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2019년 2월  
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# 한반도 서남부에 분포하는 백악기 능주분지의 기원지

조선대학교 대학원

에너지자원공학과

권민규

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Provenance of the Cretaceous Neungju Basin, southwestern  
Korea

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## ABSTRACT

### Provenance of the Cretaceous Neungju Basin, southwestern Korea

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The Neungju Basin is a Cretaceous nonmarine basin located in the southwestern Korean Peninsula. Basinfill of the Neungju Basin consists mainly of conglomerate, sandstone, siltstone, and tuff. The strata of the Neungju Group consist of Oyeri Fm., Manweolsan Tuff, Jangdong Fm., Yeonhwari Fm., Yeonsan Fm., Jeokbyeok Tuff, and Ongam Conglomerate up sequence. The Jangdong Tuff, one of the strata comprising the Neungju Group, bears dinosaur tracks and its depositional environment is interpreted to be a lake margin. However, sedimentological characteristics of the whole Neungju Basin have not been studied yet. Thus, we carried out petrography and detrital zircon geochronology analyses on the Neungju Basin sedimentary rocks to constrain their depositional periods and provenance.

Petrographic analysis on the Neungju Basin sediments reveals that the sandstones and matrices of the conglomerate are comprised mainly by angular grains of quartz, feldspar, and metasedimentary and volcanic rock fragments. The conglomerates are generally matrix-supported and contain angular clasts such as quartzite, schist, granite, and tuff. The amount of rock fragments increase up sequence.

Zircon grains in tuffs in the Neungju Basin show ages of 96-88 Ma and indicate depositional period of the basin. Conglomerates and sandstones mainly contain detrital



zircons of Jurassic (187 Ma) and Paleoproterozoic age (1853 Ma), but no Cretaceous zircons. Oyeri and Yeonsan Fm., located in the northernmost part of the basin contain Jurassic (187 Ma) and Paleoproterozoic zircon grains (1854 Ma). Jeokbyeok Tuff and Ongam Conglomerate, located in eastern of the basin contain only detrital zircons of Paleoproterozoic (1848~2476 Ma). Jandong Fm., located in southwestern of the basin mainly contains Jurassic zircons (187 Ma).

Deposition of the Neungju Basin was begun at about 96~94 Ma, earlier than the eruption time of the Mudeungsan Tuff (86~84 Ma) covered the Neungju Basin sediments except for the Ongam Conglomerate. Sediments comprising clastic rocks of the Neungju Basin were mainly supplied from nearby basement rocks such as Jurassic granite, Paleozoic metasediments, and Paleoproterozoic gneiss. Considering that the clastic sedimentary rocks do not contain Cretaceous zircons, the pyroclastic material was supplied intermittently from the southwest of the basin during the deposition of the Basin.

## 제1장 서론

능주분지는 광주광역시외의 무등산 동측에 북동-남서 방향으로 옥천습곡대의 동측 연변부를 따라 신장된 방추형으로 발달한 퇴적분지이며, 전남지방의 백악기 소분지 중 가장 분포 면적이 넓다. 능주분지의 기반암으로는 선캠브리아기의 변성암류와 소규모의 탄층을 협재한 상부 고생대 퇴적암류가 분포하며, 중생대 화강암류에 의해 관입되어 있다(Kim and Park, 1966). 일반적으로 능주분지의 지질시대는 응회암과 응회질퇴적층의 흔한 협재와 많은 공룡발자국 화석을 바탕으로 경상분지의 하양층군 상부에서 유천층군의 퇴적시기인 백악기 후기에 대비되는 것으로 해석된다(Paik et al., 2007). 또한 최근의 연구(Kim and Kang, 2012)에서는 K-Ar 절대연령 측정을 통해 능주분지의 퇴적층 중 장동층의 퇴적시기 및 공룡활동시기를 70-65 Ma로 보고하였다.

능주 분지를 충전한 지층들은 주로 전남 화순군 및 담양군 일대에 노출되어 있는데 이는 동북도폭과 창평도폭에서 설명된다. 동북도폭(Kim and Park, 1966)에서는 최하부 오예리층을 시작으로 하여 만월산 응회암층, 장동응회암(장동층), 적벽응회암에서 상위에 부정합으로 피복하는 무등산 용암으로 이어지는 것으로 나타나 있고, 창평도폭(Son and Kim, 1966)에서는 오예리층, 만월산 응회암, 장동층, 연화리층, 연산층으로 이어지는 것으로 나타나 있다.

능주분지에는 역암, 사암, 셰일, 응회암 등 다양한 암상과 퇴적구조들이 나타나고, 특히 화순군 북면에 분포하는 장동층에서는 공룡발자국 화석, 익룡 발자국 화석 등 주요 자연사 기록들이 보고된 바가 있다(Huh et al., 2006; Paik et al., 2007; Kim et al., 2012). 또한 적벽응회암은 동북호를 따라 노두가 드러나 있어 뛰어난 경관을 자랑하고 있다.

하지만 이러한 지질학적 중요성에 비하여 능주분지의 형성 및 발달사에 대한 정보는 거의 알려져 있지 않았으며, 층서에 대한 문제점도 야기되고 있는 실정이다. 따라서 이 연구에서 능주분지 각 층 별로 산출하는 역암, 사암 및 응회암에 대하여 저어콘 연령 측정을 이용하여 능주분지의 퇴적시기를 제한하고 기원지를 규명하여 능주분지의 발달에 대한 정보를 제공하고자 한다.

## 제2장 지질학적 배경

능주 분지는 중생대 백악기 소분지 중 하나로 화순 일대와 담양, 곡성, 보성 일대에 분포하고 있는 전라남도 일대의 가장 큰 백악기 퇴적분지이다(Figure 2-1). 북동-남서 방향으로 발달한 능주 분지는 옥천 변성대 동쪽 연변부를 따라 신장된 방추형으로 분포한다. 연구지역은 경상누층군의 유천층군에 대비되며(Paik et al., 2007), 동북 도폭(Kim and Park, 1966)과 창평 도폭(Son and Kim, 1966)에 의한 대략적인 층서(Table 2-1)와 기반암에 대한 설명은 다음과 같다

능주분지를 둘러싸고 있는 기반암은 동쪽은 주로 선캠브리아기 메타텍틱 편마암, 화강암질 편마암, 고생대 퇴적암이 주로 분포하고 있고, 북쪽과 서쪽에는 선캠브리아기 화강암질 편마암, 쥐라기 화강암이 주를 이루며 분포하고 있다.

능주 분지의 층서는 최하부의 오예리층부터 만월산응회암, 장동층(장동응회암), 연화리층, 연산층, 적벽응회암, 무등산용암, 웅암역암 순으로 되어있다.

오예리층은 능주 분지의 최하부 층으로 하부의 역암, 사암, 셰일 등으로 된 부분(40m)과 상부의 응회암으로 된 부분(350m)으로 양분되어 있고 최상부에 자색사질셰일이 발달하기도 하며, 가끔 박층의 셰일이 협재되기도 한다.

만월산 응회암은 오예리층을 정합으로 피복하고 있고, 전체적으로 녹색 내지 녹회색 세립 응회암층(50m)으로 구성되어 있으며, 층의 상부에는 흑색 셰일층이 발달되어 있다. 흑색 셰일층은 남측으로 감에 따라서 점차로 얇아지는 경향을 보인다.

장동층은 만월산 응회암을 정합으로 피복하고 있고, 분지 전체적으로 분포하고 있으나 분지 남쪽에서는 고생대 함탄대에 의하여 동서로 양분된다. 북쪽에는 흑색 셰일, 회색 셰일, 세립질 사암 등(300m)이 우세하게 발달하지만, 남서쪽으로 갈수록 응회암층이 발달한다. 하부에는 10cm 내외의 역을 가지는 각력암층이 발달한다.

연화리층은 오예리층을 부정합으로 피복하고 연산층에 의하여 부정합으로 피복된다. 하부는 역암과 사암 및 사질 셰일로 구성(30m)되고 상부는 역질 사암과 이암, 응회암 등(20~60m)으로 구성되며 그 위로 100m정도의 이암이 있다. 역암의 기질은 자색이며, 역은 규암, 편암, 편마암, 화강암, 응회암 등으로 구성되며, 크기는 10cm 내외의 직경을 가지는 것이 보통이고, 20~30cm 가량 되는 것도 있다.

연산층은 약 80m의 두께를 가지며, 연화리층을 부정합으로 피복하고, 무등산용암에 의해 부정합으로 피복된다. 자색 역암과 사암, 이암 및 소량의 녹색 셰일로 구성되어 있으며, 하부는 역암이 있고 그 위에는 사암이 우세하다가 상부에 가서 다시 역암이 비교적 많아진다. 역은 주로 10cm 내외의 크기를 가지며 화강암, 편마암, 편암, 응회암으로 구성되어 있다.

적벽응회암은 적벽을 중심으로 분포하고 있으며, 하부는 주로 세립질 응회암이나, 상부로 갈수록 조립질 응회암으로 되어있다. 장동 응회암을 정합적으로 피복하고 있고 하부에 녹회색 내지 회색 세립사암 및 셰일이 기재되어 있으며, 이 부분은 연흔이 발달되어 있고, 간혹 건열이 발견되기도 한다.

용암역암은 모든 응회암층과 무등산 용암을 부정합으로 피복하고 있다. 역은 응회암, 분암, 화강암질 편마암, 변성 퇴적암류 등이며 거력에서 조립질에 이르는 분급이 좋지 않은 퇴적물이다. 두께는 200m 이상으로 이에 대비되는 퇴적상이 다른 곳에서는 보이지 않는다.

앞서 기술하였듯 능주분지에 대한 기존연구는 그리 많이 이루어지지 않았다. 화순군 북면 서유리 부근에 분포하는 장동층에는 공룡발자국 화석, 익룡 발자국 화석 등이 보고된 바가 있다(Huh et al., 2006; Paik et al., 2007; Kim et al., 2012). 장동층 중 공룡발자국이 산출하는 지역은 하천 및 호수 연변부로 해석된다 (Paik et al., 2007). Kim and Kang(2012)은 서유리 일대의 백악기 퇴적층에 산출하는 화산암력 및 해당 층을 덮는 화순안산암을 대상으로 전암을 이용한 K-Ar 절대연대측정을 통해 서유리 공룡발자국 화석산지인 장동층의 퇴적시기와 공룡활동시기에 대한 최대지질연대는 약 70 Ma이며, 이는 여수 사도지역에서 공룡 발자국 화석을 포함하는 중생대층의 퇴적시기(71-66 Ma)와 대비될 가능성을 시사하였다. 그러나 이 연구 이후에 장동층 보다 상위에 놓이는 무등산 응회암의 저어콘 U-Pb 연령이 88 Ma인 것으로 보고되었는데 (Huh et al., 2013), 이로 인해 능주분지의 퇴적시기에 대한 모순이 야기된다.

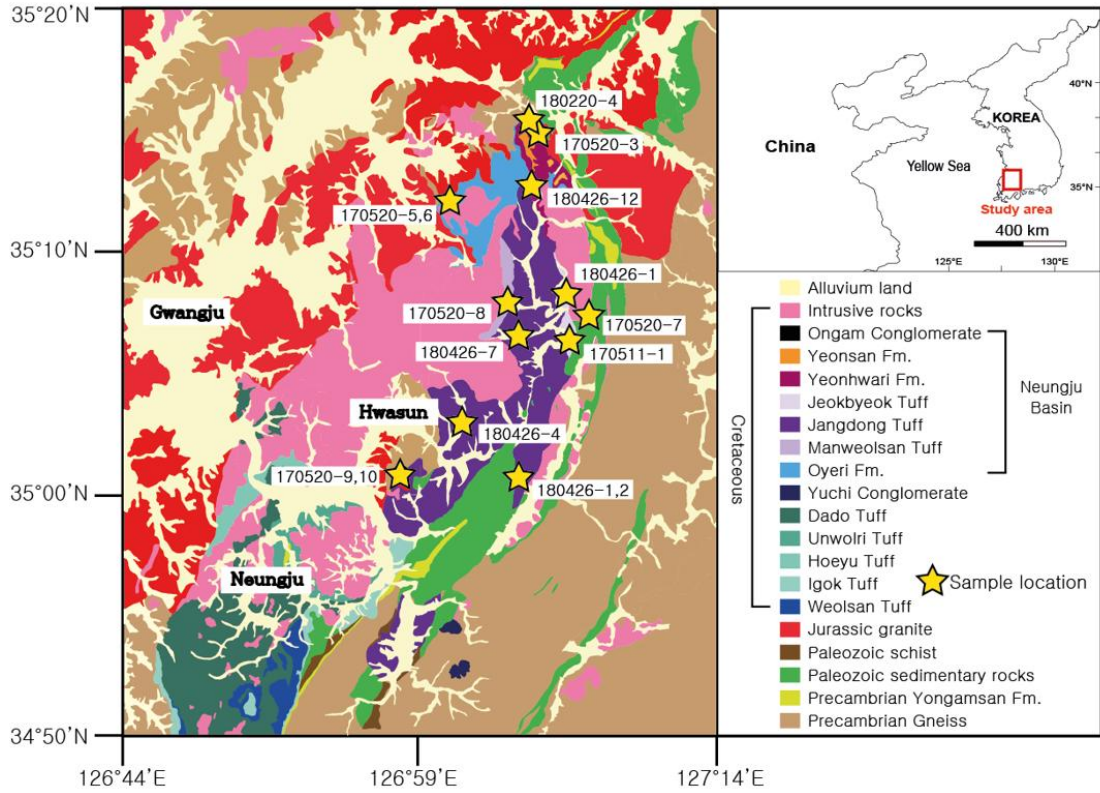


Figure 2-1. Geologic map of the Cretaceous Neungju Basin. Sample locations are marked with stars.

Table 2-1. Stratigraphy of the Neungju Basin.

| Geological time          | Changpyeong Sheet        | Dongbok Sheet            |
|--------------------------|--------------------------|--------------------------|
|                          | (Son and Kim, 1966)      | (Kim and Park, 1966)     |
| Quaternary               | Alluvial deposit         |                          |
| ~~~~~ Unconformity ~~~~~ |                          |                          |
| Cretaceous               | Intrusive rock           | Intrusive rock           |
|                          | Ongam Conglomerate       | Ongam Conglomerate       |
|                          | ~~~~~ Unconformity ~~~~~ | ~~~~~ Unconformity ~~~~~ |
|                          | Mudeungsan Lava          | Mudeungsan Lava          |
|                          | ~~~~~ Unconformity ~~~~~ | ~~~~~ Unconformity ~~~~~ |
|                          | Yeonsan Fm.              | Jeokbyeok Tuff           |
|                          | ~~~~~ Unconformity ~~~~~ |                          |
|                          | Yeonhwari Fm.            |                          |
|                          | ~~~~~ Unconformity ~~~~~ |                          |
|                          | Jangdong Fm.             | Jangdong Tuff            |
|                          | Manweolsan Tuff          | Manweolsan Tuff          |
| Oyeri Fm.                | Oyeri Fm.                |                          |

## 제3장 이론적 배경

### 제1절 U-Pb 연대 측정

방사성 동위원소 중 우라늄 계열은 여러 단계의 붕괴를 거쳐 안정한 납으로 변한다. U-Pb 연대 측정이란  $U^{238}$ ,  $U^{235}$ ,  $Th^{232}$ 과 같은 방사성 핵종이 붕괴하여 각각  $Pb^{206}$ ,  $Pb^{207}$ ,  $Pb^{208}$ 로 변하는 반응속도식  $Pb=U(e^{\lambda t} - 1)$ 에서 연대를 구하는 방법이다. 각각의 핵종에 대한 아이소크론은 아래와 같은 식으로 얻어진다.

$$Pb^{206} = U^{238}(e^{\lambda^{238}t} - 1)$$

$$Pb^{207} = U^{235}(e^{\lambda^{235}t} - 1)$$

$$Pb^{208} = U^{232}(e^{\lambda^{232}t} - 1)$$



$$Pb^{206} \text{ 측정치} = Pb^{206} \text{ 초생치} + U^{238}(e^{\lambda^{238}t} - 1)$$

$$Pb^{207} \text{ 측정치} = Pb^{207} \text{ 초생치} + U^{235}(e^{\lambda^{235}t} - 1)$$

$$Pb^{208} \text{ 측정치} = Pb^{208} \text{ 초생치} + U^{232}(e^{\lambda^{232}t} - 1)$$



$$(Pb^{206}/Pb^{204}) \text{ 측정치} = (Pb^{206}/Pb^{204}) \text{ 초생치} + (U^{238}/Pb^{204})(e^{\lambda^{238}t} - 1) \quad \rightarrow (1)$$

$$(Pb^{207}/Pb^{204}) \text{ 측정치} = (Pb^{207}/Pb^{204}) \text{ 초생치} + (U^{235}/Pb^{204})(e^{\lambda^{235}t} - 1) \quad \rightarrow (2)$$

$$(Pb^{208}/Pb^{204}) \text{ 측정치} = (Pb^{208}/Pb^{204}) \text{ 초생치} + (U^{232}/Pb^{204})(e^{\lambda^{232}t} - 1) \quad \rightarrow (3)$$



동일 기원의 암석인 경우 U-Pb 계는 위의 (1)식에서 (2)식을 나누므로 Pb와 Pb에 관한 수식으로만 표현되며, 이 식을 Pb-Pb법 또는 207-206 법이라 하며 납의 동위원소비 분석만으로 연령을 측정할 수 있다. 또한 자연계에서 납 유출입이 일어나지 않은 시료라면  $U^{238}-Pb^{206}$ ,  $U^{235}-Pb^{207}$ ,  $Th^{232}-Pb^{208}$ ,  $Pb^{207}-Pb^{206}$  법으로 얻은 연령들은 모두 일치하며 이를 일치연령(Concordant age)이라 한다. 변성작용이나 동화작용, 지각변동과 같은 지질학적 사건으로 인해 둘 이상의 측정연령이 일치하지 않을 때에는 불일치연령(Discordant age)이 얻어진다. 이러한 지질학적 사건에 의해 시료에서 납의 유실이 있는 경우에는 U-Pb, Th-Pb법의 연령은 참연령보다 짧게 얻어진다(김규한, 1991).

## 제2절 저어콘의 광물학적 특성

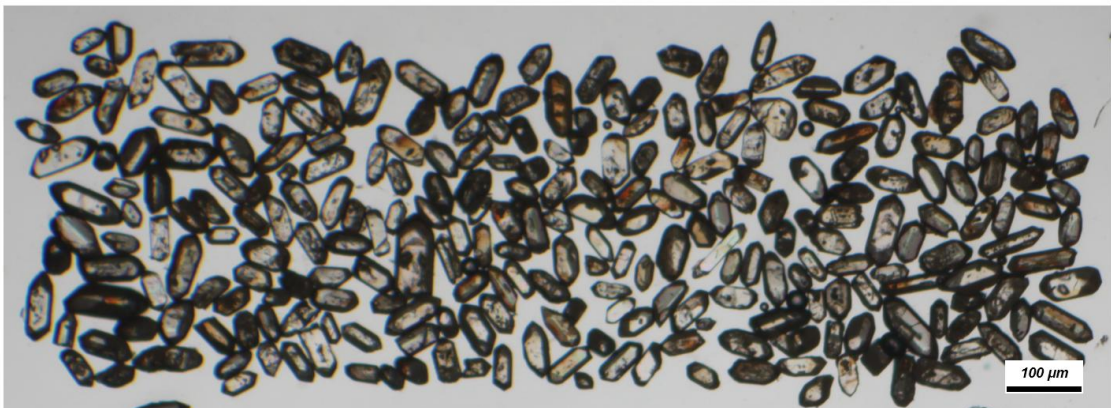


Figure 3-1. Photomicrograph of Zircons

저어콘( $ZrSiO_4$ )이란 규산염 사면체( $SiO_4$ )에 지르코늄(Zr)이 결합되어 정방정계의 결정형을 가지는 광물이다(Figure 3-1). 저어콘은 지르코늄이 너무 낮은 농도로 있지만 많다면 변성암이나 화성암에서 얼마든지 자라날 수 있다. 보통 저어콘이 가장 흔하게 발견되는 암석은 화강암 계열의 암석이나, 변성암, 퇴적암에서도 어렵지 않게 발견된다. 저어콘 입자의 크기는 보통  $100 \sim 300 \mu m$ 로 매우 작은 크기이다. 이처럼 크기가 매우 작은 광물임에도 불구하고 저어콘은 크게 두 가지의 성질 때문에 지질학적으로 매우 중요한 광물로 취급된다. 하나는 이 광물이 풍화에 아주 강해서 극심한 환경에서도 손상되지 않고 원래의 성질을 잘 유지한다는 점이고, 또 하나는 이 광물에서 Zr은 4가



양이온이며 이 자리를 우라늄과 토륨, 하프늄이 쉽게 치환할 수 있다. Zr, Hf, Th, U은 고준위원소(High Field Strength Elements, HFSEs)라고 부르는 집단에 속한다. 이 원소들은 마그마가 결정을 만들 때 대부분 참여하지 않는다. 그런데 저어콘은 이러한 고준위원소를 잘 받아들이는 마그마 속 몇 안되는 광물이다. 이러한 성질 때문에 저어콘 내에는 다른광물보다 고준위 원소의 농도가 매우 높다. 또한 이러한 고준위원소들은 연대측정에 탁월한 능력을 가진 원소들이다. 특히 그 중에서 U은 가장 정밀한 연대자료를 제공해주는 고정밀연대측정(High-precision geochronology)을 가능하게 한다(인용한 문헌 표시할 것). 그리고 연대측정에서 가장 중요한 것은 연대 초기값에 들어가는 모원소의 농도인데, 우라늄이 붕괴하여 만들어지는 납 원소는 4가 양이온이 아니라 1~2가 양이온이며, 원자반경에도 차이가 있어 저어콘이 성장할 때 우라늄은 잘 받아들이지만 납은 거의 들어갈 수가 없다. 그래서 저어콘이 성장할 때는 광물 내에 우라늄 농도는 높는데 납은 측정이 힘들 정도로 존재하지 않는다.

또한 저어콘은 풍화에 아주 강하고, 폐쇄 온도가 매우 높아서(약 900 °C; 참고문헌 필요) 생성된 후 저어콘을 포함하는 암석이 용융되더라도 종종 생존한다. 따라서 저어콘은 한번 만들어지면 암석이 다시 마그마 속에 완전히 녹아 없어지거나, 아주 오랜 시간 풍화되어서 마모되어 사라져버리지 않는 이상 처음 만들어진 지질학적 연대를 그대로 유지할 수 있다. 이러한 성질들로 인해 저어콘은 연대측정을 하기에 아주 적합한 광물이다.

### 제3절 쇄설성 저어콘 연대 분포를 이용한 퇴적물 기원지 연구

일반적으로 쇄설성 퇴적물은 전암 대비 약 1% 미만의 중광물을 함유하고 있으며, 중광물들의 종류별로 서로 다른 생성환경 및 시기를 지시하기 때문에 퇴적물의 특성화에 유용하다고 알려져 있다. 앞서 말했듯이 퇴적물에 일반적으로 함유되는 중광물 중 저어콘은 주로 규장질 화성암에서 생성되는 함우라늄 광물로서 물리·화학적으로 매우 안정하기 때문에, 극심한 변성작용(약 900 °C)을 받지 않는 이상 생성 당시 기록된 지질학적 정보를 온전히 보전할 수 있다. 퇴적암에서 산출하는 쇄설성 저어콘의 연대분포는 저어콘의 모암, 즉 기원암의 생성시기를 나타내기 때문에, 이를 이용하여 퇴적암의 퇴적시기를 제한하고, 퇴적암의 기원지를 규명할 수 있다. 퇴적암의 경우 퇴적 중

지구조적인 변화가 일어날 경우 기원지의 변화로 이어지며 이는 퇴적암의 광물조성 및 화학조성의 변화로 나타나나, 기후변화 및 암석의 광물조성 및 화학조성을 변화시키기 때문에 전암을 분석하여서는 기후변화의 영향을 배제하기 어렵다. 반면, 퇴적암에 함유된 저어콘의 경우 물리·화학적 풍화에 강하기 때문에 기후의 영향이 배제된 상태로 기원지의 변화를 복원할 수 있다는 장점이 있다.

## 제4장 시료 채취 및 실험 방법

### 제1절 시료 채취

능주분지 각 층별로 가장 대표적인 암상인 역암, 사암, 응회암 시료를 5kg 씩 채취하였다. 장동층의 경우 능주분지 내에서 분포하는 면적이 가장 넓기 때문에 위치별로 7개의 시료를 채취하였다. 각 시료에 대한 암상 및 위치는 다음과 같다(Table 4-1, Figure 4-1).

Table 4-1. List of sample the Neungju Basin.

| sample    | stratum            | lithology                    | location                |
|-----------|--------------------|------------------------------|-------------------------|
| 180104-1  | Jeokbyeok Tuff     | light gray tuff              | 35.07504 N, 127.07099 E |
| 170511-1  | Jeokbyeok Tuff     | light gray sandstone         | 35.11231 N, 127.12285 E |
| 170720-3  | Yeonsan Fm.        | redish conglomerate          | 35.15048 N, 127.05588 E |
| 170720-5  | Oyeri Fm.          | Pinkish gray tuff            | 35.12254 N, 127.01170 E |
| 170720-6  | Oyeri Fm.          | redish conglomerate          | 35.12254 N, 127.01170 E |
| 170720-7  | Ongam Conglomerate | light gray conglomerate      | 35.07488 N, 127.08265 E |
| 170720-8  | Manwolsan Tuff     | pinkish gray tuff            | 35.08155 N, 127.04104 E |
| 170720-9  | Jangdong Fm.       | redish conglomerate (matrix) | 35.01009 N, 176.58593 E |
| 170720-10 | Jangdong Fm.       | redish conglomerate (clast)  | 35.01009 N, 176.58593 E |
| 180220-4  | Yeonhwari Fm.      | redish conglomerate          | 35.15292 N, 127.05562 E |
| 180426-1  | Jangdong Fm.       | light gray sandstone         | 35.01012 N, 127.04418 E |
| 180426-2  | Jangdong Fm.       | light yellow tuff            | 35.00570 N, 127.04441 E |
| 180426-4  | Jangdong Fm.       | light gray conglomerate      | 35.03013 N, 127.01561 E |
| 180426-7  | Jangdong Fm.       | gray sandstone               | 35.06404 N, 127.04333 E |
| 180426-12 | Jangdong Fm.       | light redish sandstone       | 35.13322 N, 127.05061 E |

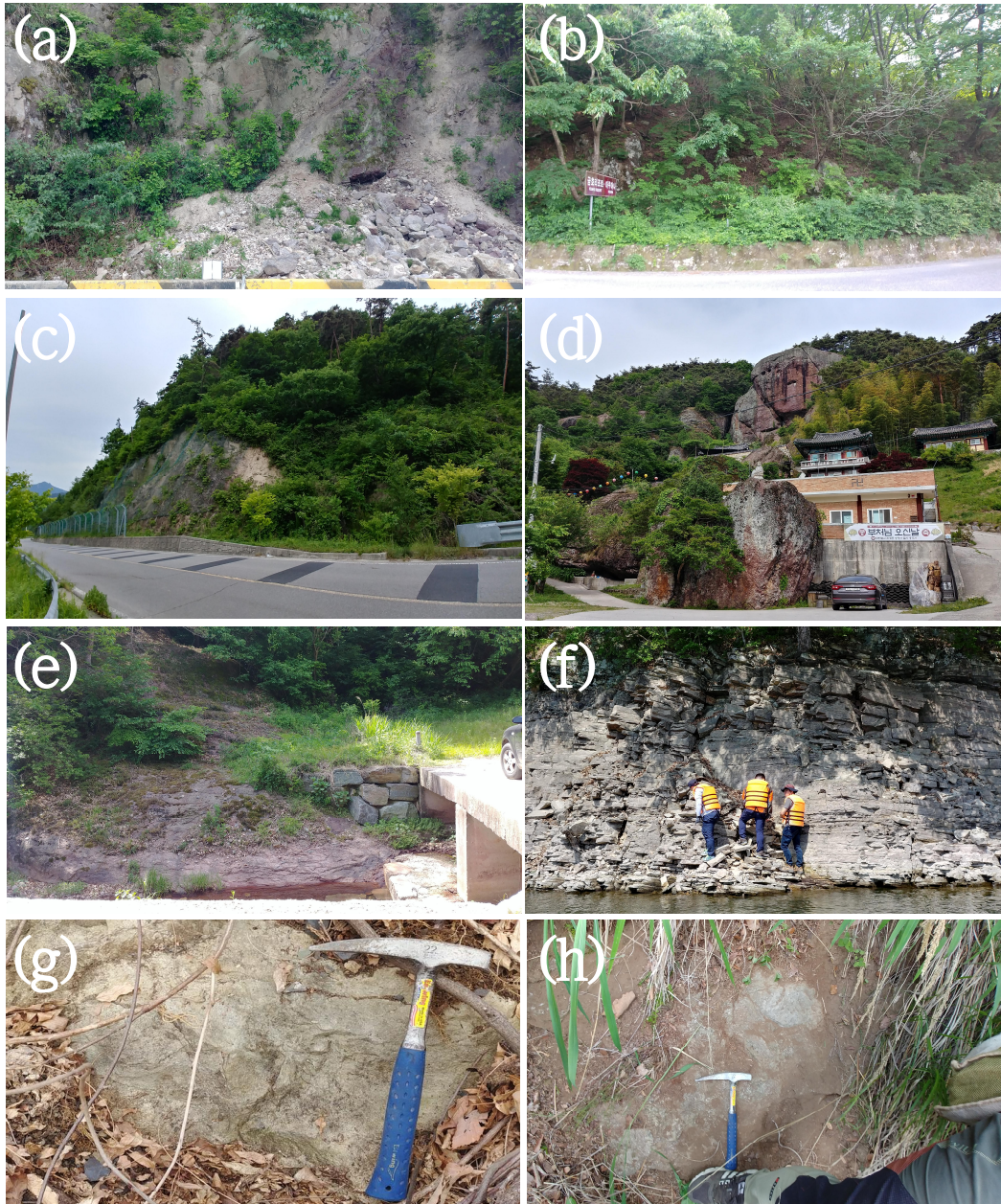


Figure 4-1. Outcrop pictures of the Neungju Basin. (a) Oyeri Fm., (b) Manweolsan Tuff, (c) Jangdong Fm., (d) Yeonhwari Fm., (e) Yeonsan Fm., (f) Jeokbyeok Tuff(sandstone), (g) Jeokbyeok Tuff, and (h) Ongam Conglomerate.



## 제2절 박편 제작 및 관찰

채취한 시료는 실험실에서 절단기를 이용하여 적절한 크기로 잘라낸 후(Figure 4-2), 연마기를 이용하여 슬라이드 글라스에 부착할 면을 연마한다(Figure 4-3). 연마한 시료를 기포나 먼지가 들어가지 않게 슬라이드 글라스에 부착한다(Figure 4-4). 접착제가 완전히 마른 후 시료의 두께가 0.03 mm가 되도록 수작업으로 연마한다(Figure 4-5). 완성된 박편을 편광현미경 하에서 관찰한다(Figure 4-6).

