with interwoven structure) and felsitic cuttings (composed of felsitic felsic, clay minerals and a small amount of plagioclase phenocryst, with felsitic texture faintly visible), subangular, particle size ≤ 1.8mm, accounting for 10% of the total. It is cemented by cryptocrystalline glassy (most of which have been devitrified and recrystallized as cryptocrystalline clay minerals), accounting for 15%. The sharp edges and corners of crystals and rock fragments show that they have experienced a very short transportation distance.

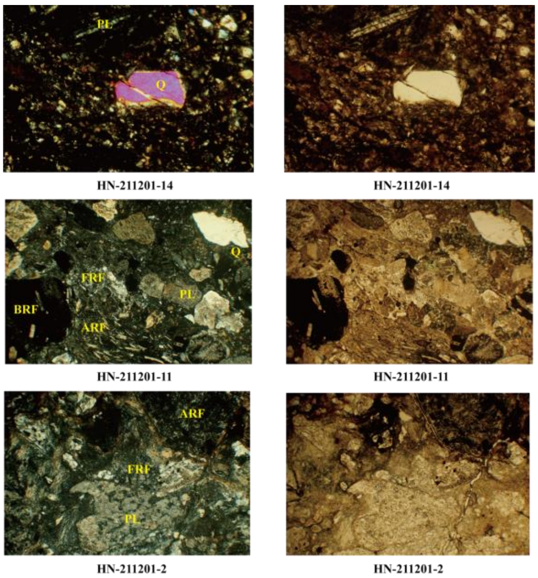

Figure 1: Thin-section microphotographs in plane-polarized light of sedimentary rock from Haenam Basin (crossed [left] and open [right] nicols). Q, quartz; PL, plagioclase; FRF, felsic rock fragments; BRF, basaltic rock fragments; VRF, volcanic fragments.

ISSN 2663-1563 Vol. 4, Issue 2: 53-59, DOI: 10.25236/AJAGE.2022.040209

4.1.2. HN-211201-11 (Basaltic andesitic volcanic breccia-lithic-crystal tuff)

The rock is mainly composed of volcanic debris, crystal debris, volcanic breccia and a small amount of cement (Figure 1). The cuttings are mainly andesitic cuttings (composed of microcrystalline plagioclase and a small amount of plagioclase phenocryst, with interwoven structure) and part of felsitic cuttings (composed of felsitic felsic and a small amount of plagioclase phenocryst), It is composed of iron oxide, some microcrystalline plagioclase and plagioclase phenocryst, with glass matrix interlacing structure. The grain size is ≤ 1.8mm, accounting for 45% of the total. The crystal chips are mainly plagioclase (varying degrees of sericitization, turbidity on the surface, most of the particles remain plate-shaped, which are phenocrysts from magmatic origin, and polysynthetic twins can be seen), It contains a small part of quartz (visible erosion structure), subangular shape, particle size ≤ 1.8mm, accounting for 23%. The breccia is composed of andesite, felsitic, basaltic, granite, etc., which is subangular, with particle size ≤ 5.0 mm, accounting for 30% of the total. The above pyroclastic rocks are cemented by cryptocrystalline iron argillaceous, accounting for 2%. The sharp edges and corners of crystals and rock fragments show that they have experienced a very short transportation distance.

4.1.3. HN-211201-14 (Andesitic crystal pyroclast-cuttings tuff)

The rock is mainly composed of volcanic cuttings and part of crystal pyroclast and cement (Figure 1). The cuttings are mainly Andesitic cuttings (composed of microcrystalline plagioclase and some cryptocrystalline iron argillaceous and glassy, visible interweaving-glass-based interweaving structure, and most of the grain boundaries are fuzzy and weakly consolidated), with a small number of felsitic cuttings (composed of felsitic felsic and felsitic texture), and subangular, particle size ≤ 0.8 (a few up to 1.8) mm, accounting for 85%. Crystal pyroclastic is composed of plagioclase (some particles are sericitized to varying degrees, and polysynthetic twins can be seen; most of the particles remain in tabular form, which are phenocrysts from magmatic origin) and quartz (visible melting structure). They are subangular, with particle size ≤ 0.7mm, accounting for 10% of the total. The above pyroclastic rocks are cemented by cryptocrystalline iron argillaceous, accounting for 5%. The sharp edges and corners of crystals and rock fragments show that they have experienced a very short transportation distance.