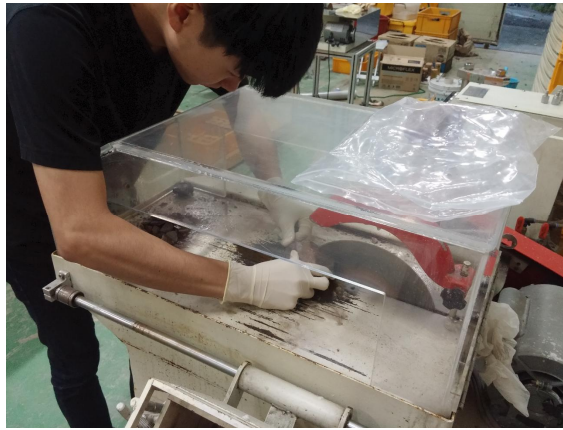


Figure 4-2. Photo of cutting with cutting machine

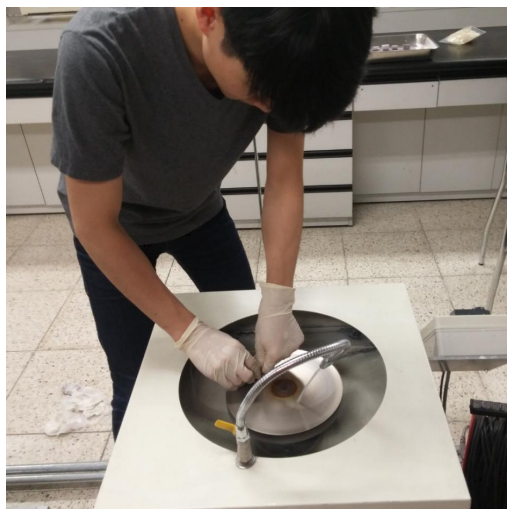


Figure 4-3. Photo of polishing with grinder

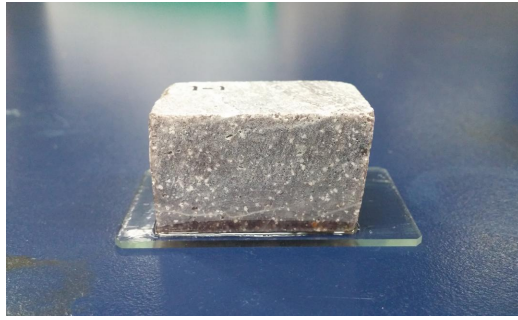


Figure 4-4. Photo of sample attached to the slide glass



Figure 4-5. The process of the polishing a samples



Figure 4-6. Observation with a polarizing microscope

### 제3절 중광물 분리 (저어콘)

채취한 시료는 실험실에서 유압파쇄기를 이용하여 1차 파쇄를 한 후(Figure 4-7), Jaw crusher, Disc mill을 이용하여 미세한 입자로 분쇄하였다(Figure 4-8). 분쇄된 시료는 습식으로 입도분리 하여 250  $\mu\text{m}$  이하의 입자들만 분리하였다(Figure 4-9). 이 후 초음파세척을 통한 Panning 작업을 하고(Figure 4-10), 수작업 및 자성분리기(Magnetic separator)를 이용하여 자성물질을 분리한 후(Figure 4-11) 중액선별 하여 중광물을 농집시켰다(Figure 4-12). 농집된 중광물 중에서 실체현미경 하에서 수작업으로 저어콘 입자들을 분리하였다(Figure 4-13).

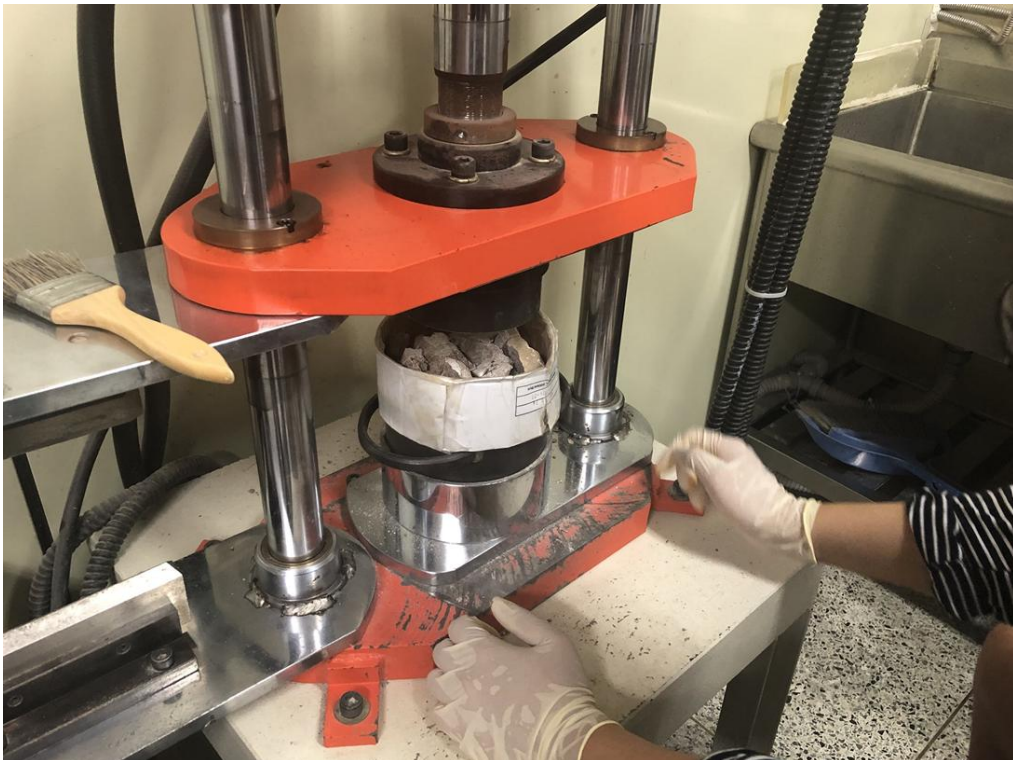


Figure 4-7. Photo of crushing with Hydraulic crusher





Figure 4-8. Photo of Jaw crusher and Disc mill



Figure 4-9. Photo of wet sieving





Figure 4-10. dust cleaning by ultrasonic wave and panning



Figure 4-11. Magnetic separator

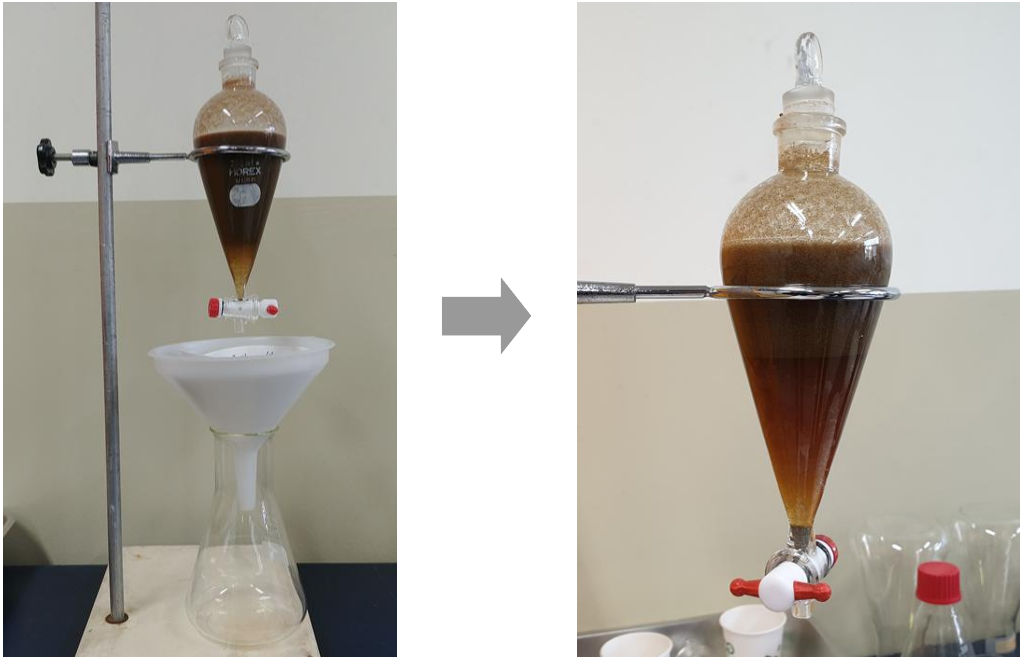


Figure 4-12. Heavy fluid separation



Figure 4-13. Stereoscopic microscope

## 제4절 저어콘 연대 분포 분석

분리한 저어콘은 마운트를 제작한 후 내부구조를 확인하기 위해 CL(Cathodoluminescence) 사진을 촬영하였다(Figure 4-14). U-Pb연대는 한국기초과학지원연구원(KBSI)의 레이저용제 유도결합 플라즈마 질량분석기(Laser ablation-multi collector-inductively coupled plasma mass spectrometer; LA-ICP-MS, 모델명 Nu Plasma II/NWR193<sup>UC</sup>)를 이용하여 측정하였다(Figure 4-15). LA-ICP-MS 분석은 Lee et al. (2018)에 기술된 U-Pb analytical methods 분석 조건에 따라 수행되었고, 분석된 자료는 ISOPLLOT 프로그램 (Ludwig,2008)을 이용하여 처리하였다. 퇴적암에서 분리한 저어콘 시료는 다양한 지질연대를 가지는 입자들로 구성되어 있어 Pb 소실에 대한 시기를 정확히 알 수 없기 때문에, 15% 이상의 불일치 또는 10% 이상의 역불일치를 보이는 연대는 이용하지 않았다. 저어콘의 U-Pb연대가 1,000 Ma 이상인 경우는 <sup>207</sup>Pb/<sup>206</sup>Pb 연대를, 1,000 Ma 이하인 경우는 <sup>207</sup>Pb/<sup>238</sup>U 연대를 이용하였다.



Figure 4-14. JSM-6610LV equipment used for SEM-CL photograph



Figure 4-15. U-Pb analysis using LA-ICP-MS (Nu Plasma II/NWR193<sup>UC</sup>)

## 제5장 연구 결과

### 제1절 박편 관찰 결과

능주 분지에서 채취한 쇠설성 퇴적암이 대부분 역암이기 때문에 정량적인 광물조성 분석을 수행하기 용이하지 않으므로, 암편 위주로 관찰하였다. 박편 관찰 결과 전반적으로 석영과 장석이 비슷한 비율로 관찰되며, 암편은 화강암편, 변성암편, 변성퇴적암편이 주로 관찰되었으며, 암편의 비율은 다음과 같다(Figure 5-1). 오예리층 역암에서는 화강암편이 규암암편 보다 우세하였고, 장동층 역암의 암편은 대부분 화강암편으로 구성되었다. 연화리층 역암에서는 화강암편, 편마암편, 규암암편이 관찰되며 규암암편이 우세하였다. 연산층 역암에서는 화강암편, 편마암편, 규암암편이 관찰되며 화강암편이 약간 우세하였다. 적벽응회암 사암 편마암편과 규암암편이 관찰되며 규암암편이 우세하였다. 웅암역암에서는 대부분 규암암편으로 관찰되었다.



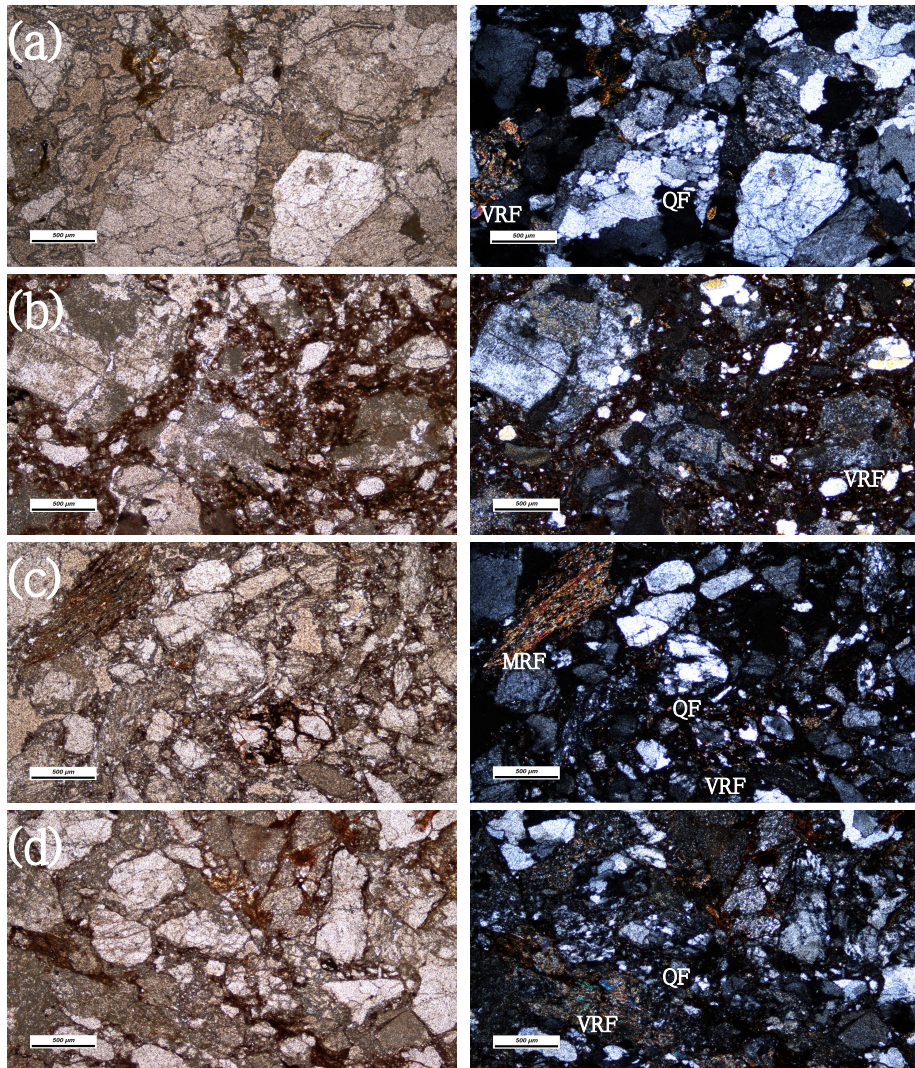


Figure 5-1. Representative photomicrographs of the Neungju Basin sediments (left: open nicols, right: cross nicols; a: Oyeri Fm., b: Jangdong Fm., c: Yeonhwari Fm., d: Yeonsan Fm., ; VRF-Volcanic rock fragment, MRF-Metamorphic rock fragment, QF-Quartzite fragment)

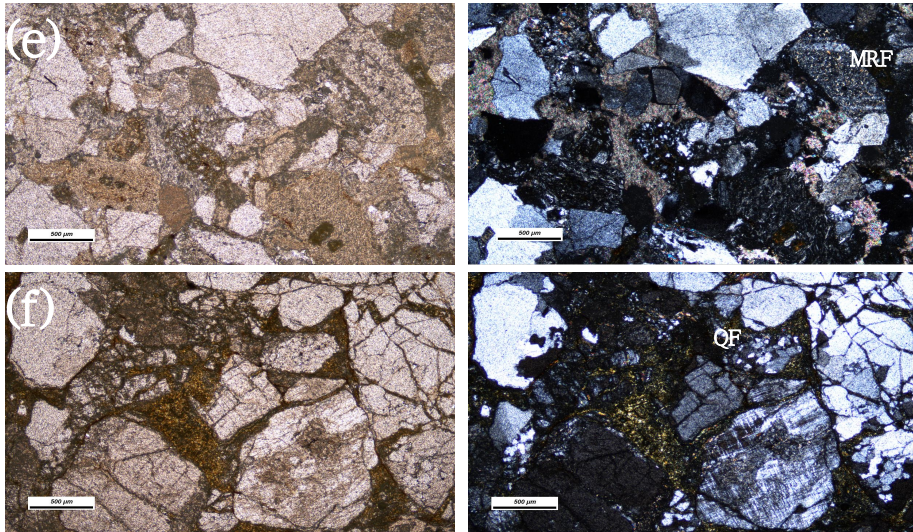


Figure 5-1(Continued). Representative photomicrographs of the Neungju Basin sediments (left: open nicols, right: cross nicols; e: Jeokbyeok Tuff, f: Ongam Conglomerate; VRF-Volcanic rock fragment, MRF-Metamorphic rock fragment, QF-Quartzite fragment)



## 제2절 저어콘 연대 분포

분리된 저어콘의 입자형태는 아원상-아각상의 외형을 보이며, CL 사진을 통한 내부 구조 관찰 결과 대부분의 저어콘은 진동형 또는 영역형 누대구조를 보이는 화성기원의 특징을 나타낸다(Figure 5-1). 저어콘의 Th/U 비는 170511-1, 170520-7 시료를 제외한 대부분의 시료에서 1200개의 분석점 중 78개를 제외한 대부분의 분석점이 0.1 이상의 값을 보여, 분석에 이용된 대부분의 저어콘 입자들이 화성기원(Vavra et al., 1999; Hartman et al., 2000)이라는 것을 지시한다(Appendix 1-14). 170511-1 시료는 50개, 170520-7 시료는 46개의 저어콘이 0.1 보다 낮은 Th/U 비를 보였다(Appendix 1, 5). 총 1400점의 레이저 분석 결과 1309개의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다. 능주 분지 저어콘의 U-Pb 연대는  $85.1 \pm 1.2$  Ma에서  $3307.8 \pm 3.5$  Ma까지 광범위한 분포를 보인다. 각 층에 대한 저어콘 연대분포는 다음과 같다.

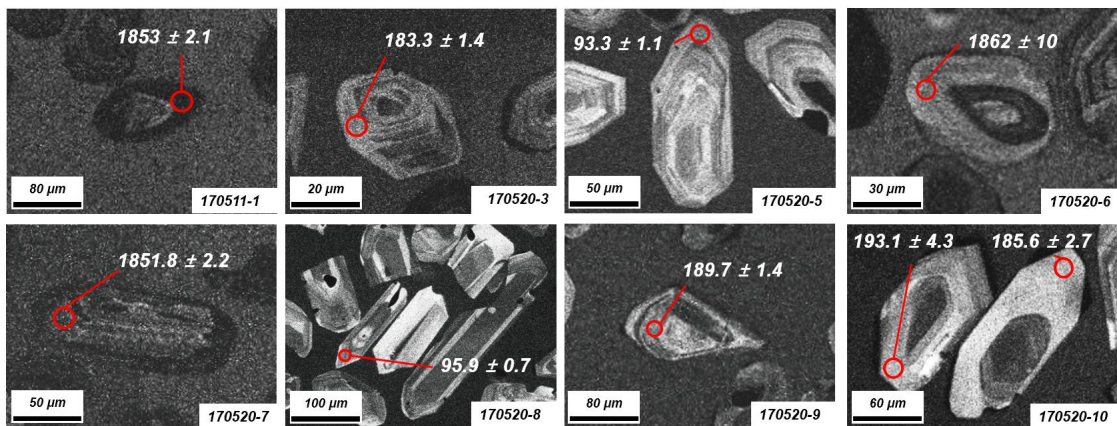


Figure 5-2. Representative selection of CL images of detrital zircons of the Neungju Basin.

저어콘의 연대분포는 막대그래프와 확률밀도 함수로 표현하였는데, 막대 그래프(Histogram-blue)는 x축에 표시된 해당 연대에 몇 개의 저어콘이 포함되었는지를 나타내고, 확률밀도 함수(Line-red)는 분석된 저어콘 중 임의의 저어콘이 어떠한 구간 내에 포함될 것인지를 확률로 나타내준다. 또한 주요 연대피크는 그래프 내에 굵은 숫자로 표시하였다(Figure 5-3~16).



### 1. 오예리층 역암

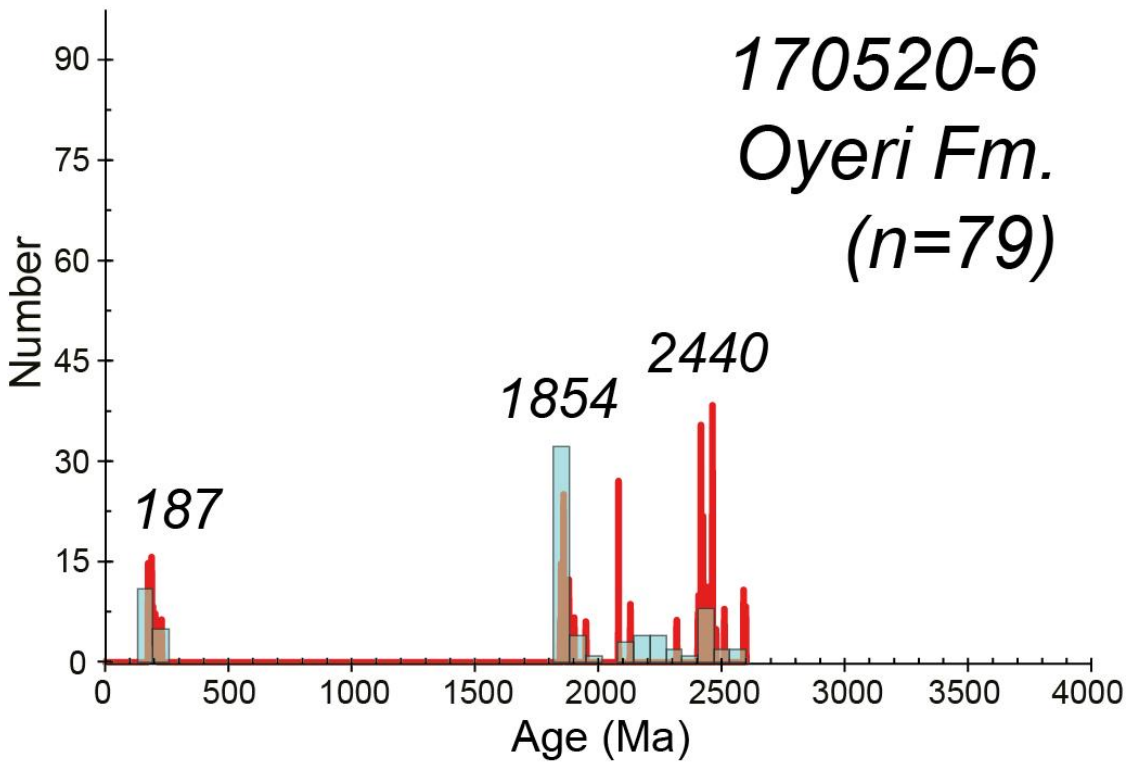


Figure 5-3. Histogram and probability-density plot of detrital zircon U-Pb ages of the Oyeri Fm. (Conglomerate)

오예리층 역암은 총 100점의 레이저 분석 결과 79개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 4). 오예리층 내 역암에서 산출하는 저어콘은 173 Ma부터 2596 Ma까지 광범위한 분포를 보인다. 1854 Ma에서 가장 높은 피크를 나타내며, 이밖에 187, 2184, 2440 Ma에서 작은 피크를 보인다.

## 2. 오예리층 응회암

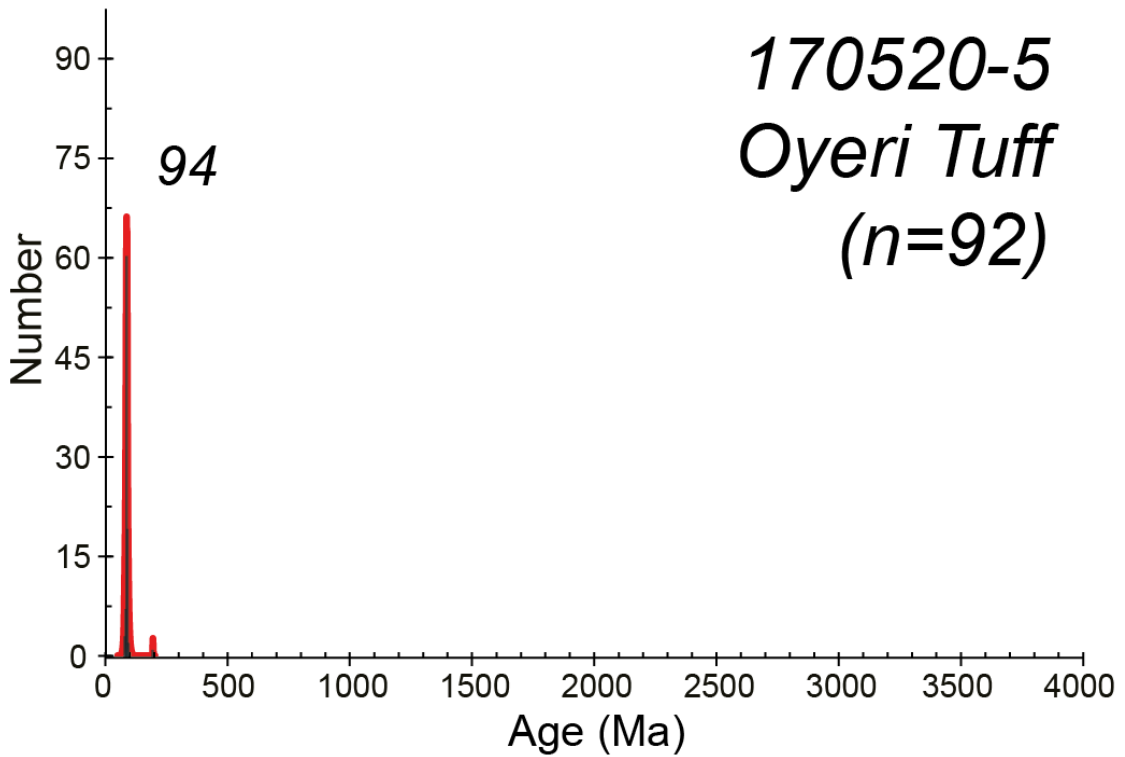


Figure 5-4. Histogram and probability-density plot of detrital zircon U-Pb ages of the Oyeri Fm. (tuff)

오예리층 응회암은 총 100점의 레이저 분석 결과 92개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 3). 오예리층 내 응회암에서 산출하는 저어콘은 88 Ma부터 165Ma 까지의 분포를 보이며, 88~99 Ma에 집중된 피크를 보인다. 대부분의 저어콘이 94 Ma의 연대를 보인다.

### 3. 만월산 응회암

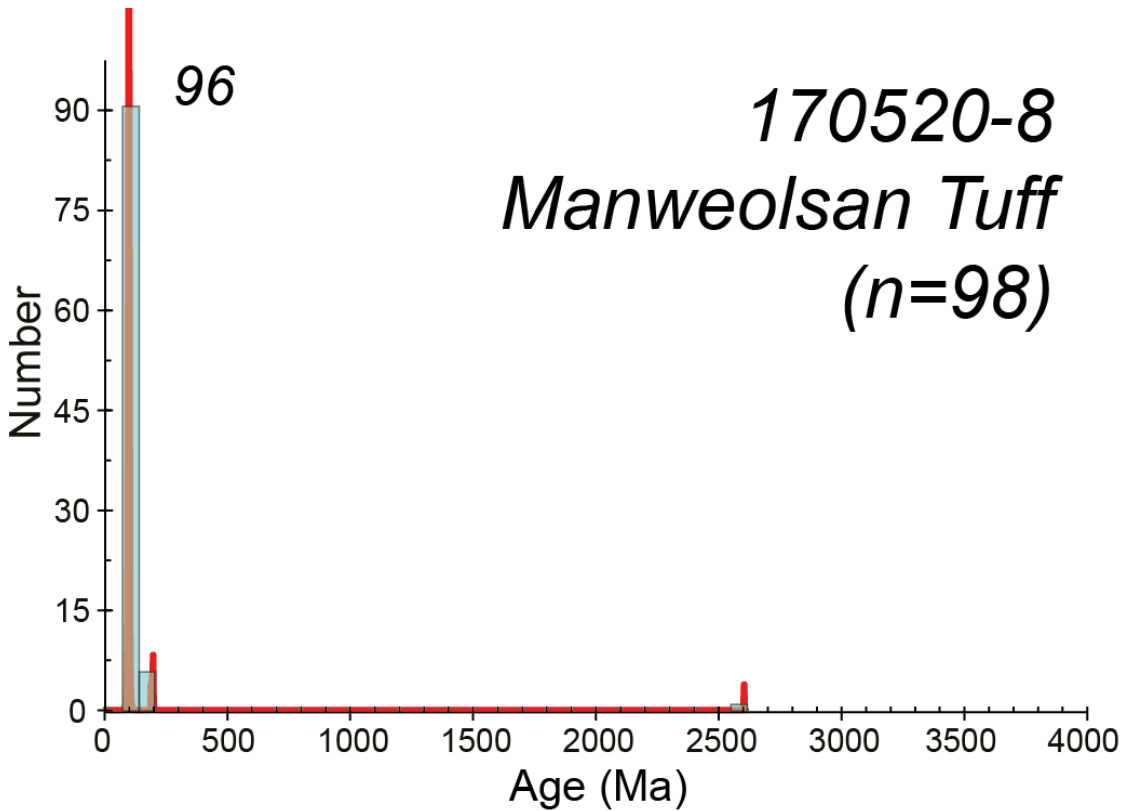


Figure 5-5. Histogram and probability-density plot of detrital zircon U-Pb ages of the Manweolsan Tuff

만월산 응회암은 총 100점의 레이저 분석 결과 98개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 6). 만월산 응회암 내 응회암에서 산출하는 저어콘은 89 Ma부터 2593Ma 까지의 분포를 보이며, 88~98 Ma에 집중된 피크를 보인다. 대부분의 저어콘이 96 Ma 의 연대를 보인다.

4. 장동층 역암 (기질) - 남서부

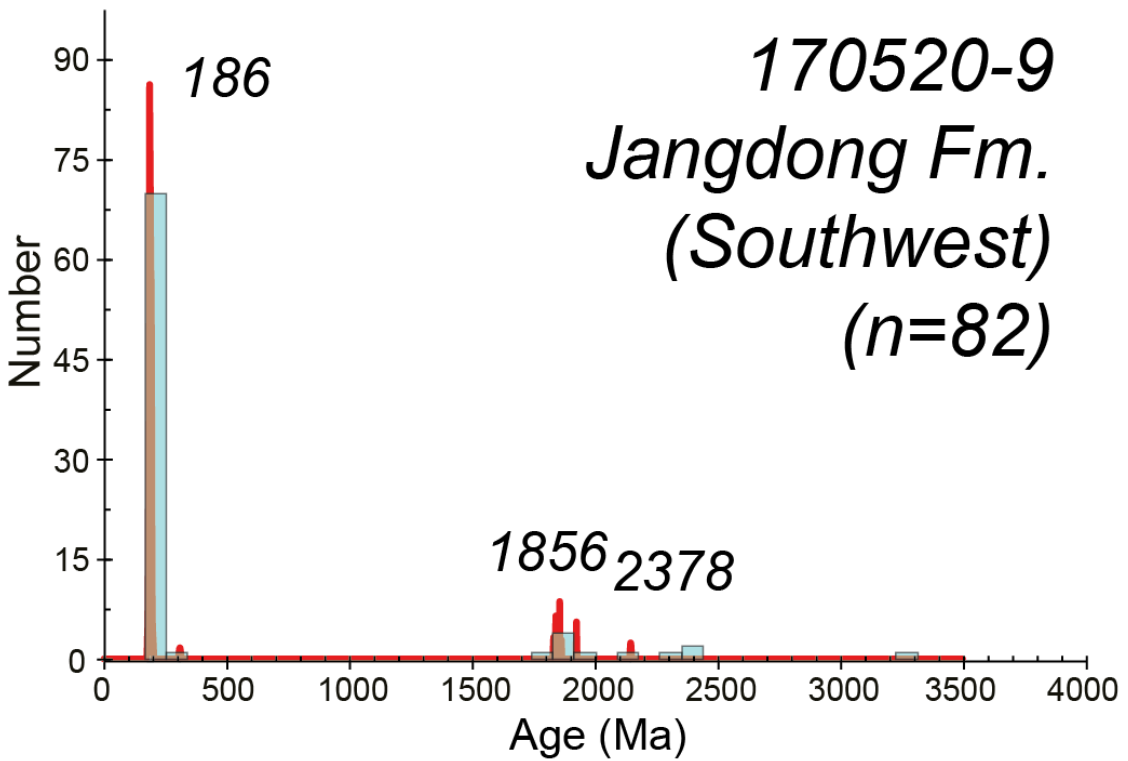


Figure 5-6. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jangdong Fm. (Southwest area, Matrix)

장동층 역암(기질)은 총 100점의 레이저 분석 결과 82개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 7). 장동층 내 역암의 기질에서 산출하는 저어콘은 178 Ma부터 3308 Ma까지 광범위한 분포를 보인다. 186~191 Ma에 집중된 피크를 보이며, 이밖에 1856 Ma에서 작은 피크를 보인다.

5. 장동층 역암 (역) - 남서부

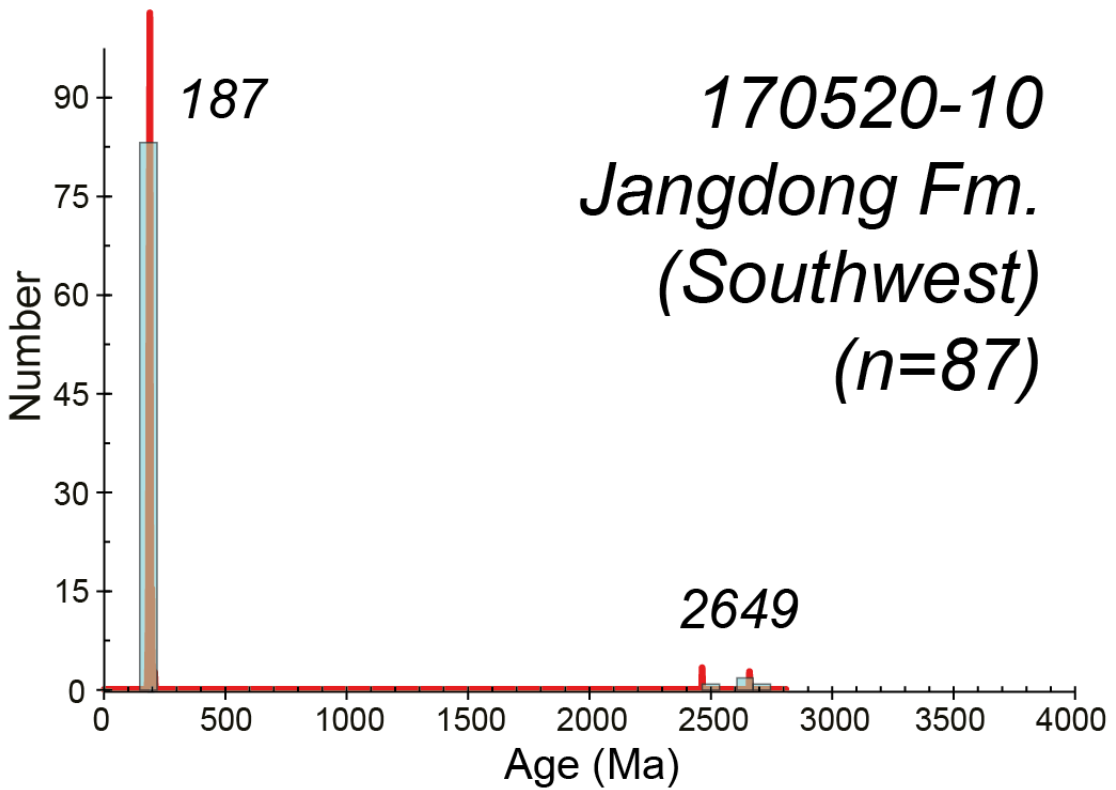


Figure 5-7. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jangdong Fm. (Southwest area, Bolder)

장동층 역암(역)은 총 100점의 레이저 분석 결과 87개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 8). 장동층 내 역암의 역에서 산출하는 저어콘은 161 Ma부터 2698 Ma까지의 분포를 보인다. 거의 모든 저어콘이 187 Ma의 연대를 보인다.

6. 장동층 역질 사암 - 남부

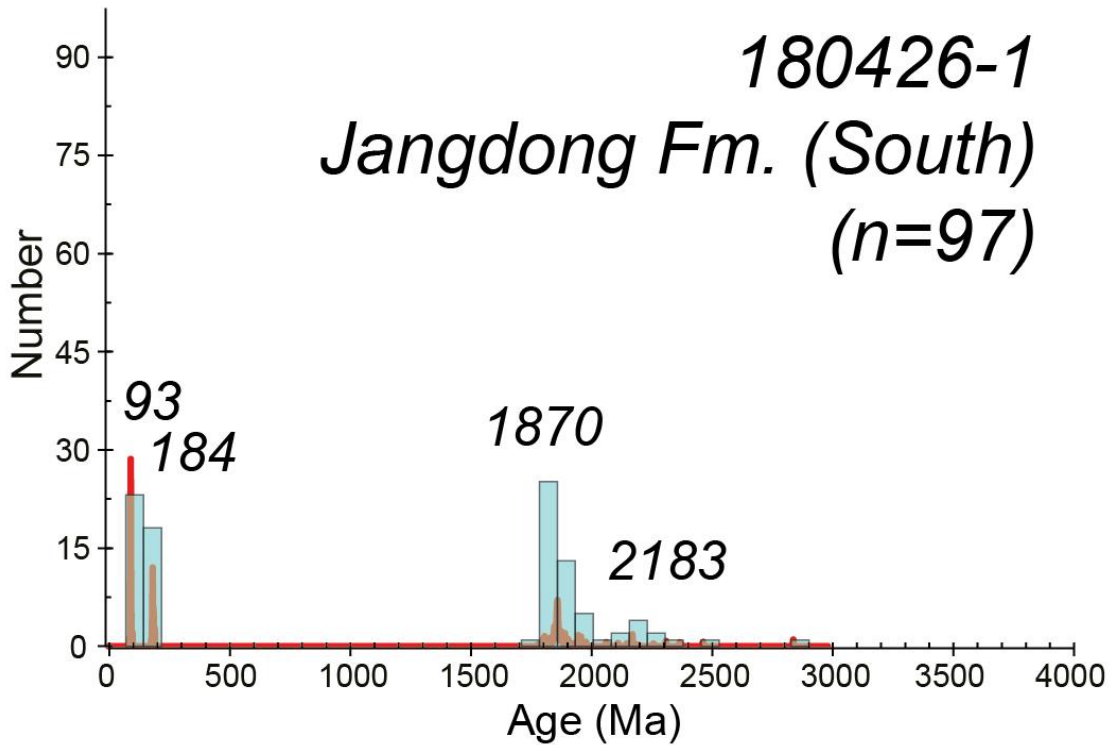


Figure 5-8. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jangdong Fm. (South area)

장동층 남부의 사암은 총 100점의 레이저 분석 결과 97개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 11). 장동층 남부의 사암에서 산출하는 저어콘은 88 Ma부터 2854 Ma까지의 분포를 보인다. 93, 184, 1870 Ma에서 높은 피크를 보이며 2183 Ma에서 낮은 피크를 보인다.

7. 장동층 역암 - 서부

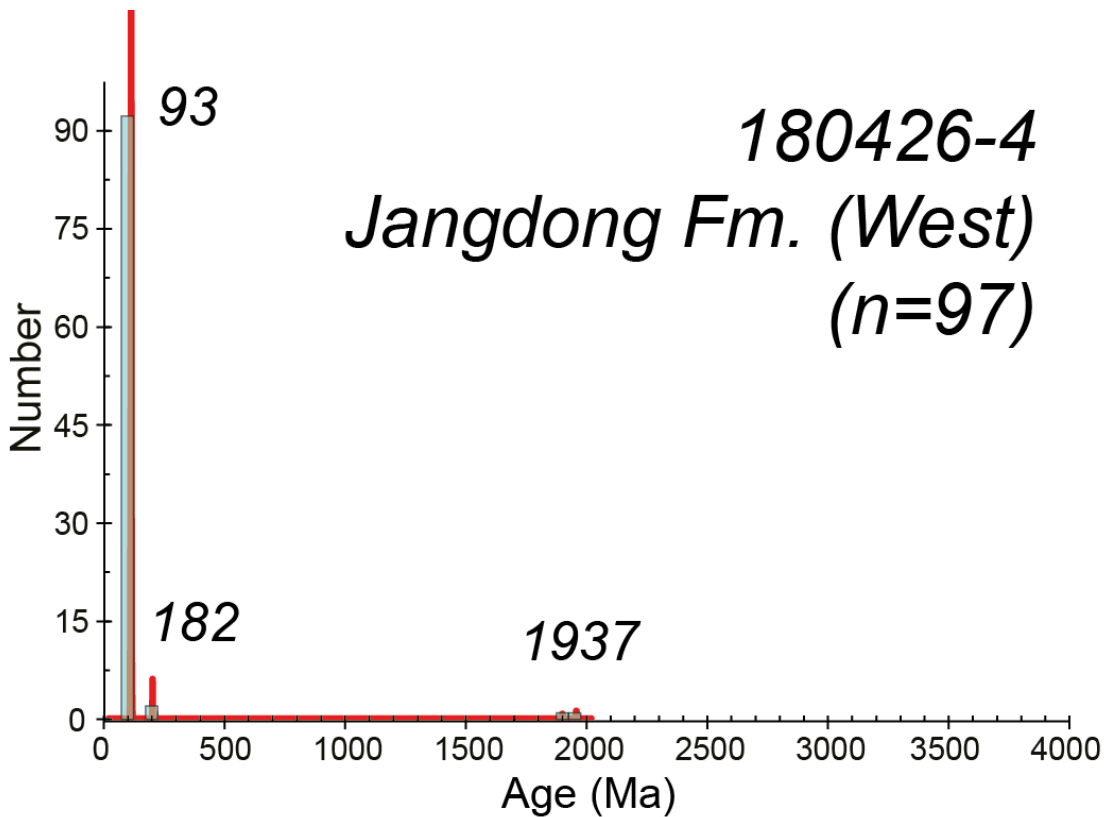


Figure 5-9. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jangdong Fm. (West area)

장동층 서부의 역암은 총 100점의 레이저 분석 결과 97개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 12). 장동층 서부의 역암에서 산출하는 저어콘은 89 Ma부터 1937 Ma까지의 분포를 보인다. 거의 모든 저어콘이 93 Ma의 연대를 보인다.

8. 장동층 사암 - 중부

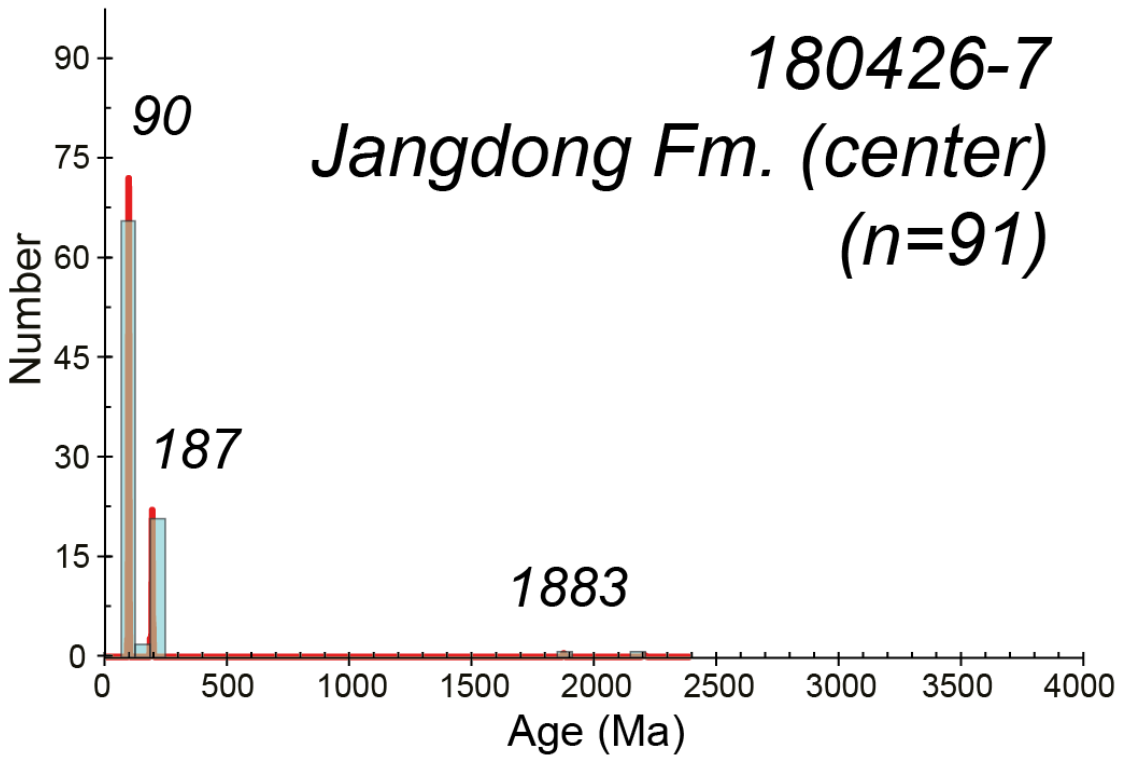


Figure 5-10. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jangdong Fm. (Center area)

장동층 중부의 사암은 총 100점의 레이저 분석 결과 91(n)개의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 13). 장동층 중부의 사암에서 산출하는 저어콘은 85 Ma부터 2215 Ma까지의 분포를 보인다. 90 Ma에서 가장 높은 피크를 보이며 187 Ma에서도 높은 피크를 보인다.



9. 장동층 사암 - 북부

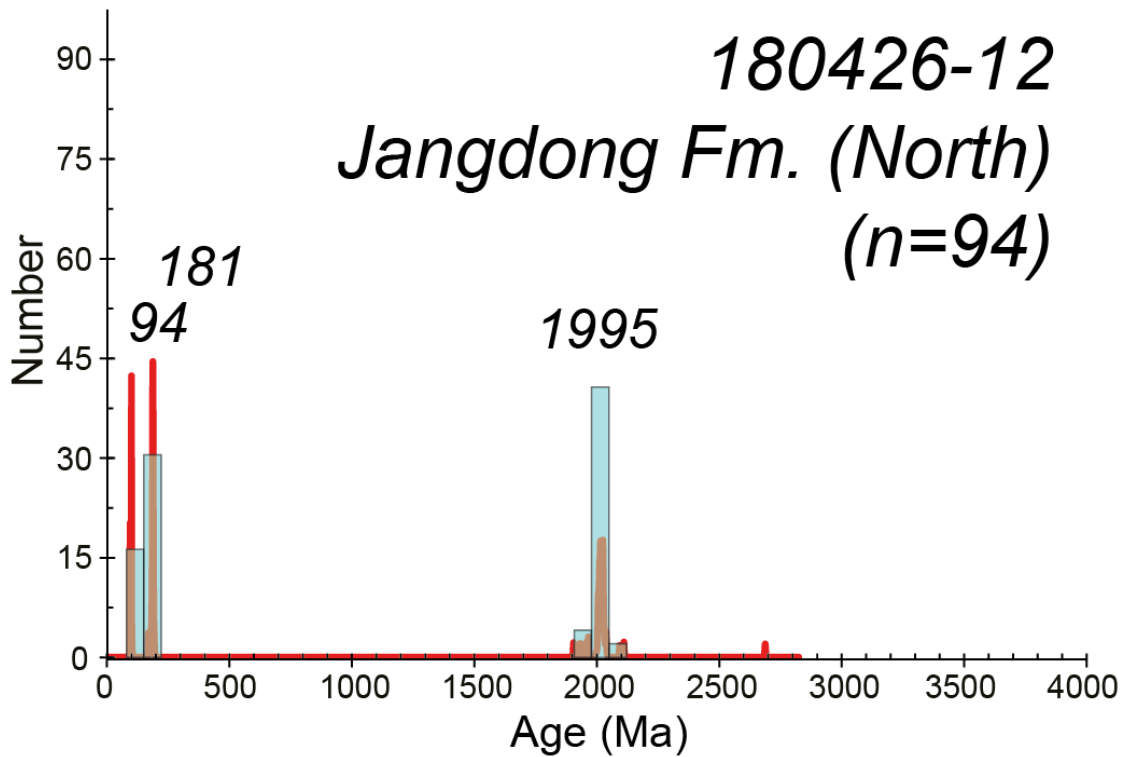


Figure 5-11. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jangdong Fm. (North area)

장동층 북부의 사암은 총 100점의 레이저 분석 결과 94개(n)의 분석 연대가 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 14). 장동층 북부 사암에서 산출하는 저어콘은 88 Ma부터 2662 Ma까지의 분포를 보인다. 181, 1995 Ma에서 높은 피크를 보이며, 94 Ma에서 작은 피크를 보인다.

## 10. 연산층 역암

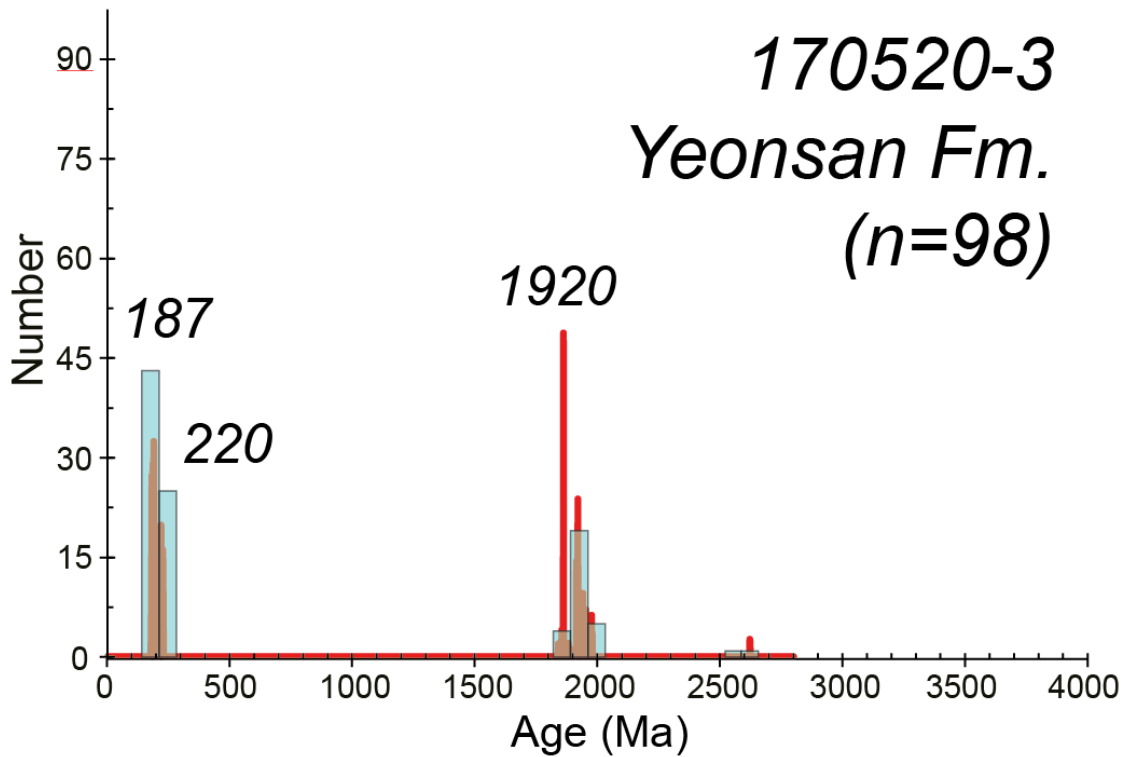


Figure 5-12. Histogram and probability-density plot of detrital zircon U-Pb ages of the Yeonsan Fm.

연산층 역암은 총 100점의 레이저 분석 결과 98개(n)의 분석 연대가 모두 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 2). 연산층 내 역암에서 산출하는 저어콘은 178 Ma부터 2620 Ma까지 광범위한 분포를 보인다. 187 Ma에서 가장 높은 피크를 나타내며, 이밖에 220, 1920 Ma에서 작은 피크를 보인다.

### 11. 연화리층 역암

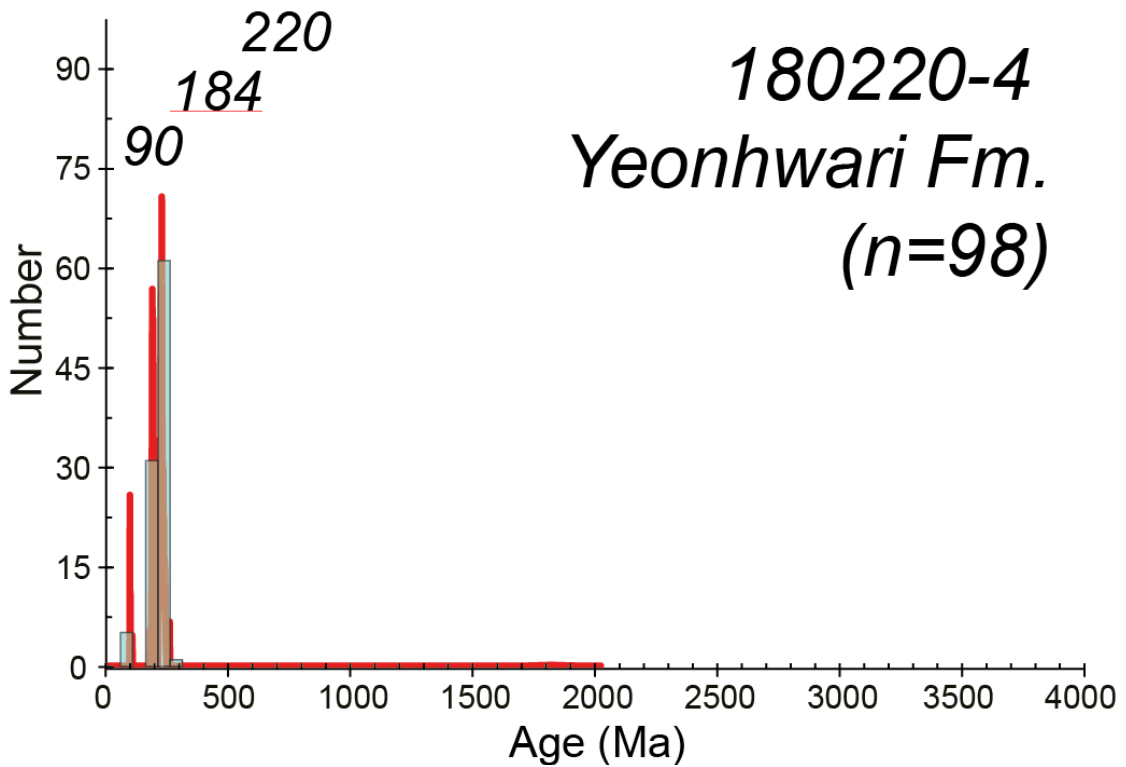


Figure 5-13. Histogram and probability-density plot of detrital zircon U-Pb ages of the Yeonhwari Fm.

연화리층 역암은 총 100점의 레이저 분석 결과 98(n)개의 분석 연대가 모두 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 10). 연화리층 내 역암에서 산출하는 저어콘은 90 Ma부터 251 Ma의 분포를 보인다. 220 Ma에서 가장 높은 피크를 나타내며, 이밖에 184, 90 Ma에서 작은 피크를 보인다.

## 12. 적벽옹회암

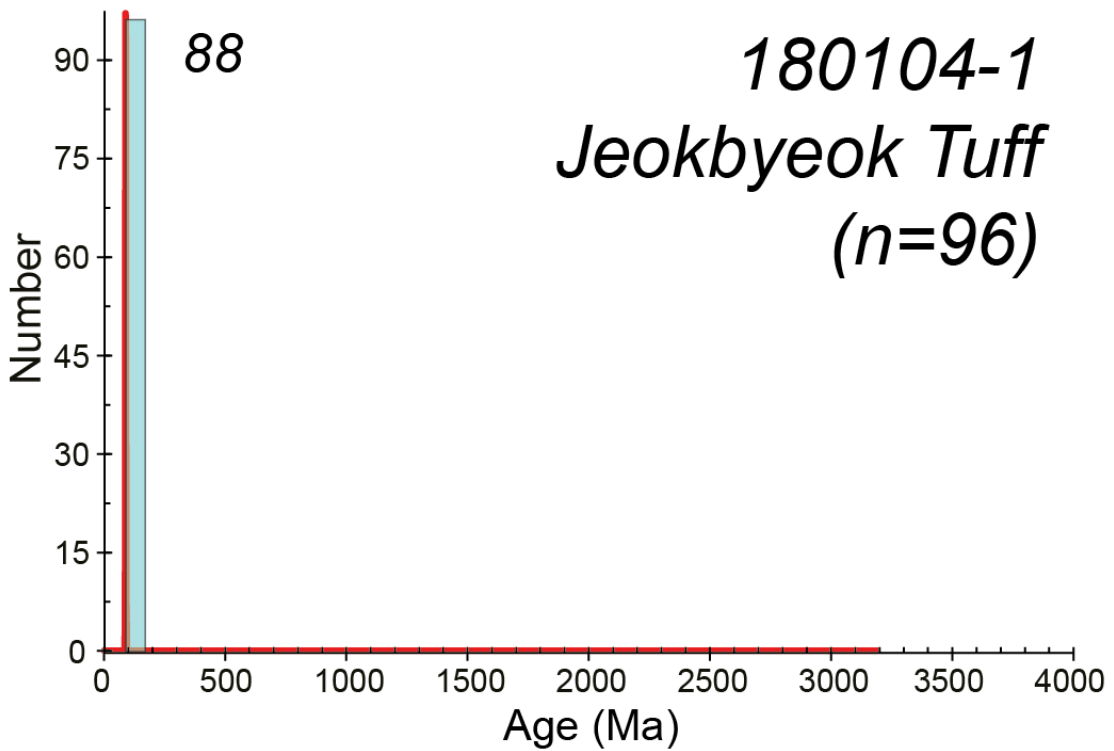


Figure 5-14. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jeokbyeok Tuff

적벽옹회암은 총 100점의 레이저 분석 결과 96개(n)의 분석 연대가 모두 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 9). 적벽옹회암 내 옹회암에서 산출하는 저어콘은 86.8 Ma부터 92.7Ma 에 집중된 피크를 나타내며, 대부분의 저어콘이 88 Ma 의 연대를 보인다.

### 13. 적벽옹회암 (사암)

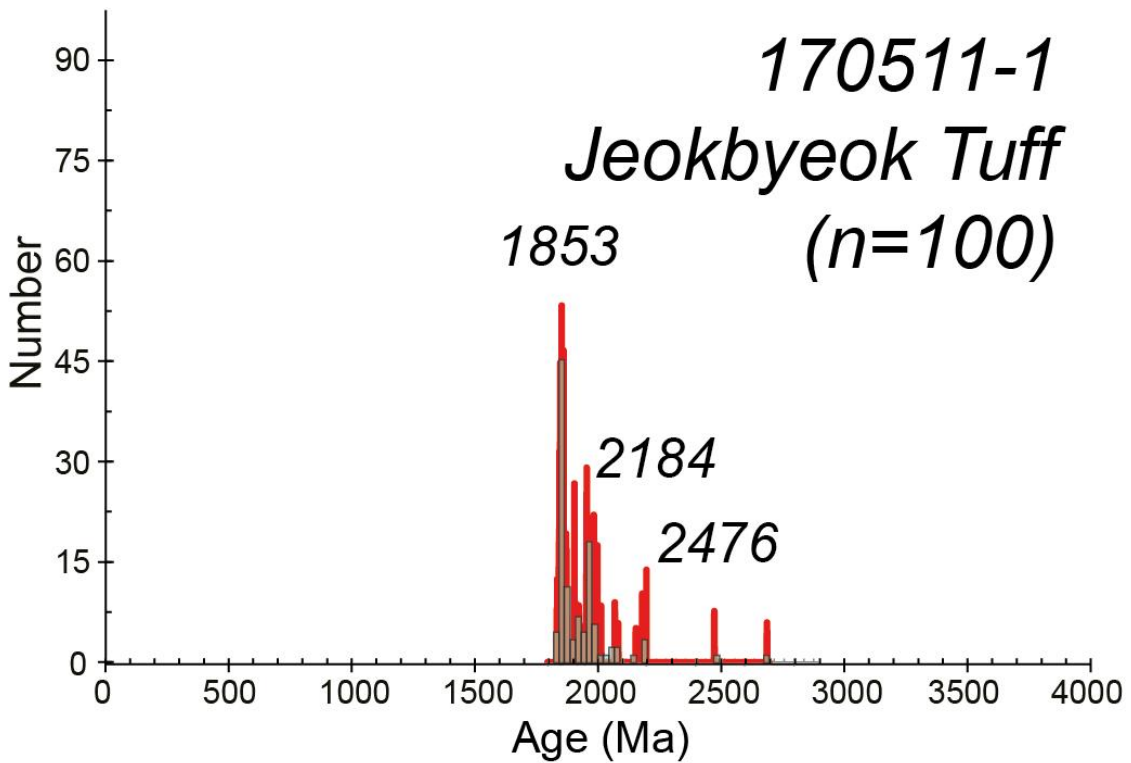


Figure 5-15. Histogram and probability-density plot of detrital zircon U-Pb ages of the Jeokbyeok Tuff (Sandstone)

적벽옹회암 내 사암은 총 100점의 레이저 분석 결과 100개(n)의 분석 연대가 모두 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 1). 적벽옹회암 내 사암에서 산출하는 저어콘은 1837 Ma부터 2690 Ma까지의 분포를 보인다. 1853 Ma에서 가장 높은 피크를 나타내며, 이밖에 1864, 1959, 1987 Ma에서 작은 피크를 보인다. 가장 젊은 저어콘의 연대가  $1837 \pm 0.6$  Ma이며, 고원생대의 저어콘만 포함한다.