4.2. Zircon U-Pb age dating

We analyzed 300 zircon grains from three samples and 247 analysis points in concordant age. Zircon grains in detrital materials have a transparent, translucent appearance and can be anhedral or euhedral. Angular and euhedral prismatic crystals have prevailed in Mesozoic zircon grains, while metamorphic overgrowth rim is dominant in Paleoproterozoic zircons (Figure 2).

The U-Pb age data are analyzed by LA-MC-ICPMS for the detrital zircons. Figure 3 illustrates Tera-Wasserburg diagrams of the U-Pb detrital zircon ages. A distribution of the age of the detrital zircons in the analyzed samples is shown in Figure 4.

Figure 2: Cathodoluminescence (CL) images of Haenam Basin zircon grains. CL imaging is used to measure zircon grains' internal textures and target coherent domains for laser analysis.

ISSN 2663-1563 Vol. 4, Issue 2: 53-59, DOI: 10.25236/AJAGE.2022.040209

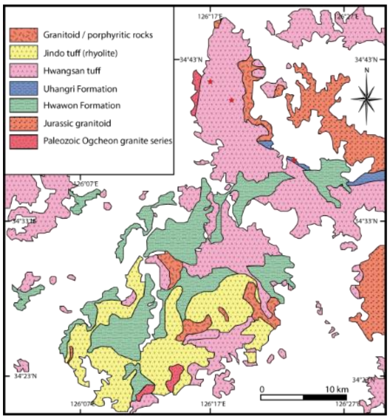

Figure 3: Geological map of Haenam basin modified after [1, 12]. The sampling points of the samples are identified by five pointed stars, which are HN-211201-14, HN-211201-11 and HN-211201-2 respectively from north to East.

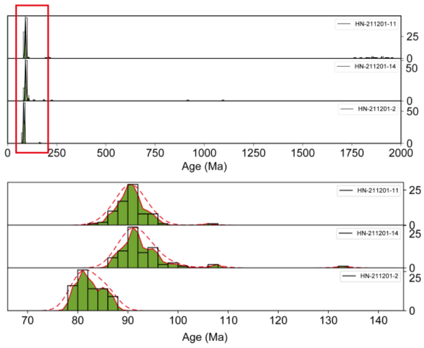

Figure 4: Relative distribution diagram of zircon ages in Haenam basin. The lower figure is the enlarged part of the upper figure, straight line represents probability density plot, dotted line represents kernel density estimate.

4.2.1. HN-211201-2

U-Pb dating of edge of grains belonging Uhangri formation showed range in 79.7 Ma to 87.1 Ma and concordant age in 82.77 ±0.44 Ma excepted one Jurassic grain. The particles of Jurassic age show deep color, broken cracks, multiple oscillatory bands and dark inclusions, and are characterized by metamorphic recrystallized zircon. Both Probability density plot and kernel density plot have the same peak point at 81 Ma.

4.2.2. HN-211201-11

U-Pb dating of edge of grains belonging Hwangsan tuff showed range in 83.6 Ma to 2073 Ma. Grains in cretaceous age ranged in 83.5 to 106 Ma and concordant age is 90.35 ±0.17 Ma (n=77), 2 grains are 197 Ma and 211 Ma corresponding in Jurassic and Triassic, Paleoproterozoic grains ranged 1769 Ma to 2073 Ma, concordant age in 1853.77 ±3.30 Ma (n=14). Both Probability density plot and kernel density plot have the same peak point at 91 Ma.