14. 용암역암

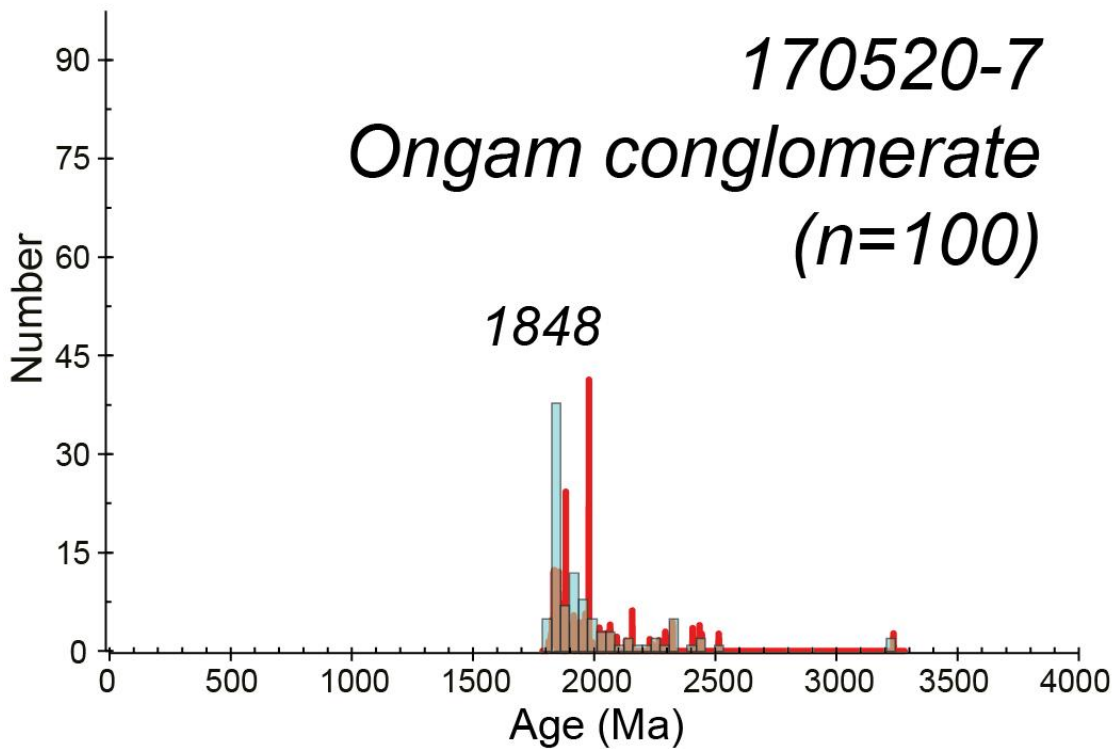


Figure 5-16. Histogram and probability-density plot of detrital zircon U-Pb ages of the Ongam Conglomerate

용암역암은 총 100점의 레이저 분석 결과 100개(n)의 분석 연대가 모두 이용 가능한 연대 범위 내에 포함되는 것으로 판명되었다(Appendix 5). 용암역암에서 산출하는 저어콘은 1825 Ma부터 3254 Ma까지의 분포를 보인다. 1848 Ma에서 가장 높은 피크를 나타내며, 이밖에 1835, 1946, 2339 Ma에서 작은 피크를 보인다. 적벽층 사암과 마찬가지로 고원생대의 저어콘이 대부분이고, 시생대의 저어콘을 일부 포함한다.

## 제6장 토의

### 제1절 저어콘 연대에 따른 퇴적시기 제한

오예리층, 만월산응회암, 적벽응회암에서 채취한 응회암에 산출하는 저어콘들은 각각 94, 96, 88 Ma의 일관된 연령 분포를 보이며, 이는 응회암의 퇴적시기로써 각 층들의 퇴적시기를 제한한다. 장동층 쇄설성 퇴적암에 산출하는 백악기 저어콘의 연대가 93-90 Ma로, 이는 장동층의 퇴적시기로 해석할 수 있다. 능주 분지 최하부층인 오예리층에 산출하는 응회암의 연령이 상부에 위치한 만월산응회암의 연령 보다 젊은 것은 층서적으로 맞지 않다. 그러나 오예리층 응회암 시료가 오예리층의 최상부에 위치한 점을 고려하면, 오예리층 최상부 응회암은 만월산 응회암과 같은 시기 동안 퇴적된 것으로 해석할 수 있다. 이는 능주 분지 퇴적이 96-94 Ma에 시작되었다는 것을 의미하고 지질시대로는 백악기 후기인 Cenomanian에 해당한다(Figure 6-1).

Jung et al., (2014)에 의하면 무등산 응회암의 연령은 86-84 Ma로, 층서 상 상위인 용암역암은 그 이후에 퇴적되었다고 추정할 수 있다. 이를 종합하면 능주분지는 백악기 후기의 시작인 Cenomanian에 퇴적되기 시작하여 대략 Campanian까지 퇴적된 것으로 추정된다.



## GSA GEOLOGIC TIME SCALE v. 5.0

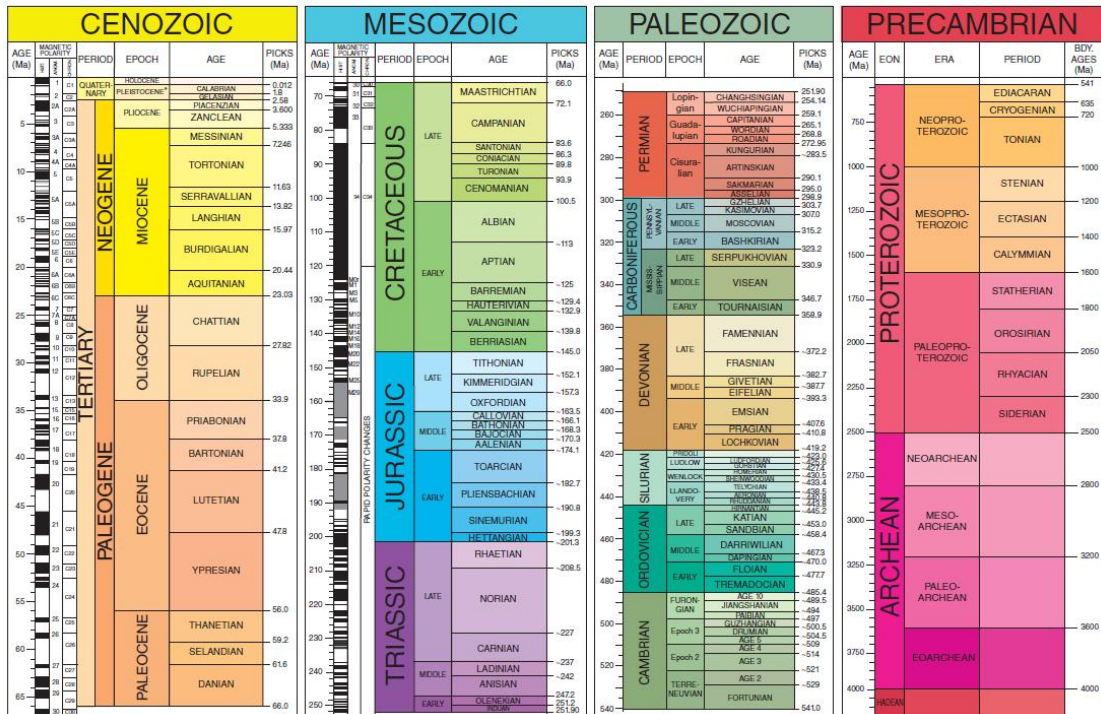


Figure 6-1. Geologic time scale (The Geological Society of America, 2018)

**Table 6-1. depositional time of the Neungju Basin.**

| Geological time | Changpyeong Sheet<br>(Son and Kim, 1966) | Dongbok Sheet<br>(Kim and Park, 1966) | Depositional period                    |
|-----------------|--|---------------------------------------|--|
| Cretaceous      | Intrusive rock                           | Intrusive rock                        |  |
|                 | Ongam Conglomerate                       | Ongam<br>Conglomerate                 |  |
|                 | ~~~~~Unconformity~~~~~                   | ~~~~~Unconformity~~~~~                |  |
|                 | Mudeungsan Lava                          | Mudeungsan Lava                       | <b>86-84 Ma</b><br>(Jung et al., 2015) |
|                 | ~~~~~Unconformity~~~~~                   | ~~~~~Unconformity~~~~~                |  |
|                 | Yeonsan Fm.                              | Jeokbyeok Tuff                        | <b>88Ma</b>                            |
|                 | ~~~~~Unconformity~~~~~                   |                                       |  |
|                 | Yeonhwari Fm.                            |                                       |  |
|                 | ~~~~~Unconformity~~~~~                   |                                       |  |
|                 | Jangdong Fm.                             | Jangdong Tuff                         | <b>93-90Ma</b>                         |
| Manwoelsan Tuff | Manwoelsan Tuff                          | <b>96-94Ma</b>                        |  |
| Oyeri Fm.       | Oyeri Fm.                                |                                       |  |

## 제2절 박편 관찰 결과 및 저어콘 연대에 따른 기원암 추정

능주 분지 쇄설성 퇴적암에서 관찰되는 암편 중 화성암편(화강암편)은 인근의 쥐라기 기반암, 변성암편(편마암편, 편암편)은 인근의 선캄브리아 기반암에서, 변성퇴적암편(규암편)은 분지 동쪽의 고생대 퇴적분지로부터 기원한 것으로 추정된다(Figure 2-1). 따라서 능주 분지 쇄설성 퇴적암의 저어콘 연대 중 쥐라기 연대를 가지는 저어콘은 쥐라기 화강암에서, 고원생대 연대를 가지는 저어콘은 선캄브리아 변성암 및 변성퇴적암에서 기원하였을 것이다.

## 제3절 분지 발달에 따른 기원지 변화

능주 분지에 산출하는 쇄설성 퇴적암들에서 장동층을 제외하면 백악기 응회암이 협재됨에도 불구하고 백악기의 저어콘은 거의 산출되지 않고, 쥐라기, 고원생대의 저어콘만 산출된다. 이들의 비율에 따른 기원지의 변화는 다음과 같다. 능주 분지 최하부층인 오예리층 내 역암(170520-6)에서는 쥐라기 저어콘이 약 27%, 고원생대 저어콘이 약 73%로, 이 시기에는 고원생대의 연대를 가지는 기원암에서 주로 퇴적물이 공급되었다. 적벽응회암 내 사암(170511-1), 용암역암(170520-7)에는 고원생대의 저어콘만 포함되어있어, 이 시기에는 쥐라기 연대를 가지는 기원암의 퇴적물 공급이 완전히 차단되었다는 것을 의미하며, 두 시료의 저어콘 연령분포가 거의 일치하므로 기원지가 같았을 것으로 추정된다. 능주 분지의 최북단에 위치한 연산층 내 역암(170520-3)에서는 쥐라기 저어콘이 약 70%로, 쥐라기 연대를 가지는 기원암에서 더 우세한 퇴적물이 공급되었음을 의미한다. 장동층은 다른 층의 쇄설성 퇴적암과는 다르게 백악기 저어콘을 다수 포함하고 있는데, 호수 환경으로 알려진 (Paik et al., 2007) 장동층이 퇴적될 당시에는 분지 남서부에 위치한 화산쇄설암들을 비롯한 인근의 기반암들로부터 각각 퇴적물이 공급되었을 것으로 해석된다.

능주분지를 둘러싼 주변 지질을 토대로 해석하자면, 백악기 저어콘은 분지 남서부의 화산성 기원물질로부터, 쥐라기 저어콘은 주로 인근의 쥐라기 화강암에서, 고원생대 저어콘은 고원생대 편마암 또는 고생대 변성퇴적암으로부터 유래했을 것이다.

이를 토대로 퇴적물이 공급된 위치를 추정해보면 분지 생성초기(①)에 퇴적된 오예리층은 분지의 서쪽, 중기(②)에 퇴적된 장동층은 분지 남서쪽, 후기(③)에 퇴적된 연산

층은 분지 북동쪽, 적벽응회암과 응암역암은 분지의 동쪽에서 퇴적물이 공급되었을 것으로 해석할 수 있다(Figure 6-2).

장동층을 제외한 능주분지의 쇄설성 퇴적암 내에서 백악기 저어콘이 산출되지 않는 점으로 미루어 보아, 장동층의 퇴적시기를 제외하면 능주분지의 퇴적 당시 화산분출물은 쇄설성 퇴적물의 기원지에서 유래하지 않았던 것으로 여겨진다. 기존 연구 (Kim and Park, 1966; Son and Kim, 1966)들은 능주분지의 응회암이 남서쪽으로 갈수록 층후가 두꺼워지는 점을 근거로 응회암이 남서쪽으로부터 유래한다고 해석하였다. 이 연구 결과는 기존 해석과 잘 일치하며, 능주분지의 응회암은 쇄설성 퇴적물 퇴적 당시 간헐적으로 별도의 기원지로부터 공급되었을 것으로 추정할 수 있다. 이는 신생대 양포분지 (Sohn et al., 2013)의 경우와 유사한 것으로 보이며, 자세한 퇴적모형은 추가적인 퇴적학적 연구가 필요하다.

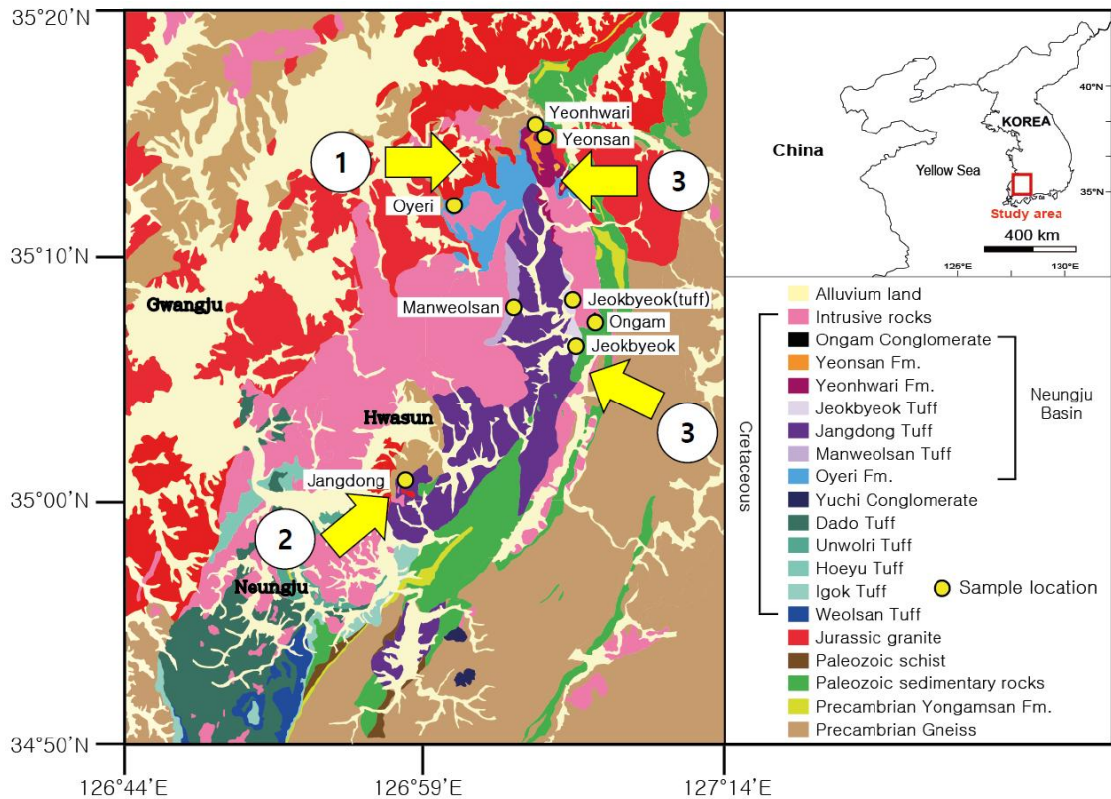


Figure 6-2. Provenance and supply direction of sediment of Neungju Basin; (Numbers indicate the order of deposition)

## 제7장 결론

능주분지는 광주광역시의 무등산 동측에 북동-남서 방향으로 옥천습곡대의 동측 연변부를 따라 신장된 방추형으로 발달한 퇴적분지이며, 전남지방의 백악기 소분지 중 가장 분포 면적이 넓다. 또한 능주 분지에는 다양한 암상과 퇴적구조들이 나타나고, 화순군 북면에 분포하는 장동층에서는 공룡발자국 화석, 익룡 발자국 화석 등 주요 자연사 기록들이 보고된 바가 있다. 하지만 이러한 지질학적 중요성에 비하여 능주분지의 형성 및 발달사에 대한 정보는 거의 알려져 있지 않았으며, 층서에 대한 문제점도 야기되고 있는 실정이었다. 따라서 이 연구에서 능주분지의 퇴적암에서 산출하는 쇄설성 저어콘의 연대분포를 이용하여 능주분지의 퇴적시기를 제한하고 기원지를 규명하여 능주분지의 발달에 대한 정보를 제공하였다.

1. 능주분지 각 층별로 가장 대표적인 암상인 역암, 사암, 응회암 시료를 채취한 후 증광물 분리과정을 거쳐 저어콘을 분리하였다. 분리한 저어콘은 마운트를 제작한 후 내부 구조를 확인하기 위해 CL 사진을 촬영하였고, 한국기초과학지원연구원의 LA-ICP-MS를 이용하여 U-Pb연대를 분석하였다. 분석된 자료는 ISOPLOT 프로그램을 이용하여 처리하였다.

2. 능주분지의 적벽층 사암, 용암역암을 제외한 대부분의 쇄설성 저어콘들이 0.1 이상의 T/U 비율을 보이는 것, 저어콘의 형태, CL 사진을 통한 내부구조 확인 결과 분석에 이용된 대부분의 저어콘 입자들이 화성기원이라는 것을 지시하였고, 저어콘의 U-Pb 연대는  $85.1 \pm 1.2$  Ma에서  $3307.8 \pm 3.5$  Ma까지 광범위한 분포를 보였다.

3. 오예리층, 만월산응회암, 적벽응회암에서 채취한 응회암에 산출하는 저어콘들은 각각 94, 96, 88 Ma의 일관된 연령 분포를 보이며, 이는 응회암의 퇴적시기로써 각 층들의 퇴적시기를 제한한다. 알려진 무등산 응회암의 연령은 86-84 Ma로, 층서 상 상위인 용암역암은 그 이후에 퇴적되었다. 이를 종합하면 능주분지는 백악기 후기의 시작인 Cenomanian에 퇴적되기 시작하여 대략 Campanian까지 퇴적된 것으로 추정된다.

4. 장동층을 제외한 능주 분지에 산출하는 쇠설성 퇴적암들에서는 백악기의 저어콘은 산출되지 않고, 쥐라기, 고원생대의 저어콘만 산출된다. 장동층은 분지 남서부의 화산성물질로부터 백악기 저어콘을 공급받았을 것으로 추정된다. 이들의 비율에 따른 기원지의 변화를 능주분지를 둘러싼 주변 지질을 토대로 퇴적물이 공급되는 위치를 추정하면 오예리층은 분지의 북서쪽①, 장동층은 분지 남서쪽②, 연산층은 분지 북동쪽③, 적벽응회암과 응암역암은 분지의 동쪽에서③ 퇴적물이 공급되었을 것으로 해석할 수 있다.

5. 장동층을 제외한 능주분지의 쇠설성 퇴적암 내에서 백악기 저어콘이 산출되지 않는 점으로 미루어 보아 능주분지의 응회암은 쇠설성 퇴적물 퇴적 당시 간헐적으로 별도의 기원지로부터 공급되었을 것으로 추정할 수 있다.



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# Appendix

Appendix 1. U-Pb ratio of Jeokbyeok Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | <sup>207</sup> Pb/ <sup>235</sup> U | 2σ    | <sup>206</sup> Pb/ <sup>238</sup> U | 2σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | 2σ     | <sup>235</sup> U- <sup>207</sup> Pb<br>age(Ma) | 2σ  | <sup>238</sup> U- <sup>206</sup> Pb<br>age(Ma) | 2σ  | <sup>207/206</sup> Pb<br>age(Ma) | 2σ  | disc.(%) |
|-------------|------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|--------|--|-----|--|-----|----------------------------------|-----|----------|
| 170511-1_86 | 0.07 | 5.174                               | 0.068 | 0.3325                              | 0.0012 | 0.1123                               | 0.0012 | 1848   | 11  | 1850.7   | 6   | 1837.3                           | 1.5 | 1.1      |
| 170511-1_11 | 0.04 | 5.096                               | 0.027 | 0.3290                              | 0.0014 | 0.1124                               | 0.0002 | 1835.5   | 4.5 | 1833.5   | 6.6 | 1839.3                           | 2.5 | 0.2      |
| 170511-1_77 | 0.02 | 5.146                               | 0.032 | 0.3311                              | 0.0016 | 0.1125                               | 0.0002 | 1843.6   | 5.3 | 1843.9   | 7.6 | 1840.8                           | 2.1 | 0.7      |
| 170511-1_1  | 0.04 | 5.227                               | 0.046 | 0.3342                              | 0.0026 | 0.1128                               | 0.0006 | 1857   | 7.5 | 1859   | 13  | 1844.1                           | 3.8 | 1.7      |
| 170511-1_47 | 0.05 | 5.185                               | 0.034 | 0.3322                              | 0.0022 | 0.1128                               | 0.0004 | 1850.1   | 5.5 | 1849   | 11  | 1845.1                           | 5   | 1.1      |
| 170511-1_75 | 0.04 | 5.191                               | 0.043 | 0.3407                              | 0.0028 | 0.1128                               | 0.0005 | 1851   | 7.1 | 1890   | 13  | 1845.9                           | 3.7 | 3.2      |
| 170511-1_65 | 0.02 | 5.125                               | 0.044 | 0.3311                              | 0.0026 | 0.1129                               | 0.0002 | 1840.2   | 7.3 | 1844   | 13  | 1846.7                           | 1.8 | 0.7      |
| 170511-1_53 | 0.04 | 5.233                               | 0.068 | 0.3355                              | 0.0036 | 0.1131                               | 0.0009 | 1858   | 11  | 1865   | 17  | 1847.2                           | 6.5 | 2.2      |
| 170511-1_36 | 0.04 | 5.205                               | 0.035 | 0.3334                              | 0.0021 | 0.1130                               | 0.0003 | 1853.3   | 5.8 | 1855   | 10  | 1848.1                           | 2.8 | 1.1      |
| 170511-1_12 | 0.04 | 5.151                               | 0.049 | 0.3310                              | 0.0028 | 0.1130                               | 0.0004 | 1844.4   | 8.1 | 1843   | 14  | 1848.3                           | 2.1 | 0.6      |
| 170511-1_52 | 0.06 | 5.174                               | 0.041 | 0.3323                              | 0.0021 | 0.1131                               | 0.0003 | 1848.4   | 6.7 | 1849.3   | 9.9 | 1848.9                           | 2.4 | 0.7      |
| 170511-1_56 | 0.06 | 5.188                               | 0.040 | 0.3331                              | 0.0026 | 0.1132                               | 0.0005 | 1850.6   | 6.5 | 1853   | 13  | 1849.2                           | 3.6 | 1.1      |
| 170511-1_5  | 0.06 | 5.192                               | 0.027 | 0.3320                              | 0.0018 | 0.1131                               | 0.0003 | 1851.2   | 4.4 | 1847.9   | 8.5 | 1850.4                           | 2.5 | 0.5      |
| 170511-1_10 | 0.09 | 5.109                               | 0.077 | 0.3285                              | 0.0045 | 0.1132                               | 0.0006 | 1838   | 13  | 1831   | 22  | 1850.7                           | 4.2 | 0.4      |
| 170511-1_99 | 0.01 | 5.300                               | 0.079 | 0.3392                              | 0.0050 | 0.1133                               | 0.0009 | 1869   | 13  | 1883   | 24  | 1850.7                           | 3.8 | 3.2      |
| 170511-1_51 | 0.03 | 5.208                               | 0.055 | 0.3329                              | 0.0023 | 0.1133                               | 0.0008 | 1854   | 8.9 | 1852   | 11  | 1851.4                           | 5.8 | 0.9      |
| 170511-1_35 | 0.01 | 5.182                               | 0.041 | 0.3327                              | 0.0025 | 0.1132                               | 0.0003 | 1849.5   | 6.8 | 1852   | 12  | 1851.6                           | 2.2 | 0.8      |

**Appendix 1.** U-Pb ratio of Jeokbyeok Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170511-1_76 | 0.13 | 5.142                            | 0.069     | 0.3307                           | 0.0035    | 0.1133                            | 0.0004    | 1843  | 11        | 1842  | 17        | 1851.6                              | 4.1       | 0.6      |
| 170511-1_23 | 0.10 | 5.240                            | 0.024     | 0.3341                           | 0.0017    | 0.1133                            | 0.0004    | 1859.1  | 3.9       | 1858  | 8.1       | 1852.2                              | 3.8       | 1.0      |
| 170511-1_45 | 0.07 | 5.216                            | 0.025     | 0.3338                           | 0.0018    | 0.1135                            | 0.0004    | 1855.1  | 4.2       | 1856.7  | 8.9       | 1852.8                              | 3         | 0.9      |
| 170511-1_42 | 0.04 | 5.188                            | 0.043     | 0.3326                           | 0.0027    | 0.1133                            | 0.0002    | 1850.5  | 7.2       | 1851  | 13        | 1852.9                              | 2.4       | 0.7      |
| 170511-1_80 | 0.02 | 5.275                            | 0.074     | 0.3362                           | 0.0035    | 0.1134                            | 0.0005    | 1865  | 12        | 1868  | 17        | 1853                                | 2.1       | 1.8      |
| 170511-1_88 | 0.05 | 5.245                            | 0.069     | 0.3389                           | 0.0036    | 0.1133                            | 0.0003    | 1860  | 11        | 1881  | 17        | 1853                                | 1         | 2.4      |
| 170511-1_74 | 0.03 | 5.330                            | 0.025     | 0.3376                           | 0.0014    | 0.1135                            | 0.0002    | 1873.6  | 3.9       | 1875.2  | 6.8       | 1854                                | 1.7       | 1.6      |
| 170511-1_78 | 0.01 | 5.250                            | 0.053     | 0.3404                           | 0.0048    | 0.1134                            | 0.0007    | 1860.7  | 8.6       | 1889  | 23        | 1854.1                              | 7.1       | 3.4      |
| 170511-1_43 | 0.11 | 5.253                            | 0.089     | 0.3347                           | 0.0054    | 0.1136                            | 0.0006    | 1861  | 14        | 1861  | 26        | 1854.6                              | 6         | 2.1      |
| 170511-1_13 | 0.15 | 5.207                            | 0.070     | 0.3335                           | 0.0055    | 0.1133                            | 0.0008    | 1854  | 12        | 1855  | 27        | 1854.8                              | 3.5       | 1.7      |
| 170511-1_98 | 0.02 | 5.236                            | 0.038     | 0.3354                           | 0.0032    | 0.1136                            | 0.0002    | 1858.5  | 6.2       | 1864  | 16        | 1856.1                              | 2.9       | 1.4      |
| 170511-1_64 | 0.05 | 5.134                            | 0.047     | 0.3309                           | 0.0022    | 0.1136                            | 0.0005    | 1841.7  | 7.8       | 1843  | 11        | 1857                                | 7         | 0.2      |
| 170511-1_38 | 0.07 | 5.237                            | 0.043     | 0.3343                           | 0.0024    | 0.1136                            | 0.0003    | 1858.5  | 7.1       | 1859  | 11        | 1857.2                              | 2.5       | 0.8      |
| 170511-1_95 | 0.02 | 5.283                            | 0.053     | 0.3369                           | 0.0026    | 0.1134                            | 0.0005    | 1866.1  | 8.6       | 1872  | 12        | 1857.3                              | 3.2       | 1.6      |
| 170511-1_8  | 0.17 | 5.195                            | 0.035     | 0.3327                           | 0.0023    | 0.1136                            | 0.0005    | 1851.8  | 5.8       | 1851  | 11        | 1857.4                              | 3.3       | 0.4      |
| 170511-1_20 | 0.06 | 5.342                            | 0.038     | 0.3381                           | 0.0024    | 0.1137                            | 0.0002    | 1875.5  | 6.1       | 1877  | 12        | 1858                                | 2.5       | 1.8      |
| 170511-1_14 | 0.04 | 5.236                            | 0.065     | 0.3345                           | 0.0029    | 0.1136                            | 0.0012    | 1858  | 11        | 1860  | 14        | 1858.3                              | 9.2       | 1.3      |
| 170511-1_67 | 0.04 | 5.124                            | 0.029     | 0.3344                           | 0.0023    | 0.1136                            | 0.0005    | 1840.2  | 4.8       | 1860  | 11        | 1858.8                              | 5.3       | 0.9      |
| 170511-1_40 | 0.02 | 5.458                            | 0.024     | 0.3485                           | 0.0016    | 0.1136                            | 0.0003    | 1894.1  | 3.7       | 1927.2  | 7.9       | 1859.3                              | 2.4       | 4.1      |
| 170511-1_70 | 0.03 | 5.180                            | 0.067     | 0.3350                           | 0.0081    | 0.1138                            | 0.0010    | 1849  | 11        | 1863  | 39        | 1859.6                              | 5.1       | 2.5      |

**Appendix 1.** U-Pb ratio of Jeokbyeok Fm. of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170511-1_82  | 0.05 | 5.489                            | 0.076     | 0.3598                           | 0.0050    | 0.1140                            | 0.0004    | 1899  | 12        | 1981  | 24        | 1861.9                           | 3.4       | 7.4      |
| 170511-1_32  | 0.28 | 5.289                            | 0.050     | 0.3365                           | 0.0025    | 0.1139                            | 0.0007    | 1867.1  | 8         | 1870  | 12        | 1864.2                           | 5.3       | 1.2      |
| 170511-1_37  | 0.06 | 5.258                            | 0.035     | 0.3346                           | 0.0026    | 0.1141                            | 0.0003    | 1862  | 5.6       | 1860  | 13        | 1864.3                           | 2.9       | 0.6      |
| 170511-1_73  | 0.03 | 5.324                            | 0.096     | 0.3380                           | 0.0032    | 0.1140                            | 0.0011    | 1873  | 15        | 1877  | 15        | 1864.4                           | 4.3       | 1.7      |
| 170511-1_26  | 0.06 | 5.249                            | 0.026     | 0.3342                           | 0.0019    | 0.1140                            | 0.0002    | 1860.6  | 4.2       | 1858.8  | 9         | 1864.5                           | 2.3       | 0.3      |
| 170511-1_31  | 0.10 | 5.297                            | 0.037     | 0.3365                           | 0.0017    | 0.1141                            | 0.0008    | 1868.4  | 5.9       | 1869.9  | 8         | 1865.4                           | 5.9       | 1.0      |
| 170511-1_66  | 0.05 | 5.229                            | 0.026     | 0.3329                           | 0.0016    | 0.1141                            | 0.0002    | 1857.2  | 4.2       | 1852.3  | 7.6       | 1866                             | 1.9       | -0.2     |
| 170511-1_81  | 0.08 | 5.166                            | 0.044     | 0.3306                           | 0.0015    | 0.1135                            | 0.0009    | 1847  | 7.2       | 1841.2  | 7.4       | 1868                             | 13        | -0.3     |
| 170511-1_100 | 0.10 | 5.190                            | 0.035     | 0.3329                           | 0.0015    | 0.1147                            | 0.0008    | 1851  | 5.7       | 1852.2  | 7.1       | 1870.2                           | 4.4       | -0.4     |
| 170511-1_90  | 0.06 | 5.269                            | 0.057     | 0.3398                           | 0.0028    | 0.1145                            | 0.0003    | 1863.8  | 9.2       | 1886  | 14        | 1872.75                          | 0.67      | 1.5      |
| 170511-1_92  | 0.11 | 5.230                            | 0.120     | 0.3358                           | 0.0053    | 0.1149                            | 0.0012    | 1857  | 19        | 1867  | 26        | 1873.8                           | 6.6       | 1.4      |
| 170511-1_41  | 0.01 | 5.416                            | 0.067     | 0.3418                           | 0.0057    | 0.1146                            | 0.0010    | 1887  | 11        | 1895  | 27        | 1874.4                           | 2.7       | 2.7      |
| 170511-1_50  | 0.07 | 5.306                            | 0.045     | 0.3364                           | 0.0026    | 0.1145                            | 0.0003    | 1870.9  | 7.5       | 1869  | 13        | 1874.9                           | 3.3       | 0.6      |
| 170511-1_84  | 0.08 | 5.342                            | 0.051     | 0.3383                           | 0.0033    | 0.1150                            | 0.0015    | 1875.6  | 8.1       | 1879  | 16        | 1876.4                           | 8.8       | 1.5      |
| 170511-1_9   | 0.32 | 5.349                            | 0.040     | 0.3371                           | 0.0023    | 0.1151                            | 0.0005    | 1876.5  | 6.5       | 1873  | 11        | 1876.8                           | 6         | 0.7      |
| 170511-1_61  | 0.02 | 5.255                            | 0.023     | 0.3323                           | 0.0038    | 0.1149                            | 0.0017    | 1861.5  | 3.7       | 1849  | 18        | 1879                             | 11        | -0.1     |
| 170511-1_30  | 0.25 | 5.335                            | 0.037     | 0.3366                           | 0.0025    | 0.1155                            | 0.0005    | 1874.2  | 5.9       | 1870  | 12        | 1889                             | 4         | -0.2     |
| 170511-1_21  | 0.02 | 5.580                            | 0.100     | 0.3455                           | 0.0069    | 0.1157                            | 0.0007    | 1912  | 16        | 1913  | 33        | 1890.1                           | 9.7       | 3.4      |
| 170511-1_79  | 0.04 | 5.194                            | 0.052     | 0.3285                           | 0.0033    | 0.1165                            | 0.0010    | 1851.6  | 8.5       | 1831  | 16        | 1905.2                           | 5.9       | -2.9     |
| 170511-1_18  | 0.20 | 5.525                            | 0.031     | 0.3430                           | 0.0018    | 0.1168                            | 0.0003    | 1904.5  | 4.8       | 1901  | 8.9       | 1908.8                           | 3.3       | 0.2      |