4.2.3. HN-211201-14

Zircon grains in Hwangsan tuff formation of HN-211201-14, U-Pb age dating of edge of grains yielded an age range of 87.3 Ma to 1095 Ma. cretaceous age ranged 87.3 Ma to 108 Ma, concordant age in 93.01 ±0.19 Ma (n=69). Two grains in Jurassic, one grain in Triassic and two grains in Proterozoic.

5. Discussion

Petrographic analysis reveals that the three samples share the same characteristics, namely quartz and anorthosite crystal debris. The anorthosite crystal debris has a tabular crystal structure, indicating that it came from a magmatic source. In addition to andesitic rock fragments, felsic rock fragments and basalt rock fragments are present in the sample. A felsic rock fragment consists of felsic, clay minerals, and plagioclase porphyry. The temperature and pressure of Mesozoic glassy volcanic rocks increased during burial, resulting in the precipitation of high-priced iron oxides. The original rock in the rock sample is intermediate to mafic extrusive volcanic rock, and it has been heavily compacted by sedimentary processes. Crystals and rock fragments exhibit sharp edges and corners which indicate that they have traveled a short distance.

In order to determine the provenance of clastic rocks, we must first constrain the timing of deposition based on the zircon chronology. Detrital zircons that originate from igneous sources are usually able to determine the maximum depositional age of sedimentary strata. The Cretaceous zircons found in the Haenam Basins all meet the criteria for igneous rocks [18]; We recommend using the age of the youngest group rather than the age of the youngest single grain to determine the maximum depositional age. As a result of a variety of factors, such as Pb loss as a result of alteration or metamorphism, zircons may deviate significantly from their original age [19].

Using three ad hoc metrics, the maximum deposition times of the Haenam Basin are constrained by the average age of the youngest age group of detrital zircons [20], finally, the maximum depositional age represented by the youngest cluster of 3 or more ages with overlapping 2σ (YC2σ (3+)) for Uhangri Formation of HN-211201-2 is 79.5 $\pm$ 0.17 Ma, for Hwangsan Formation of HN–211201-11 is 85.8 $\pm$ 0.2 Ma and HN-211201-14 is 87.6 $\pm$ 0.29 Ma (Figure 5). According to Ko, Kim [13], We can know that the sedimentary age of Hwawon Formation is about 85 Ma. In a word, the maximum sedimentary age is 79.5 $\pm$ 0.17 Ma in Campanian, the whole sedimentary process corresponds to Campanian to Santonian and accompanied by eruptive activity of volcano (Figure 6).

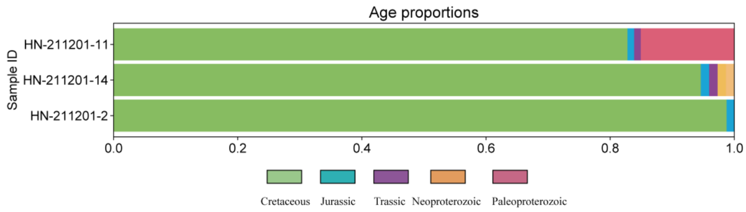

Figure 5: Age proportions of Haenam Basin in bar graph.

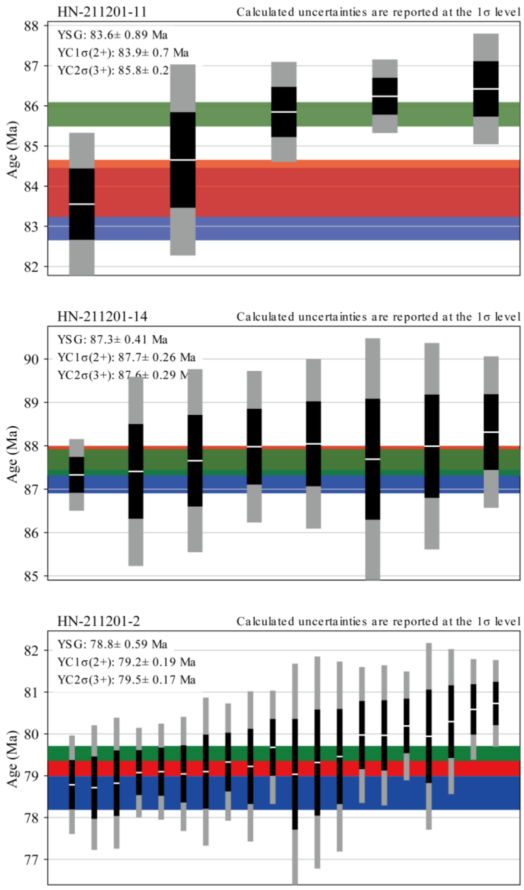

Figure 6: Maximum depositional age (MDA) calculations for the Haenam Basin.

ISSN 2663-1563 Vol. 4, Issue 2: 53-59, DOI: 10.25236/AJAGE.2022.040209

Based on the zircon age spectrum distribution and age composition, as well as previous studies, we are able to conclude that the two sedimentary formations contain a large number of Cretaceous age particles, and a small amount of Jurassic age particles, whereas the Paleozoic age particles do not appear to have any impact on Okcheon intrusive activity. In contrast to other formations, the Hwangsan formation contains a mixture of Triassic and Proterozoic sediment, indicating that there has been an exogenous sediment supply during the final closure phase of the basin. According to Kim, Kwon [21],this age combination is most similar to the central to western Yeongnam massif, where the Proterozoic rocks were replaced by Triassic rocks, which suggests that its provenance originates from the east. The Uhangri formation and the Hwawon formation do not have an old age, but the maximum deposition age of the Uhangri formation is earlier than the Hwawon formation. Observations from field outcrops indicate that a thrust nappe structure exists at the sampling site, resulting in the overturned succession of strata phenomenon. Paleontological fossils will be required to verify fault presence further.

According to Ko, Kim [13], it is possible to divide Cretaceous volcanic rocks into two groups, the first corresponding to syn-sedimentary volcanism in the Gyeongsang basin, and the second corresponding to regional volcanism and minor sedimentation on the southern Korean Peninsula, the peak of activity being between 97 and 85 Ma. Our study indicates that volcanic activity and sedimentation took place earlier, dating back as early as 79.5 Ma.

6. Conclusion

(1) The maximum depositional age for the Haenam basin is 79.5 ± 0.17 Ma in Campanian, which is earlier than previous studies.

(2) According to the detrital zircon age spectrum of the three formations and field outcrop observation, overturned succession of strata between Uhangri formation and Hwangsan formation due to thrust nappe, resulting in the old formation being placed above the new formation. More paleontological analysis evidence is needed in the future.

(3) According to the age proportions and distributions of detrital zircons, the sediment source of the basin mainly comes from the nearby syn-sedimentary volcanic eruption in the early stage of sedimentation, and mainly comes from the eastward flow transportation of the basin in the late stage, that is, from the western to the central of Yeongnam Massif.