**Appendix 1.** U-Pb ratio of Jeokbyeok Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170511-1_22 | 0.15 | 5.623                            | 0.046     | 0.3460                           | 0.0032    | 0.1172                            | 0.0004    | 1919.4  | 7         | 1915  | 16        | 1913.3                              | 3.3       | 1.1      |
| 170511-1_29 | 0.00 | 5.627                            | 0.050     | 0.3478                           | 0.0029    | 0.1172                            | 0.0003    | 1920.1  | 7.6       | 1924  | 14        | 1915.5                              | 1.9       | 1.3      |
| 170511-1_15 | 0.15 | 5.890                            | 0.180     | 0.3600                           | 0.0120    | 0.1175                            | 0.0017    | 1960  | 27        | 1980  | 57        | 1917                                | 11        | 6.6      |
| 170511-1_96 | 0.18 | 5.361                            | 0.053     | 0.3357                           | 0.0017    | 0.1181                            | 0.0010    | 1878.6  | 8.5       | 1865.8  | 8.4       | 1926                                | 9.5       | -2.3     |
| 170511-1_19 | 0.27 | 5.666                            | 0.093     | 0.3456                           | 0.0062    | 0.1182                            | 0.0015    | 1926  | 14        | 1914  | 30        | 1926.1                              | 5.9       | 1.2      |
| 170511-1_16 | 0.09 | 5.690                            | 0.100     | 0.3500                           | 0.0052    | 0.1178                            | 0.0019    | 1929  | 16        | 1934  | 25        | 1928                                | 32        | 3.3      |
| 170511-1_33 | 0.41 | 6.433                            | 0.073     | 0.3881                           | 0.0050    | 0.1194                            | 0.0012    | 2037  | 10        | 2114  | 23        | 1948                                | 11        | 9.5      |
| 170511-1_60 | 0.20 | 6.095                            | 0.056     | 0.3695                           | 0.0048    | 0.1200                            | 0.0019    | 1989.5  | 8         | 2027  | 23        | 1950                                | 12        | 5.5      |
| 170511-1_62 | 0.12 | 5.892                            | 0.072     | 0.3595                           | 0.0041    | 0.1192                            | 0.0018    | 1960  | 11        | 1980  | 20        | 1950                                | 11        | 3.1      |
| 170511-1_87 | 0.10 | 5.936                            | 0.047     | 0.3574                           | 0.0025    | 0.1199                            | 0.0006    | 1966.5  | 6.9       | 1970  | 12        | 1956.3                              | 2.5       | 1.4      |
| 170511-1_34 | 0.51 | 5.889                            | 0.066     | 0.3551                           | 0.0031    | 0.1200                            | 0.0008    | 1962  | 8.9       | 1959  | 15        | 1957.9                              | 6.2       | 1.1      |
| 170511-1_2  | 0.13 | 5.937                            | 0.084     | 0.3565                           | 0.0045    | 0.1200                            | 0.0003    | 1966  | 12        | 1966  | 21        | 1958.1                              | 2.8       | 1.6      |
| 170511-1_72 | 0.26 | 5.785                            | 0.038     | 0.3518                           | 0.0035    | 0.1202                            | 0.0005    | 1944.2  | 5.6       | 1943  | 17        | 1958.7                              | 3.8       | 0.3      |
| 170511-1_69 | 0.19 | 5.991                            | 0.058     | 0.3587                           | 0.0034    | 0.1201                            | 0.0004    | 1974.4  | 8.4       | 1976  | 16        | 1959.4                              | 4.9       | 1.9      |
| 170511-1_46 | 0.31 | 5.900                            | 0.100     | 0.3558                           | 0.0063    | 0.1203                            | 0.0005    | 1962  | 15        | 1962  | 30        | 1960.2                              | 3.5       | 1.8      |
| 170511-1_63 | 0.13 | 5.876                            | 0.042     | 0.3552                           | 0.0021    | 0.1200                            | 0.0007    | 1957.6  | 6.1       | 1959  | 10        | 1962.2                              | 9.6       | 0.8      |
| 170511-1_58 | 0.31 | 5.882                            | 0.058     | 0.3557                           | 0.0033    | 0.1204                            | 0.0006    | 1958.5  | 8.6       | 1962  | 16        | 1963                                | 4.1       | 1.0      |
| 170511-1_83 | 0.05 | 5.970                            | 0.080     | 0.3581                           | 0.0027    | 0.1207                            | 0.0012    | 1971  | 12        | 1973  | 13        | 1963.5                              | 1.7       | 1.2      |
| 170511-1_44 | 0.27 | 5.915                            | 0.065     | 0.3559                           | 0.0038    | 0.1205                            | 0.0004    | 1966  | 11        | 1963  | 18        | 1964.1                              | 2.3       | 1.0      |
| 170511-1_54 | 0.39 | 5.931                            | 0.046     | 0.3575                           | 0.0034    | 0.1209                            | 0.0005    | 1965.8  | 6.7       | 1970  | 16        | 1969.4                              | 3.2       | 1.0      |

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| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170511-1_4  | 0.62 | 5.824                            | 0.073     | 0.3524                           | 0.0015    | 0.1209                            | 0.0008    | 1950  | 11        | 1946  | 7.1       | 1969.6                              | 5.2       | -0.6     |
| 170511-1_39 | 0.26 | 5.980                            | 0.120     | 0.3569                           | 0.0065    | 0.1212                            | 0.0013    | 1973  | 17        | 1967  | 31        | 1974.1                              | 8.6       | 1.7      |
| 170511-1_91 | 0.13 | 6.030                            | 0.130     | 0.3603                           | 0.0078    | 0.1212                            | 0.0009    | 1979  | 19        | 1983  | 37        | 1975.1                              | 5.3       | 2.5      |
| 170511-1_48 | 0.10 | 5.987                            | 0.056     | 0.3580                           | 0.0041    | 0.1213                            | 0.0007    | 1974  | 8.2       | 1973  | 19        | 1975.4                              | 3.2       | 1.0      |
| 170511-1_97 | 0.39 | 6.005                            | 0.076     | 0.3593                           | 0.0046    | 0.1218                            | 0.0005    | 1976  | 11        | 1979  | 22        | 1978.9                              | 6.4       | 1.4      |
| 170511-1_55 | 0.21 | 6.002                            | 0.072     | 0.3598                           | 0.0038    | 0.1215                            | 0.0009    | 1976  | 10        | 1981  | 18        | 1979.7                              | 6.3       | 1.3      |
| 170511-1_89 | 0.41 | 6.217                            | 0.057     | 0.3707                           | 0.0023    | 0.1220                            | 0.0010    | 2006.7  | 8         | 2033  | 11        | 1984.4                              | 3.9       | 3.1      |
| 170511-1_68 | 0.24 | 6.095                            | 0.034     | 0.3615                           | 0.0018    | 0.1222                            | 0.0003    | 1989.4  | 4.9       | 1989.3  | 8.6       | 1987.3                              | 2.7       | 0.7      |
| 170511-1_49 | 0.16 | 6.067                            | 0.048     | 0.3605                           | 0.0028    | 0.1217                            | 0.0006    | 1985.4  | 6.9       | 1985  | 13        | 1987.5                              | 5.8       | 0.8      |
| 170511-1_28 | 0.25 | 6.075                            | 0.050     | 0.3608                           | 0.0052    | 0.1228                            | 0.0005    | 1986.6  | 7.2       | 1986  | 25        | 1997.5                              | 2.9       | 0.8      |
| 170511-1_3  | 0.07 | 6.079                            | 0.066     | 0.3616                           | 0.0023    | 0.1226                            | 0.0011    | 1987.2  | 9.4       | 1990  | 11        | 2002                                | 11        | 0.5      |
| 170511-1_25 | 0.37 | 6.260                            | 0.120     | 0.3644                           | 0.0045    | 0.1242                            | 0.0016    | 2012  | 16        | 2003  | 21        | 2017                                | 14        | 1.0      |
| 170511-1_93 | 0.23 | 6.073                            | 0.076     | 0.3605                           | 0.0031    | 0.1254                            | 0.0011    | 1986  | 11        | 1985  | 15        | 2032.7                              | 5         | -1.4     |
| 170511-1_24 | 0.31 | 5.795                            | 0.072     | 0.3319                           | 0.0037    | 0.1268                            | 0.0007    | 1945  | 11        | 1848  | 18        | 2056.2                              | 7.5       | -9.9     |
| 170511-1_94 | 0.08 | 6.185                            | 0.081     | 0.3596                           | 0.0031    | 0.1277                            | 0.0013    | 2002  | 11        | 1980  | 15        | 2066                                | 16        | -2.8     |
| 170511-1_17 | 0.14 | 6.739                            | 0.067     | 0.3801                           | 0.0032    | 0.1280                            | 0.0004    | 2077.6  | 8.7       | 2076  | 15        | 2072.7                              | 2.5       | 1.0      |
| 170511-1_59 | 0.36 | 6.800                            | 0.120     | 0.3821                           | 0.0026    | 0.1294                            | 0.0020    | 2085  | 16        | 2086  | 12        | 2086                                | 19        | 1.5      |
| 170511-1_57 | 0.95 | 7.340                            | 0.120     | 0.3967                           | 0.0057    | 0.1339                            | 0.0015    | 2154  | 14        | 2154  | 26        | 2158                                | 15        | 1.7      |
| 170511-1_85 | 0.13 | 7.552                            | 0.087     | 0.4017                           | 0.0031    | 0.1366                            | 0.0010    | 2179  | 10        | 2177  | 14        | 2184                                | 11        | 0.8      |
| 170511-1_7  | 0.38 | 7.590                            | 0.100     | 0.4017                           | 0.0049    | 0.1367                            | 0.0008    | 2183  | 12        | 2177  | 23        | 2189.5                              | 8.4       | 0.9      |



**Appendix 1.** U-Pb ratio of Jeokbyeok Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170511-1_27 | 0.52 | 7.635                            | 0.093     | 0.4030                           | 0.0029    | 0.1380                            | 0.0010    | 2189  | 11        | 2183  | 13        | 2201.1                              | 9.3       | 0.2      |
| 170511-1_71 | 0.54 | 10.593                           | 0.092     | 0.4719                           | 0.0020    | 0.1619                            | 0.0008    | 2488.1                                      | 8.1       | 2491.7                                      | 8.6       | 2476.4                              | 5.3       | 1.2      |
| 170511-1_6  | 1.25 | 12.960                           | 0.270     | 0.5130                           | 0.0120    | 0.1849                            | 0.0014    | 2676  | 19        | 2667  | 51        | 2690                                | 12        | 1.5      |

**Appendix 2.** U-Pb ratio of Yeonsan Fm. of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-3-9   | 0.55 | 0.194                            | 0.004     | 0.0280                           | 0.0003    | 0.0501                            | 0.0009    | 179.7                                       | 3.5       | 177.9                                       | 1.7       | 210                                 | 20        | 1.9      |
| 170520-3-2   | 0.59 | 0.191                            | 0.003     | 0.0281                           | 0.0002    | 0.0493                            | 0.0008    | 177.7                                       | 2.5       | 178.5                                       | 1.1       | 158                                 | 16        | 2.5      |
| 170520-3-14  | 0.74 | 0.197                            | 0.010     | 0.0281                           | 0.0004    | 0.0508                            | 0.0021    | 182.5                                       | 8.3       | 178.6                                       | 2.7       | 279                                 | 44        | 4.0      |
| 170520-3-7   | 0.70 | 0.192                            | 0.006     | 0.0282                           | 0.0003    | 0.0493                            | 0.0013    | 178.3                                       | 4.7       | 179   | 1.6       | 168                                 | 36        | 3.9      |
| 170520-3-11  | 1.27 | 0.195                            | 0.005     | 0.0282                           | 0.0003    | 0.0505                            | 0.0015    | 181.1                                       | 4.5       | 179   | 2         | 212                                 | 35        | 2.5      |
| 170520-3-25  | 0.67 | 0.191                            | 0.006     | 0.0282                           | 0.0006    | 0.0503                            | 0.0019    | 177.8                                       | 5.3       | 179.1                                       | 3.5       | 203                                 | 46        | 5.6      |
| 170520-3-15  | 0.88 | 0.195                            | 0.003     | 0.0282                           | 0.0002    | 0.0503                            | 0.0006    | 180.6                                       | 2.6       | 179.2                                       | 1.3       | 206                                 | 18        | 1.4      |
| 170520-3-4   | 0.72 | 0.197                            | 0.007     | 0.0282                           | 0.0004    | 0.0508                            | 0.0020    | 182.6                                       | 5.5       | 179.5                                       | 2.5       | 246                                 | 50        | 2.7      |
| 170520-3-17  | 0.72 | 0.194                            | 0.004     | 0.0282                           | 0.0002    | 0.0502                            | 0.0008    | 179.6                                       | 3.1       | 179.5                                       | 1.3       | 202                                 | 23        | 2.4      |
| 170520-3-39  | 0.63 | 0.194                            | 0.004     | 0.0282                           | 0.0003    | 0.0506                            | 0.0009    | 180.2                                       | 3.4       | 179.5                                       | 1.7       | 230                                 | 28        | 2.5      |
| 170520-3-3   | 0.60 | 0.193                            | 0.003     | 0.0284                           | 0.0002    | 0.0491                            | 0.0006    | 179.3                                       | 2.3       | 180.3                                       | 1.3       | 154                                 | 20        | 2.6      |
| 170520-3-32  | 0.68 | 0.196                            | 0.004     | 0.0284                           | 0.0002    | 0.0502                            | 0.0010    | 181.8                                       | 3.3       | 180.5                                       | 1.5       | 219                                 | 36        | 1.9      |
| 170520-3-37  | 0.59 | 0.196                            | 0.004     | 0.0285                           | 0.0002    | 0.0503                            | 0.0011    | 181.4                                       | 3.5       | 181.4                                       | 1.1       | 182                                 | 31        | 2.5      |
| 170520-3-23  | 0.64 | 0.196                            | 0.005     | 0.0286                           | 0.0002    | 0.0488                            | 0.0017    | 181.3                                       | 4.6       | 181.5                                       | 1.2       | 144                                 | 32        | 3.3      |
| 170520-3-82  | 0.58 | 0.197                            | 0.005     | 0.0286                           | 0.0002    | 0.0499                            | 0.0011    | 182.6                                       | 4.4       | 181.7                                       | 1.5       | 191                                 | 21        | 2.8      |
| 170520-3-80  | 0.55 | 0.214                            | 0.007     | 0.0288                           | 0.0005    | 0.0537                            | 0.0016    | 196.8                                       | 5.4       | 182.8                                       | 3.3       | 371                                 | 24        | -2.9     |
| 170520-3-72  | 0.64 | 0.201                            | 0.005     | 0.0289                           | 0.0002    | 0.0507                            | 0.0013    | 186.2                                       | 4.1       | 183.3                                       | 1.4       | 229                                 | 33        | 1.4      |
| 170520-3-100 | 0.56 | 0.200                            | 0.003     | 0.0289                           | 0.0002    | 0.0499                            | 0.0007    | 184.7                                       | 2.7       | 183.61                                      | 0.99      | 203                                 | 21        | 1.4      |
| 170520-3-94  | 0.92 | 0.200                            | 0.004     | 0.0290                           | 0.0003    | 0.0502                            | 0.0010    | 185.2                                       | 3.3       | 184   | 1.6       | 215                                 | 29        | 2.0      |
| 170520-3-44  | 0.54 | 0.199                            | 0.003     | 0.0290                           | 0.0002    | 0.0500                            | 0.0007    | 184.1                                       | 2.3       | 184.1                                       | 1.4       | 205                                 | 21        | 2.0      |

Appendix 2. U-Pb ratio of Yeonsan Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-3-88 | 0.77 | 0.199                            | 0.004     | 0.0290                           | 0.0004    | 0.0498                            | 0.0009    | 184.2                                       | 3.2       | 184.1                                       | 2.5       | 205                              | 28        | 3.0      |
| 170520-3-78 | 0.68 | 0.199                            | 0.002     | 0.0290                           | 0.0003    | 0.0499                            | 0.0004    | 184.1                                       | 1.9       | 184.2                                       | 1.7       | 185.5                            | 8.5       | 2.0      |
| 170520-3-68 | 0.55 | 0.199                            | 0.002     | 0.0290                           | 0.0002    | 0.0495                            | 0.0005    | 184   | 1.7       | 184.25                                      | 0.95      | 165                              | 15        | 1.6      |
| 170520-3-98 | 0.73 | 0.199                            | 0.003     | 0.0290                           | 0.0003    | 0.0501                            | 0.0004    | 184   | 2.6       | 184.5                                       | 1.9       | 191.2                            | 8.7       | 2.7      |
| 170520-3-99 | 0.55 | 0.200                            | 0.005     | 0.0291                           | 0.0003    | 0.0506                            | 0.0014    | 185   | 4.2       | 184.6                                       | 2.1       | 215                              | 42        | 3.2      |
| 170520-3-86 | 0.51 | 0.200                            | 0.004     | 0.0291                           | 0.0003    | 0.0498                            | 0.0010    | 185.3                                       | 3.6       | 185.1                                       | 1.6       | 193                              | 27        | 2.7      |
| 170520-3-34 | 0.45 | 0.200                            | 0.003     | 0.0292                           | 0.0002    | 0.0501                            | 0.0007    | 185   | 2.3       | 185.6                                       | 1         | 210                              | 17        | 2.1      |
| 170520-3-66 | 0.63 | 0.202                            | 0.003     | 0.0294                           | 0.0002    | 0.0495                            | 0.0008    | 186.8                                       | 2.7       | 186.5                                       | 1.5       | 186                              | 15        | 2.1      |
| 170520-3-95 | 0.58 | 0.203                            | 0.006     | 0.0294                           | 0.0002    | 0.0501                            | 0.0017    | 188   | 5.3       | 186.5                                       | 1         | 220                              | 41        | 2.6      |
| 170520-3-49 | 0.57 | 0.203                            | 0.003     | 0.0294                           | 0.0002    | 0.0499                            | 0.0007    | 188   | 2.5       | 186.7                                       | 1.2       | 187                              | 20        | 1.3      |
| 170520-3-27 | 0.64 | 0.204                            | 0.003     | 0.0294                           | 0.0002    | 0.0498                            | 0.0008    | 188.2                                       | 2.7       | 186.8                                       | 1.1       | 193                              | 20        | 1.3      |
| 170520-3-58 | 0.66 | 0.202                            | 0.002     | 0.0294                           | 0.0002    | 0.0499                            | 0.0005    | 186.5                                       | 1.8       | 187.1                                       | 1.1       | 192                              | 14        | 1.9      |
| 170520-3-50 | 0.60 | 0.205                            | 0.004     | 0.0295                           | 0.0002    | 0.0504                            | 0.0008    | 189.1                                       | 3.3       | 187.3                                       | 1.4       | 210                              | 31        | 1.5      |
| 170520-3-62 | 0.64 | 0.204                            | 0.004     | 0.0296                           | 0.0003    | 0.0499                            | 0.0007    | 188.2                                       | 3         | 187.8                                       | 1.6       | 211                              | 15        | 2.2      |
| 170520-3-42 | 0.51 | 0.206                            | 0.005     | 0.0296                           | 0.0002    | 0.0509                            | 0.0010    | 189.7                                       | 3.8       | 187.9                                       | 1.5       | 238                              | 21        | 1.9      |
| 170520-3-53 | 0.62 | 0.203                            | 0.004     | 0.0296                           | 0.0002    | 0.0495                            | 0.0008    | 187.7                                       | 3.1       | 188   | 1.2       | 175                              | 22        | 2.4      |
| 170520-3-74 | 0.54 | 0.205                            | 0.003     | 0.0297                           | 0.0002    | 0.0495                            | 0.0008    | 189   | 2.8       | 188.7                                       | 1.2       | 166                              | 20        | 2.0      |
| 170520-3-43 | 0.92 | 0.205                            | 0.004     | 0.0298                           | 0.0002    | 0.0505                            | 0.0010    | 189.7                                       | 3.6       | 189   | 1.5       | 201                              | 24        | 2.3      |
| 170520-3-46 | 0.60 | 0.203                            | 0.004     | 0.0298                           | 0.0002    | 0.0496                            | 0.0011    | 187.8                                       | 3.7       | 189   | 1.3       | 183                              | 24        | 3.3      |
| 170520-3-59 | 0.50 | 0.204                            | 0.005     | 0.0298                           | 0.0004    | 0.0499                            | 0.0011    | 188.6                                       | 4.4       | 189.2                                       | 2.3       | 195                              | 33        | 3.9      |

**Appendix 2.** U-Pb ratio of Yeonsan Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-3-69 | 0.61 | 0.204                            | 0.003     | 0.0298                           | 0.0002    | 0.0497                            | 0.0008    | 188.7                                       | 2.8       | 189.4                                       | 1.2       | 180                                 | 21        | 2.5      |
| 170520-3-92 | 0.89 | 0.206                            | 0.003     | 0.0298                           | 0.0003    | 0.0501                            | 0.0009    | 190.5                                       | 2.7       | 189.5                                       | 1.8       | 199                                 | 22        | 1.8      |
| 170520-3-54 | 0.58 | 0.206                            | 0.006     | 0.0299                           | 0.0003    | 0.0497                            | 0.0013    | 190.4                                       | 5.1       | 189.6                                       | 2         | 195                                 | 24        | 3.3      |
| 170520-3-31 | 0.72 | 0.231                            | 0.005     | 0.0331                           | 0.0002    | 0.0505                            | 0.0009    | 211.4                                       | 3.9       | 210.1                                       | 1.2       | 230                                 | 26        | 1.8      |
| 170520-3-8  | 0.69 | 0.232                            | 0.004     | 0.0333                           | 0.0003    | 0.0506                            | 0.0010    | 212   | 3.6       | 211.3                                       | 1.7       | 237                                 | 27        | 2.2      |
| 170520-3-5  | 0.57 | 0.234                            | 0.006     | 0.0334                           | 0.0002    | 0.0506                            | 0.0014    | 213.1                                       | 5.2       | 211.6                                       | 1.4       | 230                                 | 33        | 2.4      |
| 170520-3-1  | 0.73 | 0.239                            | 0.003     | 0.0342                           | 0.0002    | 0.0507                            | 0.0004    | 217.2                                       | 2.2       | 216.7                                       | 1.4       | 233                                 | 12        | 1.4      |
| 170520-3-79 | 0.57 | 0.241                            | 0.007     | 0.0342                           | 0.0005    | 0.0512                            | 0.0014    | 219.3                                       | 5.5       | 216.7                                       | 3.1       | 265                                 | 41        | 2.8      |
| 170520-3-12 | 0.45 | 0.239                            | 0.007     | 0.0342                           | 0.0003    | 0.0512                            | 0.0013    | 217.7                                       | 5.5       | 217   | 1.8       | 230                                 | 27        | 3.0      |
| 170520-3-20 | 1.40 | 0.240                            | 0.009     | 0.0342                           | 0.0002    | 0.0507                            | 0.0020    | 218.4                                       | 7.2       | 217   | 1.3       | 247                                 | 35        | 3.3      |
| 170520-3-13 | 0.57 | 0.241                            | 0.006     | 0.0343                           | 0.0004    | 0.0510                            | 0.0013    | 219   | 5.2       | 217.2                                       | 2.2       | 246                                 | 31        | 2.6      |
| 170520-3-24 | 0.30 | 0.240                            | 0.007     | 0.0343                           | 0.0003    | 0.0507                            | 0.0015    | 218.1                                       | 5.8       | 217.6                                       | 1.6       | 231                                 | 44        | 3.2      |
| 170520-3-19 | 0.38 | 0.242                            | 0.010     | 0.0344                           | 0.0002    | 0.0506                            | 0.0021    | 220.1                                       | 8.1       | 217.8                                       | 1.1       | 224                                 | 67        | 3.2      |
| 170520-3-26 | 0.38 | 0.239                            | 0.007     | 0.0344                           | 0.0005    | 0.0505                            | 0.0013    | 217.6                                       | 5.9       | 218.2                                       | 2.9       | 219                                 | 29        | 4.3      |
| 170520-3-91 | 0.41 | 0.241                            | 0.005     | 0.0345                           | 0.0003    | 0.0502                            | 0.0009    | 218.9                                       | 3.8       | 218.6                                       | 1.7       | 211                                 | 22        | 2.4      |
| 170520-3-6  | 0.70 | 0.243                            | 0.007     | 0.0346                           | 0.0004    | 0.0511                            | 0.0014    | 221.1                                       | 5.9       | 219.4                                       | 2.4       | 243                                 | 30        | 3.0      |
| 170520-3-85 | 0.43 | 0.242                            | 0.005     | 0.0347                           | 0.0003    | 0.0505                            | 0.0008    | 220.2                                       | 3.8       | 219.7                                       | 1.7       | 213                                 | 24        | 2.3      |
| 170520-3-89 | 0.51 | 0.243                            | 0.004     | 0.0349                           | 0.0004    | 0.0502                            | 0.0005    | 221.2                                       | 3.1       | 221.1                                       | 2.2       | 204                                 | 17        | 2.4      |
| 170520-3-81 | 0.38 | 0.244                            | 0.003     | 0.0350                           | 0.0003    | 0.0502                            | 0.0004    | 221.4                                       | 2.2       | 222   | 1.6       | 206.5                               | 9.8       | 2.0      |
| 170520-3-61 | 0.48 | 0.246                            | 0.003     | 0.0351                           | 0.0003    | 0.0512                            | 0.0007    | 223.5                                       | 2.5       | 222.1                                       | 1.6       | 252                                 | 21        | 1.2      |

**Appendix 2.** U-Pb ratio of Yeonsan Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-3-40 | 0.54 | 0.245                            | 0.004     | 0.0353                           | 0.0002    | 0.0506                            | 0.0007    | 222.2   | 3.4       | 223.4   | 1.4       | 225                              | 25        | 2.7      |
| 170520-3-56 | 0.32 | 0.248                            | 0.004     | 0.0353                           | 0.0003    | 0.0505                            | 0.0005    | 224.7   | 2.8       | 223.5   | 2.1       | 218.5                            | 8.6       | 1.7      |
| 170520-3-60 | 0.36 | 0.245                            | 0.004     | 0.0353                           | 0.0003    | 0.0505                            | 0.0006    | 222.8   | 3.6       | 223.5   | 2.1       | 230                              | 23        | 2.9      |
| 170520-3-65 | 0.79 | 0.247                            | 0.003     | 0.0353                           | 0.0002    | 0.0509                            | 0.0003    | 224.2   | 2.1       | 223.8   | 1.5       | 228                              | 9.9       | 1.4      |
| 170520-3-96 | 0.47 | 0.247                            | 0.004     | 0.0355                           | 0.0003    | 0.0502                            | 0.0007    | 223.8   | 3.3       | 225   | 1.7       | 214                              | 19        | 2.8      |
| 170520-3-77 | 0.97 | 0.249                            | 0.004     | 0.0356                           | 0.0003    | 0.0511                            | 0.0009    | 225.8   | 3.4       | 225.5   | 2.1       | 240                              | 25        | 2.3      |
| 170520-3-70 | 0.69 | 0.249                            | 0.004     | 0.0356                           | 0.0002    | 0.0506                            | 0.0007    | 225.8   | 3.2       | 225.8   | 1.3       | 226                              | 18        | 2.0      |
| 170520-3-97 | 0.55 | 0.250                            | 0.003     | 0.0357                           | 0.0002    | 0.0511                            | 0.0005    | 226.7   | 2.6       | 225.8   | 1.5       | 242                              | 15        | 1.4      |
| 170520-3-51 | 0.05 | 5.230                            | 0.100     | 0.3341                           | 0.0066    | 0.1125                            | 0.0004    | 1857  | 16        | 1858  | 32        | 1838.9                           | 2.7       | 2.9      |
| 170520-3-67 | 0.07 | 5.233                            | 0.054     | 0.3340                           | 0.0037    | 0.1133                            | 0.0002    | 1857.6  | 8.9       | 1857  | 18        | 1852.6                           | 2.2       | 1.3      |
| 170520-3-87 | 0.08 | 5.182                            | 0.045     | 0.3303                           | 0.0038    | 0.1136                            | 0.0009    | 1849.6  | 7.4       | 1840  | 18        | 1859.2                           | 3.6       | 0.1      |
| 170520-3-63 | 0.33 | 4.550                            | 0.036     | 0.2906                           | 0.0025    | 0.1134                            | 0.0006    | 1740  | 6.7       | 1644  | 13        | 1860.1                           | 7.4       | -11.9    |
| 170520-3-29 | 0.19 | 5.500                            | 0.110     | 0.3420                           | 0.0071    | 0.1149                            | 0.0007    | 1900  | 17        | 1896  | 34        | 1879.2                           | 7.2       | 3.1      |
| 170520-3-38 | 0.25 | 5.282                            | 0.059     | 0.3340                           | 0.0035    | 0.1157                            | 0.0009    | 1865.9  | 9.6       | 1858  | 17        | 1892.6                           | 7.7       | -0.5     |
| 170520-3-35 | 0.40 | 5.421                            | 0.052     | 0.3407                           | 0.0017    | 0.1161                            | 0.0010    | 1888.1  | 8.3       | 1890.1  | 8.3       | 1902                             | 14        | 0.6      |
| 170520-3-93 | 0.30 | 5.415                            | 0.074     | 0.3370                           | 0.0029    | 0.1167                            | 0.0011    | 1887  | 12        | 1872  | 14        | 1909.6                           | 7.3       | -0.9     |
| 170520-3-28 | 0.27 | 5.469                            | 0.032     | 0.3338                           | 0.0024    | 0.1173                            | 0.0011    | 1895.7  | 5         | 1857  | 11        | 1910.1                           | 8.1       | -1.8     |
| 170520-3-45 | 0.07 | 5.479                            | 0.076     | 0.3421                           | 0.0029    | 0.1171                            | 0.0009    | 1897  | 12        | 1897  | 14        | 1912.6                           | 7.2       | 0.3      |
| 170520-3-52 | 0.34 | 5.618                            | 0.055     | 0.3444                           | 0.0043    | 0.1171                            | 0.0014    | 1918.8  | 8.5       | 1908  | 20        | 1913                             | 13        | 1.5      |
| 170520-3-57 | 0.30 | 5.574                            | 0.039     | 0.3452                           | 0.0040    | 0.1170                            | 0.0006    | 1912  | 6         | 1912  | 19        | 1913.1                           | 4.2       | 1.2      |

**Appendix 2.** U-Pb ratio of Yeonsan Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-3-47 | 0.29 | 5.546                            | 0.057     | 0.3438                           | 0.0028    | 0.1175                            | 0.0006    | 1907.5  | 8.8       | 1905  | 13        | 1918                             | 5.1       | 0.3      |
| 170520-3-90 | 0.05 | 5.566                            | 0.046     | 0.3427                           | 0.0030    | 0.1175                            | 0.0006    | 1910.9  | 7.1       | 1900  | 14        | 1919.6                           | 8.7       | 0.2      |
| 170520-3-71 | 0.12 | 5.445                            | 0.081     | 0.3389                           | 0.0070    | 0.1173                            | 0.0008    | 1892  | 13        | 1881  | 33        | 1920.7                           | 8         | 0.1      |
| 170520-3-73 | 0.38 | 5.666                            | 0.075     | 0.3483                           | 0.0037    | 0.1178                            | 0.0007    | 1926  | 12        | 1926  | 17        | 1923.6                           | 7.2       | 1.4      |
| 170520-3-48 | 0.39 | 5.687                            | 0.095     | 0.3493                           | 0.0057    | 0.1182                            | 0.0008    | 1929  | 14        | 1931  | 27        | 1928.1                           | 7.5       | 1.9      |
| 170520-3-33 | 0.38 | 5.534                            | 0.084     | 0.3417                           | 0.0066    | 0.1183                            | 0.0010    | 1906  | 13        | 1895  | 32        | 1935                             | 4.8       | -0.2     |
| 170520-3-22 | 0.14 | 5.698                            | 0.034     | 0.3492                           | 0.0020    | 0.1186                            | 0.0002    | 1929.7  | 4.7       | 1930.6  | 9.8       | 1936.4                           | 3.1       | 0.4      |
| 170520-3-55 | 0.31 | 5.300                            | 0.054     | 0.3216                           | 0.0026    | 0.1189                            | 0.0006    | 1870.5  | 8.2       | 1798  | 13        | 1938.8                           | 6         | -6.8     |
| 170520-3-10 | 0.31 | 5.714                            | 0.024     | 0.3498                           | 0.0016    | 0.1188                            | 0.0004    | 1933.5  | 3.6       | 1933.7  | 7.8       | 1939.2                           | 4.7       | 0.4      |
| 170520-3-84 | 0.41 | 5.832                            | 0.039     | 0.3534                           | 0.0024    | 0.1195                            | 0.0004    | 1951.1  | 5.8       | 1951  | 11        | 1950                             | 3.4       | 0.8      |
| 170520-3-36 | 0.32 | 5.743                            | 0.056     | 0.3507                           | 0.0027    | 0.1199                            | 0.0004    | 1937.5  | 8.3       | 1938  | 13        | 1954.2                           | 3.1       | 0.0      |
| 170520-3-83 | 0.38 | 5.842                            | 0.089     | 0.3533                           | 0.0043    | 0.1201                            | 0.0007    | 1952  | 13        | 1950  | 20        | 1957.8                           | 8         | 1.0      |
| 170520-3-64 | 0.25 | 5.832                            | 0.073     | 0.3533                           | 0.0043    | 0.1204                            | 0.0006    | 1951  | 11        | 1950  | 20        | 1963.6                           | 6.2       | 0.6      |
| 170520-3-76 | 0.56 | 5.940                            | 0.180     | 0.3560                           | 0.0100    | 0.1206                            | 0.0004    | 1966  | 26        | 1961  | 48        | 1967                             | 3.9       | 2.3      |
| 170520-3-75 | 0.29 | 5.985                            | 0.081     | 0.3571                           | 0.0035    | 0.1214                            | 0.0009    | 1973  | 12        | 1969  | 17        | 1973.8                           | 6.2       | 0.9      |
| 170520-3-16 | 0.46 | 6.063                            | 0.066     | 0.3613                           | 0.0030    | 0.1214                            | 0.0010    | 1985  | 9.5       | 1988  | 14        | 1976.6                           | 8.8       | 1.7      |
| 170520-3-18 | 0.36 | 6.024                            | 0.034     | 0.3592                           | 0.0015    | 0.1221                            | 0.0007    | 1979.3  | 5         | 1978.2  | 7         | 1987.3                           | 5.1       | 0.2      |
| 170520-3-41 | 0.34 | 10.710                           | 0.130     | 0.4720                           | 0.0040    | 0.1660                            | 0.0011    | 2498  | 11        | 2492  | 18        | 2520                             | 5.3       | -0.2     |
| 170520-3-21 | 0.22 | 11.200                           | 1.000     | 0.4750                           | 0.0340    | 0.1757                            | 0.0048    | 2551  | 90        | 2500  | 150       | 2620                             | 22        | 2.1      |
| 170520-3-30 | 0.48 | 2.270                            | 0.530     | 0.0453                           | 0.0043    | 0.2980                            | 0.0480    | 1030  | 170       | 285   | 26        | 3100                             | 310       | -869.8   |

**Appendix 3.** U-Pb ratio of Oyeri Fm.(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-5-85 | 0.95 | 0.093                            | 0.005     | 0.0138                           | 0.0002    | 0.0489                            | 0.0026    | 90.6  | 4.7       | 88  | 1         | 287                                 | 81        | 3.5      |
| 170520-5-76 | 2.02 | 0.091                            | 0.002     | 0.0138                           | 0.0001    | 0.0475                            | 0.0009    | 88.3  | 1.5       | 88.08                                       | 0.43      | 124                                 | 19        | 1.9      |
| 170520-5-34 | 1.22 | 0.092                            | 0.009     | 0.0140                           | 0.0003    | 0.0478                            | 0.0044    | 88.8  | 8         | 89.6  | 1.8       | 356                                 | 74        | 11.8     |
| 170520-5-11 | 1.51 | 0.095                            | 0.005     | 0.0142                           | 0.0002    | 0.0486                            | 0.0027    | 91.5  | 4.6       | 90.6  | 1.3       | 206                                 | 57        | 5.5      |
| 170520-5-52 | 1.31 | 0.094                            | 0.003     | 0.0143                           | 0.0001    | 0.0471                            | 0.0015    | 91.4  | 2.7       | 91.62                                       | 0.8       | 153                                 | 27        | 4.1      |
| 170520-5-46 | 0.97 | 0.097                            | 0.004     | 0.0143                           | 0.0002    | 0.0492                            | 0.0021    | 93.9  | 4         | 91.8  | 1.1       | 159                                 | 45        | 3.3      |
| 170520-5-72 | 1.71 | 0.096                            | 0.005     | 0.0144                           | 0.0002    | 0.0485                            | 0.0029    | 92.8  | 4.9       | 92  | 1.2       | 279                                 | 51        | 5.8      |
| 170520-5-9  | 1.16 | 0.095                            | 0.003     | 0.0144                           | 0.0001    | 0.0480                            | 0.0014    | 92.5  | 2.6       | 92.07                                       | 0.66      | 167                                 | 36        | 3.1      |
| 170520-5-37 | 1.52 | 0.096                            | 0.005     | 0.0144                           | 0.0002    | 0.0506                            | 0.0025    | 94.8  | 4.5       | 92.1  | 1         | 326                                 | 67        | 3.0      |
| 170520-5-25 | 0.84 | 0.095                            | 0.001     | 0.0144                           | 0.0001    | 0.0479                            | 0.0007    | 92.4  | 1.3       | 92.18                                       | 0.48      | 101                                 | 19        | 1.7      |
| 170520-5-87 | 1.07 | 0.106                            | 0.016     | 0.0145                           | 0.0005    | 0.0540                            | 0.0082    | 103   | 15        | 92.5  | 3.4       | 390                                 | 170       | 8.5      |
| 170520-5-49 | 1.80 | 0.098                            | 0.008     | 0.0145                           | 0.0002    | 0.0492                            | 0.0037    | 94.3  | 6.9       | 92.56                                       | 0.99      | 260                                 | 100       | 6.6      |
| 170520-5-26 | 1.39 | 0.098                            | 0.011     | 0.0145                           | 0.0002    | 0.0489                            | 0.0053    | 94.6  | 9.9       | 92.6  | 1.4       | 425                                 | 83        | 10.0     |
| 170520-5-48 | 1.10 | 0.096                            | 0.003     | 0.0145                           | 0.0002    | 0.0489                            | 0.0015    | 93.3  | 3.3       | 92.6  | 1.5       | 182                                 | 29        | 4.4      |
| 170520-5-50 | 1.50 | 0.096                            | 0.007     | 0.0145                           | 0.0003    | 0.0467                            | 0.0029    | 92.5  | 6         | 92.6  | 1.6       | 260                                 | 130       | 8.3      |
| 170520-5-40 | 1.09 | 0.096                            | 0.003     | 0.0145                           | 0.0002    | 0.0482                            | 0.0019    | 92.6  | 3.2       | 92.7  | 1.2       | 177                                 | 46        | 4.9      |
| 170520-5-45 | 1.39 | 0.099                            | 0.009     | 0.0145                           | 0.0003    | 0.0497                            | 0.0046    | 95.8  | 8.1       | 92.7  | 1.6       | 420                                 | 82        | 7.1      |
| 170520-5-15 | 1.58 | 0.097                            | 0.008     | 0.0145                           | 0.0003    | 0.0491                            | 0.0041    | 94  | 7.5       | 92.9  | 1.7       | 440                                 | 110       | 8.7      |
| 170520-5-24 | 1.12 | 0.096                            | 0.005     | 0.0145                           | 0.0002    | 0.0479                            | 0.0025    | 93.5  | 4.4       | 92.9  | 1.2       | 176                                 | 49        | 5.4      |
| 170520-5-53 | 2.23 | 0.097                            | 0.003     | 0.0145                           | 0.0002    | 0.0484                            | 0.0012    | 93.6  | 3         | 93  | 1.3       | 148                                 | 45        | 4.0      |



**Appendix 3.** U-Pb ratio of Oyeri Fm.(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-5-77 | 1.15 | 0.097                            | 0.005     | 0.0145                           | 0.0002    | 0.0487                            | 0.0026    | 94.1  | 4.7       | 93  | 1.3       | 297                                 | 48        | 5.3      |
| 170520-5-70 | 1.07 | 0.098                            | 0.004     | 0.0145                           | 0.0002    | 0.0484                            | 0.0019    | 94.3  | 3.8       | 93.07                                       | 0.95      | 230                                 | 42        | 3.8      |
| 170520-5-38 | 1.07 | 0.099                            | 0.008     | 0.0146                           | 0.0002    | 0.0498                            | 0.0037    | 95.8  | 6.9       | 93.1  | 1.4       | 233                                 | 54        | 6.0      |
| 170520-5-41 | 1.01 | 0.095                            | 0.004     | 0.0146                           | 0.0002    | 0.0469                            | 0.0020    | 91.6  | 3.9       | 93.1  | 1         | 117                                 | 29        | 6.9      |
| 170520-5-67 | 1.14 | 0.096                            | 0.006     | 0.0146                           | 0.0002    | 0.0478                            | 0.0029    | 92.5  | 5.1       | 93.1  | 1.4       | 275                                 | 73        | 7.6      |
| 170520-5-81 | 1.07 | 0.097                            | 0.008     | 0.0145                           | 0.0002    | 0.0486                            | 0.0039    | 94  | 7.3       | 93.1  | 1.3       | 332                                 | 63        | 8.3      |
| 170520-5-69 | 0.77 | 0.096                            | 0.002     | 0.0146                           | 0.0001    | 0.0483                            | 0.0007    | 93.3  | 1.5       | 93.11                                       | 0.67      | 112                                 | 20        | 2.1      |
| 170520-5-14 | 1.75 | 0.099                            | 0.006     | 0.0146                           | 0.0002    | 0.0490                            | 0.0029    | 95.2  | 5.4       | 93.2  | 1.1       | 281                                 | 60        | 4.8      |
| 170520-5-20 | 1.35 | 0.097                            | 0.004     | 0.0146                           | 0.0002    | 0.0481                            | 0.0016    | 93.6  | 3.3       | 93.3  | 1.1       | 147                                 | 29        | 4.4      |
| 170520-5-31 | 1.15 | 0.091                            | 0.015     | 0.0146                           | 0.0003    | 0.0450                            | 0.0075    | 87  | 14        | 93.3  | 1.8       | 390                                 | 140       | 23.7     |
| 170520-5-17 | 0.72 | 0.097                            | 0.003     | 0.0146                           | 0.0001    | 0.0487                            | 0.0020    | 93.7  | 3.1       | 93.31                                       | 0.88      | 200                                 | 43        | 3.8      |
| 170520-5-47 | 1.54 | 0.097                            | 0.008     | 0.0146                           | 0.0003    | 0.0480                            | 0.0038    | 93.6  | 7.7       | 93.4  | 2.1       | 187                                 | 73        | 10.3     |
| 170520-5-23 | 1.18 | 0.096                            | 0.012     | 0.0146                           | 0.0003    | 0.0471                            | 0.0057    | 92  | 11        | 93.5  | 1.8       | 370                                 | 120       | 15.3     |
| 170520-5-27 | 0.80 | 0.096                            | 0.006     | 0.0146                           | 0.0002    | 0.0474                            | 0.0030    | 92.8  | 5.6       | 93.5  | 1.1       | 310                                 | 46        | 7.9      |
| 170520-5-74 | 1.15 | 0.097                            | 0.005     | 0.0146                           | 0.0002    | 0.0479                            | 0.0020    | 93.4  | 4.3       | 93.5  | 1.3       | 227                                 | 50        | 6.1      |
| 170520-5-63 | 0.97 | 0.097                            | 0.001     | 0.0146                           | 0.0001    | 0.0482                            | 0.0005    | 93.68                                       | 0.96      | 93.54                                       | 0.53      | 108                                 | 10        | 1.4      |
| 170520-5-56 | 1.25 | 0.096                            | 0.003     | 0.0146                           | 0.0001    | 0.0477                            | 0.0016    | 93  | 3         | 93.56                                       | 0.89      | 159                                 | 43        | 4.8      |
| 170520-5-54 | 0.63 | 0.097                            | 0.001     | 0.0146                           | 0.0001    | 0.0478                            | 0.0004    | 93.8  | 1         | 93.57                                       | 0.72      | 84.2                                | 9.6       | 1.6      |
| 170520-5-13 | 1.30 | 0.099                            | 0.006     | 0.0146                           | 0.0002    | 0.0503                            | 0.0031    | 97.3  | 5.5       | 93.6  | 1.1       | 275                                 | 41        | 3.1      |
| 170520-5-66 | 0.94 | 0.092                            | 0.015     | 0.0146                           | 0.0003    | 0.0451                            | 0.0072    | 93  | 15        | 93.6  | 2.1       | 350                                 | 140       | 18.9     |

**Appendix 3.** U-Pb ratio of Oyeri Fm.(tuff) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-5-90  | 1.62 | 0.098                            | 0.003     | 0.0146                           | 0.0001    | 0.0488                            | 0.0015    | 94.8  | 2.5       | 93.66                                       | 0.82      | 157                                 | 34        | 2.3      |
| 170520-5-68  | 1.35 | 0.096                            | 0.004     | 0.0146                           | 0.0001    | 0.0473                            | 0.0019    | 92.9  | 3.8       | 93.69                                       | 0.89      | 238                                 | 52        | 5.8      |
| 170520-5-19  | 1.10 | 0.096                            | 0.011     | 0.0146                           | 0.0003    | 0.0482                            | 0.0058    | 93  | 11        | 93.7  | 1.7       | 477                                 | 67        | 14.3     |
| 170520-5-95  | 1.35 | 0.097                            | 0.004     | 0.0146                           | 0.0002    | 0.0482                            | 0.0020    | 93.8  | 3.4       | 93.7  | 1.1       | 180                                 | 44        | 4.7      |
| 170520-5-32  | 1.32 | 0.097                            | 0.016     | 0.0147                           | 0.0002    | 0.0484                            | 0.0083    | 93  | 15        | 93.8  | 1.4       | 370                                 | 110       | 18.3     |
| 170520-5-35  | 1.14 | 0.097                            | 0.007     | 0.0147                           | 0.0002    | 0.0471                            | 0.0033    | 93.7  | 6.8       | 93.8  | 1.5       | 340                                 | 110       | 9.0      |
| 170520-5-65  | 1.05 | 0.098                            | 0.007     | 0.0147                           | 0.0002    | 0.0484                            | 0.0033    | 94.4  | 6.2       | 93.8  | 1.2       | 306                                 | 57        | 7.2      |
| 170520-5-7   | 1.39 | 0.099                            | 0.004     | 0.0147                           | 0.0001    | 0.0488                            | 0.0018    | 95.6  | 3.7       | 93.83                                       | 0.87      | 172                                 | 42        | 3.0      |
| 170520-5-100 | 1.11 | 0.099                            | 0.004     | 0.0147                           | 0.0001    | 0.0489                            | 0.0020    | 95.8  | 3.7       | 93.88                                       | 0.72      | 173                                 | 37        | 2.7      |
| 170520-5-21  | 1.06 | 0.097                            | 0.005     | 0.0147                           | 0.0002    | 0.0474                            | 0.0025    | 93.6  | 4.7       | 93.9  | 1.1       | 259                                 | 47        | 6.5      |
| 170520-5-10  | 1.02 | 0.099                            | 0.006     | 0.0147                           | 0.0002    | 0.0489                            | 0.0029    | 97  | 5.5       | 94  | 1.2       | 268                                 | 63        | 3.9      |
| 170520-5-73  | 1.46 | 0.101                            | 0.006     | 0.0147                           | 0.0002    | 0.0492                            | 0.0031    | 97.3  | 5.7       | 94  | 1.4       | 272                                 | 75        | 4.0      |
| 170520-5-88  | 0.75 | 0.098                            | 0.004     | 0.0147                           | 0.0001    | 0.0489                            | 0.0022    | 94.6  | 3.9       | 94.07                                       | 0.82      | 179                                 | 56        | 4.5      |
| 170520-5-1   | 1.37 | 0.097                            | 0.005     | 0.0147                           | 0.0002    | 0.0480                            | 0.0025    | 94.3  | 5         | 94.1  | 1         | 235                                 | 69        | 6.2      |
| 170520-5-2   | 1.12 | 0.099                            | 0.009     | 0.0147                           | 0.0002    | 0.0481                            | 0.0041    | 95.4  | 7.8       | 94.1  | 1.3       | 220                                 | 74        | 8.3      |
| 170520-5-4   | 1.19 | 0.099                            | 0.014     | 0.0147                           | 0.0003    | 0.0491                            | 0.0070    | 98  | 13        | 94.1  | 1.8       | 450                                 | 120       | 11.6     |
| 170520-5-12  | 1.47 | 0.098                            | 0.005     | 0.0147                           | 0.0002    | 0.0483                            | 0.0022    | 95.2  | 4.2       | 94.23                                       | 0.94      | 172                                 | 55        | 4.4      |
| 170520-5-58  | 1.01 | 0.098                            | 0.002     | 0.0147                           | 0.0001    | 0.0482                            | 0.0008    | 94.8  | 1.8       | 94.26                                       | 0.66      | 141                                 | 21        | 2.0      |
| 170520-5-82  | 1.25 | 0.098                            | 0.002     | 0.0147                           | 0.0001    | 0.0485                            | 0.0011    | 94.5  | 2         | 94.28                                       | 0.65      | 153                                 | 32        | 2.6      |
| 170520-5-75  | 1.29 | 0.100                            | 0.006     | 0.0147                           | 0.0002    | 0.0490                            | 0.0030    | 96.4  | 5.9       | 94.3  | 1.4       | 296                                 | 69        | 5.5      |

**Appendix 3.** U-Pb ratio of Oyeri Fm.(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-5-99 | 1.72 | 0.101                            | 0.007     | 0.0147                           | 0.0002    | 0.0501                            | 0.0034    | 97.3  | 6.4       | 94.3  | 1.2       | 360                                 | 76        | 4.9      |
| 170520-5-92 | 1.69 | 0.099                            | 0.005     | 0.0147                           | 0.0002    | 0.0488                            | 0.0024    | 95.7  | 4.7       | 94.36                                       | 0.96      | 253                                 | 45        | 4.6      |
| 170520-5-80 | 1.46 | 0.094                            | 0.007     | 0.0148                           | 0.0003    | 0.0460                            | 0.0034    | 90.5  | 6.4       | 94.4  | 1.8       | 257                                 | 60        | 12.8     |
| 170520-5-83 | 1.06 | 0.097                            | 0.008     | 0.0148                           | 0.0002    | 0.0498                            | 0.0055    | 93.6  | 7.6       | 94.4  | 1.5       | 300                                 | 150       | 10.5     |
| 170520-5-96 | 1.28 | 0.098                            | 0.005     | 0.0148                           | 0.0001    | 0.0495                            | 0.0025    | 95.9  | 4.5       | 94.4  | 0.91      | 251                                 | 51        | 4.1      |
| 170520-5-61 | 0.67 | 0.098                            | 0.001     | 0.0148                           | 0.0002    | 0.0481                            | 0.0006    | 94.4  | 1.2       | 94.49                                       | 0.99      | 95                                  | 20        | 2.4      |
| 170520-5-79 | 1.29 | 0.097                            | 0.004     | 0.0148                           | 0.0002    | 0.0470                            | 0.0016    | 93.9  | 3.2       | 94.5  | 1.2       | 179                                 | 44        | 5.3      |
| 170520-5-51 | 1.39 | 0.103                            | 0.012     | 0.0148                           | 0.0002    | 0.0505                            | 0.0056    | 100   | 11        | 94.6  | 1.4       | 280                                 | 88        | 7.4      |
| 170520-5-91 | 1.29 | 0.099                            | 0.008     | 0.0148                           | 0.0003    | 0.0487                            | 0.0043    | 96.1  | 7.5       | 94.6  | 1.6       | 233                                 | 61        | 8.0      |
| 170520-5-44 | 0.86 | 0.098                            | 0.003     | 0.0148                           | 0.0001    | 0.0485                            | 0.0014    | 95.2  | 2.5       | 94.66                                       | 0.88      | 122                                 | 33        | 3.0      |
| 170520-5-22 | 1.03 | 0.101                            | 0.006     | 0.0148                           | 0.0003    | 0.0494                            | 0.0029    | 97.4  | 5.7       | 94.7  | 1.9       | 166                                 | 53        | 5.2      |
| 170520-5-43 | 1.73 | 0.096                            | 0.008     | 0.0148                           | 0.0004    | 0.0463                            | 0.0039    | 92.6  | 7.1       | 94.8  | 2.3       | 240                                 | 140       | 12.2     |
| 170520-5-60 | 1.12 | 0.096                            | 0.006     | 0.0148                           | 0.0002    | 0.0471                            | 0.0029    | 93  | 5.2       | 94.9  | 1.1       | 318                                 | 69        | 8.6      |
| 170520-5-71 | 0.96 | 0.098                            | 0.002     | 0.0148                           | 0.0001    | 0.0480                            | 0.0006    | 95.2  | 1.4       | 94.97                                       | 0.59      | 100                                 | 18        | 1.9      |
| 170520-5-28 | 1.14 | 0.098                            | 0.010     | 0.0149                           | 0.0002    | 0.0479                            | 0.0045    | 94.8  | 8.8       | 95  | 1.4       | 440                                 | 120       | 10.9     |
| 170520-5-36 | 0.75 | 0.098                            | 0.003     | 0.0148                           | 0.0003    | 0.0478                            | 0.0010    | 95  | 2.3       | 95  | 1.8       | 99                                  | 26        | 4.3      |
| 170520-5-42 | 1.83 | 0.094                            | 0.022     | 0.0149                           | 0.0004    | 0.0460                            | 0.0110    | 91  | 20        | 95.1  | 2.8       | 460                                 | 180       | 28.3     |
| 170520-5-93 | 1.68 | 0.106                            | 0.019     | 0.0149                           | 0.0006    | 0.0517                            | 0.0084    | 102   | 17        | 95.3  | 3.5       | 290                                 | 120       | 14.5     |
| 170520-5-86 | 0.74 | 0.100                            | 0.002     | 0.0149                           | 0.0001    | 0.0485                            | 0.0010    | 96.4  | 1.9       | 95.4  | 0.54      | 166                                 | 27        | 1.5      |
| 170520-5-62 | 0.91 | 0.099                            | 0.001     | 0.0149                           | 0.0001    | 0.0480                            | 0.0003    | 95.5  | 0.7       | 95.45                                       | 0.47      | 101.8                               | 8.3       | 1.2      |

**Appendix 3.** U-Pb ratio of Oyeri Fm.(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-5-97 | 0.84 | 0.099                            | 0.001     | 0.0149                           | 0.0001    | 0.0482                            | 0.0004    | 95.98                                       | 0.83      | 95.45                                       | 0.51      | 118.9                               | 9.8       | 0.8      |
| 170520-5-84 | 1.02 | 0.099                            | 0.004     | 0.0149                           | 0.0002    | 0.0480                            | 0.0014    | 96  | 3.4       | 95.47                                       | 0.93      | 130                                 | 25        | 4.0      |
| 170520-5-59 | 1.25 | 0.099                            | 0.004     | 0.0149                           | 0.0001    | 0.0484                            | 0.0019    | 96.3  | 3.5       | 95.53                                       | 0.84      | 220                                 | 35        | 3.7      |
| 170520-5-16 | 0.98 | 0.100                            | 0.005     | 0.0150                           | 0.0001    | 0.0479                            | 0.0020    | 96.6  | 4.4       | 95.77                                       | 0.9       | 187                                 | 81        | 4.7      |
| 170520-5-89 | 0.91 | 0.098                            | 0.003     | 0.0150                           | 0.0002    | 0.0484                            | 0.0017    | 94.6  | 2.9       | 95.8  | 1.2       | 147                                 | 42        | 5.5      |
| 170520-5-94 | 1.11 | 0.102                            | 0.008     | 0.0150                           | 0.0002    | 0.0502                            | 0.0038    | 98.1  | 7         | 95.8  | 1.5       | 338                                 | 90        | 6.5      |
| 170520-5-98 | 0.88 | 0.100                            | 0.001     | 0.0150                           | 0.0001    | 0.0482                            | 0.0005    | 96.3  | 1.3       | 95.87                                       | 0.7       | 113                                 | 11        | 1.6      |
| 170520-5-6  | 1.18 | 0.103                            | 0.011     | 0.0150                           | 0.0003    | 0.0501                            | 0.0054    | 99  | 10        | 96  | 1.8       | 550                                 | 100       | 9.2      |
| 170520-5-55 | 1.15 | 0.102                            | 0.007     | 0.0150                           | 0.0002    | 0.0487                            | 0.0033    | 98.5  | 6.2       | 96  | 1.5       | 247                                 | 74        | 5.4      |
| 170520-5-78 | 0.97 | 0.095                            | 0.012     | 0.0150                           | 0.0007    | 0.0448                            | 0.0071    | 92  | 11        | 96  | 4.3       | 140                                 | 120       | 20.1     |
| 170520-5-3  | 1.13 | 0.101                            | 0.012     | 0.0150                           | 0.0004    | 0.0486                            | 0.0051    | 98  | 11        | 96.1  | 2.4       | 200                                 | 100       | 12.0     |
| 170520-5-33 | 1.38 | 0.099                            | 0.009     | 0.0150                           | 0.0004    | 0.0484                            | 0.0050    | 95.2  | 8.5       | 96.2  | 2.3       | 390                                 | 120       | 12.3     |
| 170520-5-39 | 0.93 | 0.100                            | 0.006     | 0.0151                           | 0.0002    | 0.0483                            | 0.0033    | 96.9  | 5.3       | 96.4  | 1.6       | 140                                 | 110       | 6.6      |
| 170520-5-29 | 0.82 | 0.100                            | 0.005     | 0.0152                           | 0.0003    | 0.0474                            | 0.0022    | 96.9  | 4.6       | 96.9  | 1.7       | 211                                 | 43        | 6.5      |
| 170520-5-18 | 1.10 | 0.099                            | 0.012     | 0.0152                           | 0.0004    | 0.0474                            | 0.0058    | 95  | 11        | 97.1  | 2.6       | 147                                 | 95        | 16.2     |
| 170520-5-64 | 1.28 | 0.100                            | 0.007     | 0.0152                           | 0.0002    | 0.0500                            | 0.0031    | 99.1  | 6.1       | 97.4  | 1.5       | 257                                 | 58        | 6.1      |
| 170520-5-5  | 0.60 | 0.102                            | 0.006     | 0.0153                           | 0.0002    | 0.0482                            | 0.0026    | 98.5  | 5.3       | 97.8  | 1.5       | 147                                 | 44        | 6.2      |
| 170520-5-30 | 1.04 | 0.103                            | 0.011     | 0.0155                           | 0.0003    | 0.0480                            | 0.0050    | 99  | 10        | 99.1  | 2.1       | 353                                 | 90        | 12.3     |
| 170520-5-8  | 1.20 | 0.105                            | 0.038     | 0.0156                           | 0.0007    | 0.0480                            | 0.0170    | 99  | 35        | 99.8  | 4.1       | 610                                 | 220       | 40.0     |
| 170520-5-57 | 0.34 | 0.176                            | 0.002     | 0.0258                           | 0.0002    | 0.0498                            | 0.0005    | 164.3                                       | 1.5       | 164.5                                       | 1         | 197                                 | 12        | 1.6      |