References

[1] Chough, S., Tectonic and sedimentary evolution of the Korean peninsula: a review and new view. Earth-Science Reviews, 2000. 52(1-3): p. 175-235.
[2] Lee, D.W., Strike–slip fault tectonics and basin formation during the Cretaceous in the Korean Peninsula. Island Arc, 2002. 8(2): p. 218-231.
[3] Chough, S. and Y. Sohn, Tectonic and sedimentary evolution of a Cretaceous continental arc–backarc system in the Korean peninsula: new view. Earth-Science Reviews, 2010. 101(3-4): p. 225-249.
[4] Park, K., Late Cretaceous volcanic mega-breccia in the Haenam area of South West Korea. KIGAM Bull., 1997. 1: p. 1-13.
[5] Hwang, K.-G., et al., New pterosaur tracks (Pteraichnidae) from the Late Cretaceous Uhangri formation, southwestern Korea. Geological Magazine, 2002. 139(4): p. 421-435.
[6] Moon, H.-S., et al., K-Ar ages of alunite and sericite in altered rocks, and volcanic rocks around the Haenam area, southwest Korea. Economic and Environmental Geology, 1990. 23(2): p. 135-141.
[7] Kim, I.J. and K. Nagao, K-Ar ages of the hydrothermal clay deposits and the surrounding igneous rocks in southwest Korea. The Journal of the Petrological Society of Korea, 1992. 1(1): p. 58-70.
[8] Bowden, C.D., Epithermal systems of the Seongsan district, South Korea an investigation on the geological setting and spatial and temporal relationships between high and low sulfidation systems. 2007, James Cook University.
[9] Koh, Geochemical characteristics of the cretaceous volcanic rocks and Bukok hydrothermal deposits in the Haenam volcanic field, Chollanamdo, Korea. 1996, Seoul National University Graduate School.
[10] Kim, I., Geochemistry of hydrothermal alteration and clay deposits in the Haenam area, southwest Korea. Ph. D. Thesis, Univ. Tokyo, 1991: p. 169-219.
[11] Chun, S.S. and S.K. Chough, The Cretaceous Uhangri Formation, SW Korea: lacustrine margin facies. Sedimentology, 1995. 42(2): p. 293-322.
[12] Yang, S.-J., P. Duuring, and Y.-S. Kim, Structural genesis of the Eunsan and Moisan low-

ISSN 2663-1563 Vol. 4, Issue 2: 53-59, DOI: 10.25236/AJAGE.2022.040209

sulphidation epithermal Au–Ag deposits, Seongsan district, Southwest Korea. Mineralium Deposita, 2012. 48(4): p. 467-483.
[13] Ko, K., S. Kim, and Y. Gihm, U-Pb Age Dating and Geochemistry of Soft-Sediment Deformation Structure-Bearing Late Cretaceous Volcano-Sedimentary Basins in the SW Korean Peninsula and Their Tectonic Implications. Minerals, 2021. 11(5).
[14] Bruguier, O., J. Lancelot, and J. Malavieille, U–Pb dating on single detrital zircon grains from the Triassic Songpan–Ganze flysch (Central China): provenance and tectonic correlations. Earth and Planetary Science Letters, 1997. 152(1-4): p. 217-231.
[15] Leier, A.L., et al., Detrital zircon geochronology of Carboniferous–Cretaceous strata in the Lhasa terrane, Southern Tibet. Basin Research, 2007. 19(3): p. 361-378.
[16] Leier, A.L., et al., Detrital zircon geochronology of Carboniferous?Cretaceous strata in the Lhasa terrane, Southern Tibet. Basin Research, 2007. 19(3): p. 361-378.
[17] Ross, G.M., R.R. Parrish, and D. Winston, Provenance and U-Pb geochronology of the Mesoproterozoic Belt Supergroup (northwestern United States): Implications for age of deposition and pre-Panthalassa plate reconstructions. Earth and Planetary Science Letters, 1992. 113(1-2): p. 57-76.
[18] Vavra, G., R. Schmid, and D. Gebauer, Internal morphology, habit and U-Th-Pb microanalysis of amphibolite-to-granulite facies zircons: geochronology of the Ivrea Zone (Southern Alps). Contributions to Mineralogy and Petrology, 1999. 134(4): p. 380-404.
[19] Kröner, A., P. Jaeckel, and I. Williams, Pb-loss patterns in zircons from a high-grade metamorphic terrain as revealed by different dating methods: UPb and PbPb ages for igneous and metamorphic zircons from northern Sri Lanka. Precambrian Research, 1994. 66(1-4): p. 151-181.
[20] Dickinson, W.R. and G.E. Gehrels, Use of U–Pb ages of detrital zircons to infer maximum depositional ages of strata: A test against a Colorado Plateau Mesozoic database. Earth and Planetary Science Letters, 2009. 288(1-2): p. 115-125.
[21] Kim, S.W., et al., Arc magmatism in the Yeongnam massif, Korean Peninsula: Imprints of Columbia and Rodinia supercontinents. Gondwana Research, 2014. 26(3-4): p. 1009-1027.