**Appendix 4.** U-Pb ratio of Oyeri Fm.(conglomerate) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-6-57 | 0.16 | 0.186                            | 0.002     | 0.0272                           | 0.0002    | 0.0495                            | 0.0005    | 173.4                                       | 1.3       | 173   | 1.1       | 172                                 | 14        | 1.2      |
| 170520-6-42 | 0.20 | 0.187                            | 0.002     | 0.0273                           | 0.0001    | 0.0494                            | 0.0005    | 174.4                                       | 1.5       | 173.62                                      | 0.69      | 168                                 | 13        | 0.8      |
| 170520-6-1  | 0.46 | 0.190                            | 0.003     | 0.0278                           | 0.0002    | 0.0497                            | 0.0006    | 177   | 2.4       | 176.9                                       | 1.3       | 186                                 | 24        | 2.0      |
| 170520-6-7  | 0.34 | 0.191                            | 0.005     | 0.0282                           | 0.0002    | 0.0489                            | 0.0012    | 177.5                                       | 4         | 179   | 1.2       | 163                                 | 34        | 3.7      |
| 170520-6-95 | 0.34 | 0.196                            | 0.003     | 0.0286                           | 0.0001    | 0.0494                            | 0.0008    | 181.6                                       | 2.9       | 181.75                                      | 0.88      | 176                                 | 19        | 2.2      |
| 170520-6-32 | 0.57 | 0.197                            | 0.006     | 0.0287                           | 0.0004    | 0.0496                            | 0.0014    | 182.6                                       | 5.1       | 182.5                                       | 2.4       | 207                                 | 32        | 4.1      |
| 170520-6-53 | 0.63 | 0.201                            | 0.003     | 0.0293                           | 0.0002    | 0.0497                            | 0.0007    | 186.1                                       | 2.9       | 186.2                                       | 1.1       | 180                                 | 23        | 2.2      |
| 170520-6-54 | 0.40 | 0.207                            | 0.007     | 0.0294                           | 0.0004    | 0.0504                            | 0.0019    | 191   | 5.5       | 186.7                                       | 2.7       | 228                                 | 37        | 2.1      |
| 170520-6-85 | 1.77 | 0.204                            | 0.005     | 0.0296                           | 0.0003    | 0.0493                            | 0.0014    | 188.1                                       | 4.1       | 188.3                                       | 1.9       | 190                                 | 27        | 3.3      |
| 170520-6-63 | 1.17 | 0.205                            | 0.007     | 0.0297                           | 0.0003    | 0.0499                            | 0.0018    | 189   | 6.1       | 188.7                                       | 1.9       | 234                                 | 36        | 4.1      |
| 170520-6-93 | 0.18 | 0.209                            | 0.004     | 0.0303                           | 0.0002    | 0.0497                            | 0.0008    | 192.9                                       | 3.1       | 192.6                                       | 1.3       | 189                                 | 29        | 2.1      |
| 170520-6-94 | 0.60 | 0.212                            | 0.013     | 0.0308                           | 0.0005    | 0.0502                            | 0.0019    | 195   | 11        | 195.6                                       | 3         | 197                                 | 34        | 7.5      |
| 170520-6-90 | 0.20 | 0.220                            | 0.002     | 0.0310                           | 0.0001    | 0.0515                            | 0.0004    | 201.7                                       | 1.3       | 196.88                                      | 0.54      | 263.9                               | 8.2       | -1.5     |
| 170520-6-2  | 1.68 | 0.212                            | 0.009     | 0.0315                           | 0.0004    | 0.0488                            | 0.0021    | 194.8                                       | 7.9       | 200.1                                       | 2.2       | 262                                 | 45        | 7.7      |
| 170520-6-17 | 1.70 | 0.219                            | 0.004     | 0.0318                           | 0.0002    | 0.0505                            | 0.0008    | 201.1                                       | 3.1       | 201.7                                       | 1.4       | 211                                 | 23        | 2.5      |
| 170520-6-35 | 0.55 | 0.252                            | 0.003     | 0.0359                           | 0.0004    | 0.0511                            | 0.0006    | 227.8                                       | 2.7       | 227.6                                       | 2.2       | 229                                 | 18        | 2.1      |
| 170520-6-45 | 0.01 | 2.425                            | 0.024     | 0.1601                           | 0.0013    | 0.1085                            | 0.0007    | 1249.8                                      | 7.3       | 957.6                                       | 7.1       | 1774.8                              | 9.7       | -83.6    |
| 170520-6-68 | 0.03 | 2.494                            | 0.019     | 0.1659                           | 0.0011    | 0.1092                            | 0.0004    | 1270.1                                      | 5.6       | 989.3                                       | 6.3       | 1786.7                              | 4.2       | -79.5    |
| 170520-6-11 | 0.15 | 2.919                            | 0.034     | 0.1779                           | 0.0017    | 0.1190                            | 0.0005    | 1386.3                                      | 8.7       | 1055.5                                      | 9.5       | 1940.8                              | 5.8       | -82.4    |
| 170520-6-75 | 0.21 | 3.328                            | 0.048     | 0.2189                           | 0.0026    | 0.1101                            | 0.0007    | 1487  | 11        | 1276  | 14        | 1802.6                              | 9.1       | -39.5    |

**Appendix 4.** U-Pb ratio of Oyeri Fm.(conglomerate) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-6-39 | 0.24 | 4.869                            | 0.053     | 0.2361                           | 0.0016    | 0.1492                            | 0.0008    | 1796.8                                      | 9.1       | 1366.2                                      | 8.5       | 2334                             | 6.7       | -69.7    |
| 170520-6-23 | 0.04 | 3.871                            | 0.061     | 0.2518                           | 0.0034    | 0.1114                            | 0.0003    | 1607  | 13        | 1448  | 18        | 1821.7                           | 3.8       | -24.3    |
| 170520-6-76 | 0.18 | 4.117                            | 0.060     | 0.2662                           | 0.0036    | 0.1125                            | 0.0005    | 1658  | 12        | 1521  | 19        | 1838.9                           | 3.7       | -19.4    |
| 170520-6-37 | 0.17 | 4.207                            | 0.033     | 0.2663                           | 0.0021    | 0.1146                            | 0.0006    | 1675.2                                      | 6.5       | 1522  | 11        | 1875.7                           | 6.4       | -22.1    |
| 170520-6-56 | 0.16 | 4.146                            | 0.065     | 0.2685                           | 0.0032    | 0.1123                            | 0.0005    | 1666  | 11        | 1533  | 16        | 1837.7                           | 7         | -18.4    |
| 170520-6-14 | 0.21 | 4.198                            | 0.051     | 0.2717                           | 0.0033    | 0.1115                            | 0.0004    | 1673  | 10        | 1549  | 17        | 1826.7                           | 3.3       | -16.6    |
| 170520-6-44 | 0.01 | 4.408                            | 0.033     | 0.2829                           | 0.0019    | 0.1126                            | 0.0002    | 1713.6                                      | 6.1       | 1605.7                                      | 9.4       | 1840.3                           | 2.5       | -13.9    |
| 170520-6-59 | 0.06 | 4.485                            | 0.033     | 0.2846                           | 0.0018    | 0.1133                            | 0.0003    | 1728  | 6         | 1614.3                                      | 8.8       | 1853.1                           | 2.8       | -14.1    |
| 170520-6-36 | 0.14 | 4.489                            | 0.043     | 0.2854                           | 0.0025    | 0.1134                            | 0.0005    | 1728.6                                      | 8         | 1618  | 13        | 1855.5                           | 3.9       | -13.6    |
| 170520-6-47 | 0.07 | 4.749                            | 0.051     | 0.2862                           | 0.0025    | 0.1199                            | 0.0007    | 1775.8                                      | 9         | 1623  | 12        | 1958.1                           | 4.6       | -19.6    |
| 170520-6-89 | 0.02 | 4.449                            | 0.029     | 0.2871                           | 0.0017    | 0.1125                            | 0.0002    | 1721.2                                      | 5.4       | 1626.9                                      | 8.6       | 1840.8                           | 1.5       | -12.5    |
| 170520-6-70 | 0.10 | 4.569                            | 0.045     | 0.2887                           | 0.0026    | 0.1149                            | 0.0004    | 1743.2                                      | 8.2       | 1635  | 13        | 1879                             | 3         | -13.9    |
| 170520-6-16 | 0.16 | 4.513                            | 0.047     | 0.2895                           | 0.0025    | 0.1136                            | 0.0004    | 1734.1                                      | 9.1       | 1641  | 12        | 1858                             | 3.6       | -12.3    |
| 170520-6-52 | 0.18 | 4.588                            | 0.082     | 0.2930                           | 0.0048    | 0.1121                            | 0.0004    | 1750  | 16        | 1656  | 24        | 1829.5                           | 5.8       | -8.7     |
| 170520-6-3  | 0.11 | 4.596                            | 0.044     | 0.2944                           | 0.0026    | 0.1125                            | 0.0004    | 1748.4                                      | 8.1       | 1663  | 13        | 1841.1                           | 2.7       | -9.8     |
| 170520-6-41 | 0.02 | 5.032                            | 0.031     | 0.2968                           | 0.0016    | 0.1231                            | 0.0004    | 1824.6                                      | 5.3       | 1675.3                                      | 7.9       | 2002                             | 4.7       | -18.7    |
| 170520-6-86 | 0.07 | 5.038                            | 0.074     | 0.3009                           | 0.0021    | 0.1220                            | 0.0017    | 1825  | 12        | 1696  | 11        | 1985                             | 24        | -15.0    |
| 170520-6-66 | 0.02 | 4.851                            | 0.024     | 0.3046                           | 0.0015    | 0.1158                            | 0.0002    | 1793.6                                      | 4.1       | 1714.2                                      | 7.5       | 1891.4                           | 2.1       | -9.8     |
| 170520-6-99 | 0.11 | 4.790                            | 0.042     | 0.3051                           | 0.0022    | 0.1133                            | 0.0003    | 1782.8                                      | 7.3       | 1716  | 11        | 1854.4                           | 3.1       | -7.2     |
| 170520-6-73 | 0.11 | 4.815                            | 0.044     | 0.3076                           | 0.0050    | 0.1137                            | 0.0012    | 1787.5                                      | 7.7       | 1729  | 25        | 1852.3                           | 4.6       | -5.4     |

**Appendix 4.** U-Pb ratio of Oyeri Fm.(conglomerate) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-6-78 | 0.02 | 5.120                            | 0.130     | 0.3084                           | 0.0036    | 0.1204                            | 0.0020    | 1837  | 23        | 1733  | 18        | 1960                                | 29        | -10.4    |
| 170520-6-24 | 0.11 | 4.790                            | 0.038     | 0.3093                           | 0.0017    | 0.1134                            | 0.0010    | 1783.2                                      | 6.7       | 1737.1                                      | 8.2       | 1851.6                              | 8.7       | -5.6     |
| 170520-6-97 | 0.12 | 4.857                            | 0.044     | 0.3125                           | 0.0023    | 0.1122                            | 0.0002    | 1794.6                                      | 7.6       | 1753  | 11        | 1837.5                              | 3.1       | -4.0     |
| 170520-6-92 | 0.01 | 4.912                            | 0.033     | 0.3142                           | 0.0022    | 0.1134                            | 0.0004    | 1804.3                                      | 5.7       | 1761  | 11        | 1853.9                              | 2.7       | -4.5     |
| 170520-6-74 | 0.01 | 4.891                            | 0.057     | 0.3149                           | 0.0030    | 0.1129                            | 0.0006    | 1800.6                                      | 9.8       | 1765  | 15        | 1842.1                              | 6.6       | -3.1     |
| 170520-6-72 | 0.13 | 5.010                            | 0.033     | 0.3182                           | 0.0018    | 0.1143                            | 0.0003    | 1820.9                                      | 5.5       | 1781.1                                      | 8.9       | 1867.6                              | 3.1       | -4.2     |
| 170520-6-6  | 0.01 | 4.950                            | 0.034     | 0.3187                           | 0.0031    | 0.1129                            | 0.0005    | 1810.8                                      | 5.8       | 1783  | 15        | 1846                                | 2.9       | -2.5     |
| 170520-6-98 | 0.01 | 5.158                            | 0.061     | 0.3197                           | 0.0018    | 0.1171                            | 0.0008    | 1845  | 10        | 1788.3                                      | 9         | 1910.9                              | 9.6       | -5.8     |
| 170520-6-64 | 0.06 | 5.415                            | 0.034     | 0.3260                           | 0.0021    | 0.1199                            | 0.0005    | 1887.2                                      | 5.3       | 1819  | 10        | 1955.2                              | 4         | -6.7     |
| 170520-6-20 | 0.27 | 5.070                            | 0.063     | 0.3281                           | 0.0036    | 0.1133                            | 0.0007    | 1831  | 11        | 1829  | 17        | 1850.5                              | 5.6       | 0.1      |
| 170520-6-40 | 0.09 | 5.111                            | 0.046     | 0.3281                           | 0.0047    | 0.1146                            | 0.0011    | 1838  | 7.7       | 1829  | 23        | 1872.6                              | 9.1       | -0.6     |
| 170520-6-22 | 0.28 | 5.159                            | 0.040     | 0.3283                           | 0.0029    | 0.1133                            | 0.0013    | 1845.8                                      | 6.6       | 1830  | 14        | 1862                                | 10        | -0.4     |
| 170520-6-28 | 0.08 | 5.114                            | 0.040     | 0.3299                           | 0.0026    | 0.1128                            | 0.0010    | 1838.4                                      | 6.7       | 1838  | 12        | 1846.9                              | 4.4       | 0.4      |
| 170520-6-58 | 0.01 | 5.168                            | 0.059     | 0.3304                           | 0.0033    | 0.1133                            | 0.0005    | 1847.3                                      | 9.7       | 1840  | 16        | 1854.4                              | 4         | 0.3      |
| 170520-6-55 | 0.10 | 5.139                            | 0.091     | 0.3310                           | 0.0049    | 0.1128                            | 0.0007    | 1842  | 15        | 1843  | 24        | 1844.1                              | 4.4       | 1.5      |
| 170520-6-91 | 0.26 | 5.149                            | 0.049     | 0.3311                           | 0.0033    | 0.1129                            | 0.0002    | 1843.9                                      | 8         | 1843  | 16        | 1846.9                              | 2.9       | 0.8      |
| 170520-6-88 | 0.14 | 5.961                            | 0.044     | 0.3323                           | 0.0018    | 0.1309                            | 0.0004    | 1969.9                                      | 6.5       | 1849.4                                      | 8.8       | 2109.9                              | 4.1       | -13.4    |
| 170520-6-82 | 0.14 | 5.200                            | 0.039     | 0.3323                           | 0.0022    | 0.1139                            | 0.0004    | 1852.5                                      | 6.4       | 1850  | 11        | 1861                                | 5         | 0.3      |
| 170520-6-10 | 0.23 | 5.201                            | 0.042     | 0.3330                           | 0.0015    | 0.1137                            | 0.0008    | 1852.7                                      | 6.9       | 1852.8                                      | 7.4       | 1857.9                              | 6.8       | 0.5      |
| 170520-6-19 | 0.16 | 5.205                            | 0.064     | 0.3330                           | 0.0045    | 0.1131                            | 0.0004    | 1853  | 10        | 1853  | 22        | 1851.7                              | 1.2       | 1.3      |



**Appendix 4.** U-Pb ratio of Oyeri Fm.(conglomerate) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-6-21  | 0.05 | 5.195                            | 0.029     | 0.3333                           | 0.0048    | 0.1143                            | 0.0015    | 1851.7                                      | 4.7       | 1854  | 23        | 1869.9                              | 1.7       | 0.5      |
| 170520-6-80  | 0.42 | 5.206                            | 0.050     | 0.3336                           | 0.0031    | 0.1135                            | 0.0003    | 1853.4                                      | 8.2       | 1855  | 15        | 1856.4                              | 2.7       | 0.9      |
| 170520-6-100 | 0.16 | 5.251                            | 0.043     | 0.3341                           | 0.0016    | 0.1137                            | 0.0010    | 1861  | 7         | 1858.4                                      | 7.8       | 1862.2                              | 5.3       | 0.5      |
| 170520-6-83  | 0.08 | 5.251                            | 0.043     | 0.3352                           | 0.0027    | 0.1137                            | 0.0003    | 1860.7                                      | 7.1       | 1863  | 13        | 1859                                | 3.6       | 1.1      |
| 170520-6-5   | 0.16 | 5.274                            | 0.063     | 0.3354                           | 0.0033    | 0.1140                            | 0.0007    | 1864  | 10        | 1864  | 16        | 1863.7                              | 3.4       | 1.1      |
| 170520-6-9   | 0.16 | 5.290                            | 0.031     | 0.3354                           | 0.0020    | 0.1137                            | 0.0008    | 1867.2                                      | 5         | 1864.4                                      | 9.6       | 1853.8                              | 6.4       | 1.4      |
| 170520-6-62  | 0.46 | 5.282                            | 0.043     | 0.3360                           | 0.0026    | 0.1147                            | 0.0007    | 1865.8                                      | 6.9       | 1867  | 13        | 1875.6                              | 3.9       | 0.4      |
| 170520-6-26  | 0.10 | 5.317                            | 0.064     | 0.3361                           | 0.0017    | 0.1145                            | 0.0013    | 1872  | 10        | 1868.1                                      | 8.1       | 1871.5                              | 1.5       | 0.3      |
| 170520-6-8   | 0.21 | 5.289                            | 0.068     | 0.3365                           | 0.0037    | 0.1137                            | 0.0007    | 1867  | 11        | 1870  | 18        | 1856.9                              | 7         | 2.0      |
| 170520-6-46  | 0.32 | 5.323                            | 0.042     | 0.3374                           | 0.0031    | 0.1145                            | 0.0006    | 1872.3                                      | 6.8       | 1874  | 15        | 1868.4                              | 4.4       | 1.3      |
| 170520-6-15  | 0.18 | 5.349                            | 0.050     | 0.3375                           | 0.0027    | 0.1148                            | 0.0005    | 1876.4                                      | 8.1       | 1875  | 13        | 1877.7                              | 4.1       | 0.8      |
| 170520-6-61  | 0.34 | 5.385                            | 0.042     | 0.3397                           | 0.0022    | 0.1149                            | 0.0005    | 1883  | 6.8       | 1885  | 11        | 1878.8                              | 3.7       | 1.1      |
| 170520-6-4   | 0.15 | 5.513                            | 0.090     | 0.3421                           | 0.0020    | 0.1164                            | 0.0017    | 1902  | 14        | 1896.5                                      | 9.5       | 1900                                | 20        | 1.4      |
| 170520-6-31  | 0.05 | 6.531                            | 0.090     | 0.3546                           | 0.0033    | 0.1332                            | 0.0010    | 2050  | 12        | 1957  | 16        | 2139                                | 11        | -7.9     |
| 170520-6-60  | 0.18 | 5.861                            | 0.076     | 0.3549                           | 0.0042    | 0.1195                            | 0.0005    | 1955  | 11        | 1958  | 20        | 1948                                | 3.7       | 1.7      |
| 170520-6-30  | 0.19 | 6.870                            | 0.087     | 0.3654                           | 0.0041    | 0.1363                            | 0.0005    | 2095  | 11        | 2008  | 19        | 2183.6                              | 4.6       | -7.6     |
| 170520-6-65  | 1.12 | 7.073                            | 0.045     | 0.3691                           | 0.0021    | 0.1390                            | 0.0004    | 2120.5                                      | 5.7       | 2025  | 9.8       | 2213.6                              | 2.7       | -8.7     |
| 170520-6-69  | 0.05 | 6.640                            | 0.130     | 0.3748                           | 0.0054    | 0.1281                            | 0.0024    | 2064  | 18        | 2052  | 25        | 2080                                | 13        | 0.5      |
| 170520-6-29  | 0.24 | 7.040                            | 0.110     | 0.3750                           | 0.0045    | 0.1366                            | 0.0007    | 2116  | 13        | 2053  | 21        | 2185                                | 5.6       | -5.1     |
| 170520-6-77  | 0.91 | 7.088                            | 0.075     | 0.3769                           | 0.0023    | 0.1365                            | 0.0007    | 2122.4                                      | 9.4       | 2062  | 11        | 2182.8                              | 3.6       | -5.2     |

**Appendix 4.** U-Pb ratio of Oyeri Fm.(conglomerate) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-6-81 | 0.09 | 7.090                            | 0.150     | 0.3896                           | 0.0055    | 0.1323                            | 0.0012    | 2122  | 19        | 2121  | 25        | 2128                                | 14        | 1.5      |
| 170520-6-84 | 0.71 | 7.363                            | 0.079     | 0.3963                           | 0.0024    | 0.1352                            | 0.0008    | 2156.4                                      | 9.7       | 2152  | 11        | 2167.9                              | 4.8       | 0.0      |
| 170520-6-49 | 0.57 | 7.720                            | 0.069     | 0.3987                           | 0.0021    | 0.1407                            | 0.0008    | 2199  | 8         | 2162.8                                      | 9.7       | 2242                                | 17        | -2.4     |
| 170520-6-51 | 0.39 | 7.910                            | 0.110     | 0.4004                           | 0.0063    | 0.1434                            | 0.0025    | 2220  | 12        | 2171  | 29        | 2268                                | 25        | -2.0     |
| 170520-6-43 | 1.56 | 7.970                            | 0.200     | 0.4050                           | 0.0110    | 0.1436                            | 0.0049    | 2228  | 23        | 2193  | 51        | 2269                                | 13        | -0.5     |
| 170520-6-33 | 0.62 | 8.350                            | 0.180     | 0.4194                           | 0.0047    | 0.1456                            | 0.0029    | 2270  | 19        | 2258  | 21        | 2303                                | 11        | -0.6     |
| 170520-6-25 | 0.47 | 8.680                            | 0.270     | 0.4290                           | 0.0075    | 0.1475                            | 0.0027    | 2304  | 28        | 2301  | 34        | 2316                                | 18        | 1.6      |
| 170520-6-13 | 0.76 | 9.630                            | 0.240     | 0.4384                           | 0.0094    | 0.1581                            | 0.0019    | 2399  | 23        | 2343  | 42        | 2440                                | 11        | -1.9     |
| 170520-6-27 | 0.51 | 9.540                            | 0.330     | 0.4430                           | 0.0096    | 0.1563                            | 0.0026    | 2391  | 32        | 2364  | 43        | 2414                                | 14        | 0.3      |
| 170520-6-38 | 0.40 | 9.390                            | 0.360     | 0.4440                           | 0.0160    | 0.1562                            | 0.0018    | 2376  | 34        | 2365  | 70        | 2423                                | 21        | 1.4      |
| 170520-6-50 | 1.06 | 9.540                            | 0.160     | 0.4494                           | 0.0051    | 0.1545                            | 0.0022    | 2391  | 16        | 2393  | 23        | 2405                                | 21        | 1.3      |
| 170520-6-18 | 0.46 | 9.700                            | 0.170     | 0.4517                           | 0.0063    | 0.1562                            | 0.0014    | 2406  | 16        | 2403  | 28        | 2421.9                              | 7.6       | 0.7      |
| 170520-6-67 | 0.99 | 9.740                            | 0.150     | 0.4543                           | 0.0062    | 0.1551                            | 0.0005    | 2410  | 14        | 2414  | 28        | 2402.4                              | 3.8       | 1.8      |
| 170520-6-34 | 1.97 | 9.970                            | 0.110     | 0.4543                           | 0.0064    | 0.1603                            | 0.0010    | 2432  | 10        | 2415  | 28        | 2461                                | 24        | 0.2      |
| 170520-6-87 | 0.89 | 9.850                            | 0.210     | 0.4545                           | 0.0036    | 0.1584                            | 0.0018    | 2421  | 19        | 2415  | 16        | 2438.3                              | 8.1       | 0.0      |
| 170520-6-12 | 1.36 | 10.002                           | 0.066     | 0.4581                           | 0.0027    | 0.1585                            | 0.0007    | 2434.8                                      | 6.1       | 2431  | 12        | 2441.6                              | 3.9       | 0.2      |
| 170520-6-48 | 1.49 | 10.460                           | 0.280     | 0.4680                           | 0.0130    | 0.1615                            | 0.0015    | 2473  | 25        | 2473  | 59        | 2475                                | 8.7       | 2.7      |
| 170520-6-71 | 1.16 | 10.585                           | 0.035     | 0.4702                           | 0.0091    | 0.1651                            | 0.0014    | 2487.4                                      | 3.1       | 2484  | 40        | 2509.5                              | 7.7       | 0.9      |
| 170520-6-96 | 0.77 | 11.680                           | 0.210     | 0.4890                           | 0.0100    | 0.1733                            | 0.0019    | 2579  | 17        | 2565  | 44        | 2587.3                              | 4.8       | 1.0      |
| 170520-6-79 | 1.42 | 11.850                           | 0.210     | 0.4966                           | 0.0064    | 0.1736                            | 0.0013    | 2596  | 15        | 2599  | 28        | 2596                                | 10        | 1.6      |

**Appendix 5.** U-Pb ratio of Ongam Conglomerate of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-7-5   | 0.03 | 5.200                            | 0.031     | 0.3351                           | 0.0029    | 0.1116                            | 0.0009    | 1852.6                                      | 5         | 1863  | 14        | 1825.2                              | 7.3       | 3.2      |
| 170520-7-99  | 0.03 | 5.228                            | 0.036     | 0.3396                           | 0.0012    | 0.1118                            | 0.0009    | 1857.2                                      | 5.9       | 1884.6                                      | 5.9       | 1827.5                              | 7.7       | 3.8      |
| 170520-7-69  | 0.06 | 5.235                            | 0.037     | 0.3376                           | 0.0025    | 0.1120                            | 0.0006    | 1858.4                                      | 6         | 1875  | 12        | 1832.8                              | 2.2       | 3.0      |
| 170520-7-29  | 0.06 | 5.130                            | 0.057     | 0.3312                           | 0.0020    | 0.1122                            | 0.0006    | 1841  | 9.4       | 1844.3                                      | 9.8       | 1835                                | 4.8       | 1.3      |
| 170520-7-97  | 0.06 | 5.129                            | 0.035     | 0.3313                           | 0.0026    | 0.1124                            | 0.0003    | 1840.8                                      | 5.8       | 1845  | 13        | 1837                                | 1.5       | 1.2      |
| 170520-7-10  | 0.05 | 5.196                            | 0.026     | 0.3324                           | 0.0017    | 0.1124                            | 0.0001    | 1851.8                                      | 4.2       | 1850  | 8.1       | 1838.9                              | 1.3       | 1.1      |
| 170520-7-93  | 0.12 | 5.159                            | 0.058     | 0.3330                           | 0.0037    | 0.1124                            | 0.0006    | 1845.9                                      | 9.5       | 1853  | 18        | 1839.7                              | 4.2       | 1.9      |
| 170520-7-1   | 0.04 | 5.218                            | 0.026     | 0.3338                           | 0.0016    | 0.1125                            | 0.0002    | 1855.4                                      | 4.3       | 1856.5                                      | 7.6       | 1840.4                              | 1.7       | 1.4      |
| 170520-7-92  | 0.03 | 5.157                            | 0.054     | 0.3326                           | 0.0042    | 0.1125                            | 0.0007    | 1845.6                                      | 9         | 1851  | 20        | 1841.3                              | 4.1       | 1.8      |
| 170520-7-81  | 0.28 | 5.210                            | 0.066     | 0.3352                           | 0.0044    | 0.1127                            | 0.0005    | 1854  | 11        | 1864  | 21        | 1844                                | 2.7       | 2.3      |
| 170520-7-55  | 0.01 | 5.231                            | 0.027     | 0.3358                           | 0.0008    | 0.1128                            | 0.0006    | 1857.6                                      | 4.4       | 1866.4                                      | 3.7       | 1844.7                              | 1.8       | 1.5      |
| 170520-7-88  | 0.02 | 5.236                            | 0.090     | 0.3341                           | 0.0030    | 0.1128                            | 0.0005    | 1858  | 15        | 1858  | 15        | 1845.3                              | 3.2       | 1.7      |
| 170520-7-22  | 0.06 | 5.141                            | 0.027     | 0.3311                           | 0.0017    | 0.1128                            | 0.0001    | 1842.7                                      | 4.5       | 1843.8                                      | 8         | 1845.7                              | 1.4       | 0.4      |
| 170520-7-42  | 0.05 | 5.343                            | 0.020     | 0.3444                           | 0.0010    | 0.1128                            | 0.0006    | 1875.8                                      | 3.2       | 1907.5                                      | 4.7       | 1845.8                              | 3.5       | 3.7      |
| 170520-7-38  | 0.04 | 5.107                            | 0.050     | 0.3294                           | 0.0030    | 0.1128                            | 0.0004    | 1837.2                                      | 8.3       | 1835  | 15        | 1846.4                              | 3.9       | 0.4      |
| 170520-7-100 | 0.12 | 5.239                            | 0.045     | 0.3364                           | 0.0032    | 0.1130                            | 0.0011    | 1858.9                                      | 7.3       | 1870  | 15        | 1847.5                              | 7.7       | 2.4      |
| 170520-7-28  | 0.05 | 5.172                            | 0.024     | 0.3318                           | 0.0014    | 0.1130                            | 0.0002    | 1848  | 4         | 1847.2                                      | 6.7       | 1847.8                              | 2.6       | 0.5      |
| 170520-7-15  | 0.06 | 5.213                            | 0.038     | 0.3333                           | 0.0022    | 0.1130                            | 0.0003    | 1854.6                                      | 6.2       | 1854  | 11        | 1848.1                              | 4.4       | 1.1      |
| 170520-7-26  | 0.03 | 5.181                            | 0.062     | 0.3326                           | 0.0032    | 0.1132                            | 0.0004    | 1849  | 10        | 1851  | 16        | 1848.2                              | 4.6       | 1.3      |
| 170520-7-14  | 0.03 | 5.249                            | 0.073     | 0.3354                           | 0.0038    | 0.1132                            | 0.0008    | 1861  | 12        | 1864  | 18        | 1849.3                              | 6.4       | 2.1      |

**Appendix 5.** U-Pb ratio of Ongam Conglomerate of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-7-17 | 0.03 | 5.188                            | 0.027     | 0.3327                           | 0.0016    | 0.1131                            | 0.0002    | 1850.4  | 4.4       | 1851.6  | 7.7       | 1849.8                           | 1.4       | 0.6      |
| 170520-7-39 | 0.05 | 5.211                            | 0.023     | 0.3331                           | 0.0014    | 0.1131                            | 0.0003    | 1854.3  | 3.8       | 1853.2  | 7         | 1850.8                           | 2.5       | 0.6      |
| 170520-7-59 | 0.02 | 5.314                            | 0.025     | 0.3430                           | 0.0010    | 0.1132                            | 0.0003    | 1871.1  | 4         | 1901  | 4.7       | 1851.8                           | 2.2       | 3.0      |
| 170520-7-18 | 0.05 | 5.184                            | 0.035     | 0.3329                           | 0.0021    | 0.1132                            | 0.0002    | 1849.8  | 5.8       | 1853  | 10        | 1852.3                           | 1.3       | 0.6      |
| 170520-7-83 | 0.04 | 5.251                            | 0.063     | 0.3359                           | 0.0036    | 0.1132                            | 0.0005    | 1861  | 10        | 1867  | 18        | 1853.1                           | 4.1       | 1.9      |
| 170520-7-56 | 0.05 | 5.171                            | 0.027     | 0.3327                           | 0.0018    | 0.1134                            | 0.0006    | 1847.8  | 4.4       | 1851.5  | 8.6       | 1853.6                           | 4.6       | 0.6      |
| 170520-7-6  | 0.04 | 5.260                            | 0.046     | 0.3346                           | 0.0027    | 0.1134                            | 0.0005    | 1862.3  | 7.4       | 1861  | 13        | 1854.7                           | 5.1       | 1.3      |
| 170520-7-66 | 0.03 | 5.233                            | 0.029     | 0.3346                           | 0.0024    | 0.1133                            | 0.0006    | 1857.9  | 4.8       | 1861  | 12        | 1855.3                           | 3.9       | 1.2      |
| 170520-7-79 | 0.04 | 5.232                            | 0.081     | 0.3342                           | 0.0048    | 0.1136                            | 0.0009    | 1858  | 13        | 1859  | 23        | 1856.2                           | 8.7       | 1.9      |
| 170520-7-32 | 0.02 | 5.341                            | 0.037     | 0.3380                           | 0.0021    | 0.1135                            | 0.0005    | 1877.8  | 7.1       | 1877  | 10        | 1856.7                           | 5.3       | 1.9      |
| 170520-7-16 | 0.03 | 5.236                            | 0.033     | 0.3340                           | 0.0027    | 0.1137                            | 0.0004    | 1858.4  | 5.4       | 1858  | 13        | 1859.8                           | 2.8       | 0.8      |
| 170520-7-71 | 0.02 | 5.285                            | 0.016     | 0.3362                           | 0.0021    | 0.1139                            | 0.0005    | 1866.5  | 2.6       | 1868  | 10        | 1860.9                           | 5.8       | 1.2      |
| 170520-7-63 | 0.03 | 5.229                            | 0.034     | 0.3338                           | 0.0019    | 0.1139                            | 0.0002    | 1857.2  | 5.5       | 1858.2  | 8.9       | 1862.9                           | 2         | 0.3      |
| 170520-7-70 | 0.02 | 5.356                            | 0.053     | 0.3411                           | 0.0027    | 0.1140                            | 0.0004    | 1877.8  | 8.4       | 1892  | 13        | 1864                             | 4.2       | 2.4      |
| 170520-7-77 | 0.03 | 5.288                            | 0.065     | 0.3364                           | 0.0046    | 0.1142                            | 0.0005    | 1867  | 11        | 1869  | 22        | 1865.7                           | 7.3       | 1.7      |
| 170520-7-46 | 0.34 | 5.220                            | 0.044     | 0.3327                           | 0.0021    | 0.1141                            | 0.0010    | 1855.9  | 7.1       | 1852  | 10        | 1866                             | 10        | 0.3      |
| 170520-7-73 | 0.13 | 5.362                            | 0.051     | 0.3393                           | 0.0039    | 0.1146                            | 0.0010    | 1878.7  | 8.1       | 1883  | 19        | 1868.6                           | 8.5       | 2.2      |
| 170520-7-80 | 0.05 | 5.329                            | 0.057     | 0.3384                           | 0.0042    | 0.1143                            | 0.0003    | 1873.5  | 9.2       | 1879  | 20        | 1869.4                           | 2.3       | 1.7      |
| 170520-7-40 | 0.02 | 5.246                            | 0.051     | 0.3353                           | 0.0030    | 0.1146                            | 0.0003    | 1860.2  | 8.3       | 1864  | 14        | 1871.5                           | 2.2       | 0.5      |
| 170520-7-91 | 0.06 | 5.334                            | 0.054     | 0.3377                           | 0.0032    | 0.1145                            | 0.0004    | 1874.2  | 8.6       | 1876  | 15        | 1871.8                           | 3.7       | 1.2      |

**Appendix 5.** U-Pb ratio of Ongam Conglomerate of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-7-78 | 0.16 | 5.307                            | 0.088     | 0.3362                           | 0.0039    | 0.1145                            | 0.0010    | 1870  | 14        | 1868  | 19        | 1872                                | 13        | 1.5      |
| 170520-7-96 | 0.01 | 5.319                            | 0.076     | 0.3374                           | 0.0018    | 0.1145                            | 0.0012    | 1872  | 12        | 1874  | 8.5       | 1872.8                              | 4.7       | 0.8      |
| 170520-7-65 | 0.08 | 5.380                            | 0.059     | 0.3397                           | 0.0038    | 0.1147                            | 0.0004    | 1881.6                                      | 9.3       | 1885  | 18        | 1874.8                              | 3.3       | 1.7      |
| 170520-7-85 | 0.36 | 5.351                            | 0.031     | 0.3378                           | 0.0019    | 0.1148                            | 0.0004    | 1877  | 4.9       | 1876.2                                      | 9.2       | 1876.7                              | 4.6       | 0.7      |
| 170520-7-90 | 0.29 | 5.379                            | 0.041     | 0.3395                           | 0.0023    | 0.1150                            | 0.0005    | 1881.4                                      | 6.5       | 1884  | 11        | 1880.1                              | 3.5       | 1.0      |
| 170520-7-54 | 0.08 | 5.465                            | 0.051     | 0.3451                           | 0.0018    | 0.1153                            | 0.0007    | 1895  | 8         | 1911.4                                      | 8.5       | 1882.2                              | 3         | 2.1      |
| 170520-7-68 | 0.06 | 5.346                            | 0.054     | 0.3371                           | 0.0025    | 0.1160                            | 0.0011    | 1876.1                                      | 8.6       | 1873  | 12        | 1896                                | 14        | 0.2      |
| 170520-7-37 | 0.17 | 5.450                            | 0.042     | 0.3413                           | 0.0012    | 0.1162                            | 0.0009    | 1892.7                                      | 6.6       | 1892.9                                      | 5.5       | 1896.2                              | 9.5       | 0.6      |
| 170520-7-95 | 0.16 | 5.515                            | 0.039     | 0.3436                           | 0.0028    | 0.1164                            | 0.0006    | 1903  | 6         | 1904  | 13        | 1902.3                              | 5.1       | 1.0      |
| 170520-7-72 | 0.06 | 5.543                            | 0.063     | 0.3448                           | 0.0039    | 0.1166                            | 0.0002    | 1907.1                                      | 9.8       | 1910  | 19        | 1906.1                              | 1.8       | 1.3      |
| 170520-7-41 | 0.23 | 5.762                            | 0.028     | 0.3617                           | 0.0012    | 0.1172                            | 0.0004    | 1940.7                                      | 4.2       | 1990.2                                      | 5.6       | 1913.2                              | 2         | 4.3      |
| 170520-7-49 | 0.23 | 5.647                            | 0.042     | 0.3476                           | 0.0019    | 0.1171                            | 0.0005    | 1923.3                                      | 6.4       | 1923.2                                      | 9         | 1915.7                              | 4         | 1.1      |
| 170520-7-21 | 0.16 | 5.847                            | 0.087     | 0.3539                           | 0.0027    | 0.1176                            | 0.0005    | 1953  | 13        | 1953  | 13        | 1920.1                              | 4.5       | 2.6      |
| 170520-7-23 | 0.27 | 5.707                            | 0.049     | 0.3513                           | 0.0054    | 0.1178                            | 0.0012    | 1932.3                                      | 7.4       | 1941  | 26        | 1924.9                              | 4.8       | 2.4      |
| 170520-7-74 | 0.04 | 5.380                            | 0.110     | 0.3394                           | 0.0030    | 0.1154                            | 0.0016    | 1881  | 17        | 1884  | 14        | 1925                                | 46        | 1.0      |
| 170520-7-47 | 0.10 | 5.772                            | 0.079     | 0.3518                           | 0.0042    | 0.1181                            | 0.0008    | 1942  | 12        | 1943  | 20        | 1928.6                              | 8.8       | 2.2      |
| 170520-7-35 | 0.07 | 5.649                            | 0.064     | 0.3478                           | 0.0013    | 0.1182                            | 0.0010    | 1923.4                                      | 9.7       | 1924.1                                      | 6.1       | 1929                                | 14        | 0.8      |
| 170520-7-20 | 0.47 | 5.780                            | 0.120     | 0.3503                           | 0.0044    | 0.1186                            | 0.0015    | 1944  | 18        | 1936  | 21        | 1937                                | 15        | 1.8      |
| 170520-7-7  | 0.40 | 5.559                            | 0.045     | 0.3332                           | 0.0016    | 0.1190                            | 0.0008    | 1909.8                                      | 6.9       | 1853.8                                      | 7.9       | 1944.9                              | 9.3       | -4.0     |
| 170520-7-52 | 0.19 | 5.820                            | 0.180     | 0.3549                           | 0.0043    | 0.1193                            | 0.0025    | 1948  | 26        | 1958  | 20        | 1945                                | 37        | 3.6      |

**Appendix 5.** U-Pb ratio of Ongam Conglomerate of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-7-27 | 0.42 | 5.975                            | 0.055     | 0.3606                           | 0.0048    | 0.1195                            | 0.0015    | 1972.2  | 8.1       | 1985  | 22        | 1947                                | 12        | 3.6      |
| 170520-7-48 | 0.18 | 5.820                            | 0.021     | 0.3533                           | 0.0016    | 0.1195                            | 0.0002    | 1949.3  | 3.2       | 1950.2  | 7.6       | 1949.5                              | 1.6       | 0.5      |
| 170520-7-36 | 0.24 | 5.817                            | 0.052     | 0.3528                           | 0.0020    | 0.1204                            | 0.0007    | 1948.9  | 7.7       | 1947.8  | 9.6       | 1964.4                              | 3.7       | -0.2     |
| 170520-7-51 | 0.51 | 5.794                            | 0.033     | 0.3477                           | 0.0024    | 0.1207                            | 0.0008    | 1945.5  | 4.9       | 1924  | 11        | 1965                                | 1.6       | -1.5     |
| 170520-7-33 | 0.20 | 6.089                            | 0.067     | 0.3634                           | 0.0039    | 0.1209                            | 0.0012    | 1988.6  | 9.6       | 1998  | 19        | 1970.1                              | 9.7       | 2.8      |
| 170520-7-62 | 0.28 | 5.969                            | 0.057     | 0.3619                           | 0.0019    | 0.1210                            | 0.0006    | 1971.2  | 8.3       | 1991.1  | 9.1       | 1970.9                              | 3.3       | 1.6      |
| 170520-7-25 | 0.31 | 6.036                            | 0.065     | 0.3603                           | 0.0038    | 0.1210                            | 0.0010    | 1980.9  | 9.4       | 1984  | 18        | 1971.3                              | 6         | 1.8      |
| 170520-7-89 | 0.56 | 6.026                            | 0.036     | 0.3593                           | 0.0023    | 0.1213                            | 0.0004    | 1979.5  | 5.2       | 1979  | 11        | 1976.2                              | 3.6       | 0.9      |
| 170520-7-57 | 0.43 | 5.953                            | 0.050     | 0.3572                           | 0.0019    | 0.1214                            | 0.0007    | 1969  | 7.3       | 1969  | 9.2       | 1977.2                              | 6.6       | 0.4      |
| 170520-7-31 | 0.35 | 6.114                            | 0.049     | 0.3615                           | 0.0021    | 0.1218                            | 0.0003    | 1992.2  | 7         | 1989.2  | 9.8       | 1982.7                              | 2.8       | 1.0      |
| 170520-7-60 | 0.29 | 6.020                            | 0.043     | 0.3589                           | 0.0031    | 0.1226                            | 0.0005    | 1978.6  | 6.3       | 1977  | 14        | 1992                                | 2.7       | 0.1      |
| 170520-7-84 | 0.44 | 6.130                            | 0.110     | 0.3629                           | 0.0023    | 0.1225                            | 0.0018    | 1994  | 16        | 1996  | 11        | 1992                                | 16        | 1.6      |
| 170520-7-11 | 0.21 | 6.132                            | 0.086     | 0.3620                           | 0.0049    | 0.1222                            | 0.0007    | 1995  | 12        | 1992  | 23        | 1992.2                              | 9.6       | 1.6      |
| 170520-7-50 | 0.05 | 5.979                            | 0.044     | 0.3581                           | 0.0018    | 0.1227                            | 0.0004    | 1972.7  | 6.4       | 1972.9  | 8.6       | 1996.8                              | 3.8       | -0.6     |
| 170520-7-75 | 0.14 | 6.270                            | 0.140     | 0.3667                           | 0.0037    | 0.1234                            | 0.0015    | 2014  | 20        | 2014  | 17        | 2005                                | 21        | 2.3      |
| 170520-7-64 | 0.45 | 6.379                            | 0.066     | 0.3699                           | 0.0020    | 0.1252                            | 0.0010    | 2029.2  | 9.1       | 2028.9  | 9.6       | 2035                                | 11        | 0.7      |
| 170520-7-58 | 0.45 | 6.147                            | 0.072     | 0.3625                           | 0.0033    | 0.1257                            | 0.0008    | 1997  | 10        | 1994  | 16        | 2042                                | 11        | -1.1     |
| 170520-7-61 | 0.50 | 6.557                            | 0.036     | 0.3749                           | 0.0026    | 0.1272                            | 0.0004    | 2053.5  | 4.8       | 2052  | 12        | 2057.7                              | 2         | 0.4      |
| 170520-7-86 | 0.37 | 6.942                            | 0.038     | 0.3942                           | 0.0042    | 0.1277                            | 0.0015    | 2104  | 4.8       | 2142  | 19        | 2068                                | 4.1       | 4.5      |
| 170520-7-87 | 0.08 | 6.749                            | 0.046     | 0.3809                           | 0.0023    | 0.1281                            | 0.0004    | 2079  | 6         | 2081  | 11        | 2072.2                              | 4.6       | 1.2      |

**Appendix 5.** U-Pb ratio of Ongam Conglomerate of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-7-67 | 0.62 | 6.687                            | 0.088     | 0.3776                           | 0.0046    | 0.1287                            | 0.0009    | 2072  | 11        | 2068  | 21        | 2079.7                              | 7.2       | 0.8      |
| 170520-7-45 | 0.24 | 7.035                            | 0.048     | 0.3887                           | 0.0020    | 0.1308                            | 0.0007    | 2115.8                                      | 6.1       | 2116.7                                      | 9.2       | 2107                                | 11        | 1.4      |
| 170520-7-3  | 0.31 | 7.499                            | 0.054     | 0.4002                           | 0.0026    | 0.1336                            | 0.0005    | 2172.8                                      | 6.5       | 2170  | 12        | 2146.1                              | 5.6       | 1.9      |
| 170520-7-24 | 0.59 | 7.462                            | 0.047     | 0.3996                           | 0.0021    | 0.1356                            | 0.0004    | 2168.1                                      | 5.6       | 2167.3                                      | 9.5       | 2171.4                              | 2.9       | 0.4      |
| 170520-7-43 | 1.08 | 7.257                            | 0.090     | 0.3921                           | 0.0041    | 0.1361                            | 0.0011    | 2143  | 11        | 2133  | 19        | 2176.5                              | 3         | -1.0     |
| 170520-7-2  | 1.00 | 8.200                            | 0.110     | 0.4183                           | 0.0053    | 0.1409                            | 0.0008    | 2253  | 12        | 2252  | 24        | 2244.3                              | 6.4       | 1.7      |
| 170520-7-44 | 0.86 | 8.500                            | 0.100     | 0.4248                           | 0.0052    | 0.1425                            | 0.0020    | 2285  | 11        | 2282  | 24        | 2253                                | 15        | 3.0      |
| 170520-7-9  | 0.27 | 8.600                            | 0.110     | 0.4285                           | 0.0054    | 0.1445                            | 0.0002    | 2296  | 12        | 2299  | 25        | 2282                                | 1.9       | 1.9      |
| 170520-7-98 | 0.20 | 8.726                            | 0.072     | 0.4317                           | 0.0028    | 0.1467                            | 0.0004    | 2309.8                                      | 7.5       | 2313  | 13        | 2308.6                              | 7.5       | 1.1      |
| 170520-7-30 | 0.48 | 9.045                            | 0.069     | 0.4383                           | 0.0029    | 0.1485                            | 0.0006    | 2342.6                                      | 6.9       | 2343  | 13        | 2332                                | 11        | 1.5      |
| 170520-7-34 | 0.09 | 8.970                            | 0.100     | 0.4380                           | 0.0041    | 0.1491                            | 0.0003    | 2335  | 10        | 2342  | 18        | 2339                                | 10        | 1.3      |
| 170520-7-13 | 0.94 | 9.080                            | 0.130     | 0.4394                           | 0.0042    | 0.1493                            | 0.0009    | 2345  | 13        | 2348  | 19        | 2339.1                              | 8.5       | 1.6      |
| 170520-7-12 | 0.08 | 8.750                            | 0.160     | 0.4229                           | 0.0049    | 0.1499                            | 0.0033    | 2312  | 16        | 2274  | 22        | 2344                                | 25        | -1.0     |
| 170520-7-94 | 0.46 | 8.370                            | 0.140     | 0.4057                           | 0.0026    | 0.1505                            | 0.0020    | 2271  | 15        | 2195  | 12        | 2354                                | 17        | -5.9     |
| 170520-7-76 | 0.86 | 9.886                            | 0.082     | 0.4571                           | 0.0029    | 0.1570                            | 0.0006    | 2424.1                                      | 7.7       | 2427  | 13        | 2421.7                              | 4         | 0.9      |
| 170520-7-53 | 0.77 | 9.980                            | 0.130     | 0.4582                           | 0.0069    | 0.1595                            | 0.0011    | 2432  | 12        | 2431  | 31        | 2450.4                              | 6.9       | 0.8      |
| 170520-7-8  | 0.71 | 10.297                           | 0.093     | 0.4641                           | 0.0039    | 0.1602                            | 0.0005    | 2461.4                                      | 8.4       | 2460  | 18        | 2459.6                              | 4.7       | 0.9      |
| 170520-7-4  | 0.60 | 11.189                           | 0.086     | 0.4820                           | 0.0034    | 0.1673                            | 0.0008    | 2538.7                                      | 7.1       | 2536  | 15        | 2530                                | 7.6       | 1.1      |
| 170520-7-82 | 0.59 | 22.240                           | 0.200     | 0.6266                           | 0.0030    | 0.2572                            | 0.0011    | 3194.3                                      | 8.6       | 3136  | 12        | 3230.2                              | 4.3       | -2.5     |
| 170520-7-19 | 0.49 | 23.410                           | 0.360     | 0.6551                           | 0.0080    | 0.2611                            | 0.0023    | 3243  | 15        | 3247  | 31        | 3254                                | 12        | 1.1      |

**Appendix 6.** U-Pb ratio of Manwolsan Tuff of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-8-59  | 0.89 | 0.092                            | 0.006     | 0.0139                           | 0.0002    | 0.0475                            | 0.0031    | 89  | 5.5       | 88.8  | 1.5       | 160                                 | 120       | 7.7      |
| 170520-8-82  | 0.53 | 0.093                            | 0.006     | 0.0141                           | 0.0001    | 0.0476                            | 0.0027    | 90.3  | 5.4       | 90.07   | 0.89      | 220                                 | 150       | 6.7      |
| 170520-8-71  | 0.91 | 0.096                            | 0.006     | 0.0142                           | 0.0002    | 0.0493                            | 0.0031    | 93.2  | 5.2       | 91  | 1.1       | 290                                 | 74        | 4.5      |
| 170520-8-1   | 0.95 | 0.116                            | 0.006     | 0.0143                           | 0.0002    | 0.0588                            | 0.0030    | 111.4   | 5.2       | 91.5  | 1         | 581                                 | 78        | -15.0    |
| 170520-8-78  | 0.57 | 0.097                            | 0.005     | 0.0144                           | 0.0003    | 0.0483                            | 0.0021    | 93.5  | 4.7       | 91.9  | 2.1       | 172                                 | 44        | 5.7      |
| 170520-8-84  | 0.60 | 0.096                            | 0.002     | 0.0144                           | 0.0001    | 0.0485                            | 0.0013    | 93.4  | 2.2       | 92.16   | 0.79      | 162                                 | 31        | 1.9      |
| 170520-8-85  | 0.54 | 0.100                            | 0.009     | 0.0144                           | 0.0002    | 0.0506                            | 0.0046    | 97  | 8.6       | 92.3  | 1.4       | 320                                 | 120       | 5.7      |
| 170520-8-81  | 0.68 | 0.096                            | 0.006     | 0.0145                           | 0.0002    | 0.0485                            | 0.0031    | 93.2  | 5.6       | 92.6  | 1         | 460                                 | 250       | 6.5      |
| 170520-8-98  | 0.62 | 0.096                            | 0.004     | 0.0145                           | 0.0002    | 0.0479                            | 0.0018    | 92.8  | 3.4       | 92.7  | 1         | 168                                 | 63        | 4.6      |
| 170520-8-72  | 0.73 | 0.097                            | 0.009     | 0.0145                           | 0.0002    | 0.0482                            | 0.0044    | 94  | 8.4       | 93  | 1.5       | 205                                 | 78        | 9.6      |
| 170520-8-94  | 0.48 | 0.099                            | 0.010     | 0.0145                           | 0.0004    | 0.0488                            | 0.0050    | 96  | 9.7       | 93  | 2.3       | 130                                 | 100       | 9.7      |
| 170520-8-86  | 0.50 | 0.096                            | 0.003     | 0.0145                           | 0.0002    | 0.0479                            | 0.0018    | 93.1  | 3         | 93.06   | 0.95      | 215                                 | 37        | 4.2      |
| 170520-8-83  | 0.70 | 0.098                            | 0.006     | 0.0146                           | 0.0003    | 0.0496                            | 0.0028    | 96.4  | 4.8       | 93.2  | 1.9       | 256                                 | 90        | 3.8      |
| 170520-8-100 | 0.58 | 0.098                            | 0.003     | 0.0146                           | 0.0001    | 0.0492                            | 0.0015    | 95.1  | 2.9       | 93.22   | 0.87      | 227                                 | 41        | 2.0      |
| 170520-8-89  | 1.20 | 0.097                            | 0.003     | 0.0146                           | 0.0001    | 0.0485                            | 0.0014    | 94.3  | 2.5       | 93.42   | 0.68      | 174                                 | 27        | 2.5      |
| 170520-8-99  | 0.75 | 0.098                            | 0.003     | 0.0146                           | 0.0001    | 0.0490                            | 0.0017    | 95.1  | 3         | 93.45   | 0.8       | 173                                 | 30        | 2.3      |
| 170520-8-95  | 0.59 | 0.095                            | 0.004     | 0.0146                           | 0.0001    | 0.0465                            | 0.0021    | 91.6  | 4.1       | 93.48   | 0.91      | 189                                 | 51        | 7.4      |
| 170520-8-97  | 0.71 | 0.099                            | 0.007     | 0.0146                           | 0.0002    | 0.0498                            | 0.0034    | 96.6  | 6.2       | 93.5  | 1.2       | 384                                 | 71        | 4.6      |
| 170520-8-87  | 0.48 | 0.097                            | 0.002     | 0.0146                           | 0.0001    | 0.0483                            | 0.0009    | 94.2  | 1.6       | 93.58   | 0.66      | 145                                 | 21        | 1.8      |
| 170520-8-90  | 0.71 | 0.097                            | 0.007     | 0.0146                           | 0.0002    | 0.0483                            | 0.0036    | 93.9  | 6.5       | 93.6  | 1.4       | 271                                 | 75        | 8.1      |



**Appendix 6.** U-Pb ratio of Manwolsan Tuff of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-8-76 | 0.79 | 0.097                            | 0.003     | 0.0146                           | 0.0001    | 0.0482                            | 0.0014    | 93.8  | 2.8       | 93.61                                       | 0.69      | 165                                 | 32        | 3.5      |
| 170520-8-77 | 0.71 | 0.097                            | 0.002     | 0.0146                           | 0.0001    | 0.0482                            | 0.0011    | 94  | 2.1       | 93.63                                       | 0.66      | 158                                 | 26        | 2.6      |
| 170520-8-80 | 0.69 | 0.098                            | 0.003     | 0.0146                           | 0.0001    | 0.0491                            | 0.0013    | 94.8  | 2.3       | 93.66                                       | 0.68      | 170                                 | 33        | 2.0      |
| 170520-8-88 | 0.62 | 0.097                            | 0.004     | 0.0146                           | 0.0001    | 0.0476                            | 0.0018    | 93.6  | 3.5       | 93.69                                       | 0.91      | 202                                 | 71        | 4.8      |
| 170520-8-73 | 0.68 | 0.096                            | 0.005     | 0.0147                           | 0.0002    | 0.0473                            | 0.0024    | 93.1  | 4.3       | 93.8  | 1.4       | 172                                 | 28        | 6.8      |
| 170520-8-74 | 0.68 | 0.096                            | 0.008     | 0.0147                           | 0.0003    | 0.0474                            | 0.0037    | 93.3  | 7.1       | 93.8  | 1.7       | 220                                 | 120       | 9.9      |
| 170520-8-40 | 0.57 | 0.097                            | 0.003     | 0.0147                           | 0.0001    | 0.0481                            | 0.0016    | 93.7  | 2.7       | 93.92                                       | 0.67      | 176                                 | 38        | 3.8      |
| 170520-8-13 | 0.50 | 0.100                            | 0.005     | 0.0147                           | 0.0002    | 0.0492                            | 0.0026    | 96.5  | 4.3       | 94  | 1.1       | 207                                 | 74        | 3.1      |
| 170520-8-60 | 0.55 | 0.097                            | 0.009     | 0.0147                           | 0.0002    | 0.0481                            | 0.0042    | 94.2  | 8.4       | 94.1  | 1.3       | 370                                 | 190       | 10.2     |
| 170520-8-79 | 0.60 | 0.097                            | 0.004     | 0.0147                           | 0.0002    | 0.0482                            | 0.0020    | 94.3  | 3.7       | 94.1  | 1.1       | 206                                 | 53        | 4.9      |
| 170520-8-96 | 0.59 | 0.100                            | 0.006     | 0.0147                           | 0.0002    | 0.0491                            | 0.0027    | 97.4  | 5         | 94.1  | 1         | 246                                 | 66        | 2.9      |
| 170520-8-28 | 0.59 | 0.098                            | 0.005     | 0.0147                           | 0.0002    | 0.0483                            | 0.0025    | 95.2  | 4.3       | 94.2  | 1.3       | 188                                 | 33        | 4.9      |
| 170520-8-92 | 0.75 | 0.097                            | 0.004     | 0.0147                           | 0.0002    | 0.0474                            | 0.0017    | 93.6  | 3.7       | 94.2  | 1.2       | 236                                 | 68        | 5.8      |
| 170520-8-26 | 0.77 | 0.097                            | 0.006     | 0.0148                           | 0.0002    | 0.0473                            | 0.0031    | 93.5  | 5.8       | 94.5  | 1.1       | 254                                 | 86        | 8.4      |
| 170520-8-7  | 0.86 | 0.098                            | 0.003     | 0.0148                           | 0.0001    | 0.0482                            | 0.0014    | 95  | 2.6       | 94.53                                       | 0.64      | 199                                 | 42        | 2.9      |
| 170520-8-10 | 0.90 | 0.099                            | 0.005     | 0.0148                           | 0.0002    | 0.0489                            | 0.0024    | 95.7  | 4.4       | 94.6  | 1.1       | 169                                 | 56        | 4.7      |
| 170520-8-45 | 0.76 | 0.100                            | 0.006     | 0.0148                           | 0.0003    | 0.0495                            | 0.0026    | 96.8  | 5.1       | 94.7  | 1.6       | 310                                 | 110       | 4.9      |
| 170520-8-93 | 1.04 | 0.099                            | 0.002     | 0.0148                           | 0.0001    | 0.0487                            | 0.0010    | 95.6  | 1.8       | 94.71                                       | 0.57      | 147                                 | 23        | 1.6      |
| 170520-8-5  | 0.63 | 0.100                            | 0.004     | 0.0148                           | 0.0001    | 0.0491                            | 0.0017    | 96.7  | 3.4       | 94.82                                       | 0.76      | 203                                 | 36        | 2.4      |
| 170520-8-6  | 0.96 | 0.100                            | 0.004     | 0.0148                           | 0.0001    | 0.0489                            | 0.0022    | 96.4  | 3.3       | 94.82                                       | 0.81      | 206                                 | 53        | 2.7      |

**Appendix 6.** U-Pb ratio of Manwolsan Tuff of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-8-22 | 0.64 | 0.100                            | 0.005     | 0.0148                           | 0.0002    | 0.0487                            | 0.0025    | 96.4  | 4.9       | 94.9  | 1.5       | 187                                 | 87        | 5.2      |
| 170520-8-91 | 0.81 | 0.156                            | 0.064     | 0.0148                           | 0.0009    | 0.0740                            | 0.0290    | 146   | 56        | 94.9  | 5.5       | 1220                                | 890       | 11.0     |
| 170520-8-37 | 0.61 | 0.099                            | 0.003     | 0.0149                           | 0.0002    | 0.0485                            | 0.0016    | 96.2  | 3.2       | 95  | 0.94      | 197                                 | 33        | 3.1      |
| 170520-8-20 | 0.50 | 0.098                            | 0.003     | 0.0149                           | 0.0001    | 0.0477                            | 0.0012    | 94.6  | 2.5       | 95.05   | 0.71      | 131                                 | 28        | 3.9      |
| 170520-8-11 | 0.75 | 0.101                            | 0.006     | 0.0149                           | 0.0002    | 0.0497                            | 0.0031    | 97.7  | 5.9       | 95.2  | 1.3       | 246                                 | 78        | 4.9      |
| 170520-8-14 | 0.72 | 0.099                            | 0.003     | 0.0149                           | 0.0001    | 0.0478                            | 0.0015    | 95.3  | 2.8       | 95.36   | 0.53      | 155                                 | 31        | 3.6      |
| 170520-8-68 | 0.90 | 0.098                            | 0.004     | 0.0149                           | 0.0002    | 0.0476                            | 0.0017    | 94.7  | 3.6       | 95.43   | 0.96      | 187                                 | 33        | 5.5      |
| 170520-8-51 | 0.63 | 0.100                            | 0.006     | 0.0149                           | 0.0002    | 0.0509                            | 0.0041    | 96.3  | 5.3       | 95.46   | 0.93      | 332                                 | 90        | 5.6      |
| 170520-8-12 | 0.59 | 0.100                            | 0.005     | 0.0149                           | 0.0002    | 0.0484                            | 0.0025    | 96.7  | 4.5       | 95.5  | 1.4       | 200                                 | 110       | 4.9      |
| 170520-8-64 | 0.78 | 0.099                            | 0.005     | 0.0150                           | 0.0004    | 0.0481                            | 0.0022    | 95.5  | 4.9       | 95.6  | 2.6       | 203                                 | 95        | 7.9      |
| 170520-8-67 | 0.67 | 0.099                            | 0.003     | 0.0149                           | 0.0001    | 0.0484                            | 0.0013    | 96  | 2.3       | 95.63   | 0.54      | 207                                 | 37        | 2.6      |
| 170520-8-43 | 0.57 | 0.099                            | 0.003     | 0.0150                           | 0.0001    | 0.0486                            | 0.0017    | 96.1  | 3.2       | 95.67   | 0.87      | 277                                 | 75        | 3.8      |
| 170520-8-15 | 0.61 | 0.100                            | 0.004     | 0.0150                           | 0.0001    | 0.0487                            | 0.0018    | 97.4  | 3.5       | 95.68   | 0.67      | 228                                 | 38        | 2.6      |
| 170520-8-18 | 0.84 | 0.100                            | 0.006     | 0.0150                           | 0.0002    | 0.0484                            | 0.0029    | 96.4  | 5         | 95.7  | 1         | 287                                 | 94        | 5.5      |
| 170520-8-66 | 0.64 | 0.099                            | 0.002     | 0.0150                           | 0.0001    | 0.0483                            | 0.0012    | 95.3  | 2.1       | 95.72   | 0.66      | 145                                 | 25        | 3.3      |
| 170520-8-36 | 1.05 | 0.099                            | 0.002     | 0.0150                           | 0.0001    | 0.0477                            | 0.0009    | 96  | 1.7       | 95.74   | 0.64      | 136                                 | 25        | 2.2      |
| 170520-8-31 | 0.61 | 0.100                            | 0.004     | 0.0150                           | 0.0002    | 0.0490                            | 0.0021    | 96.7  | 3.8       | 95.8  | 1.1       | 236                                 | 57        | 4.2      |
| 170520-8-47 | 0.62 | 0.101                            | 0.004     | 0.0150                           | 0.0001    | 0.0484                            | 0.0018    | 97.7  | 4         | 95.82   | 0.71      | 237                                 | 47        | 3.0      |
| 170520-8-69 | 0.54 | 0.099                            | 0.004     | 0.0150                           | 0.0001    | 0.0481                            | 0.0016    | 95.5  | 3.2       | 95.83   | 0.82      | 190                                 | 41        | 4.5      |
| 170520-8-58 | 0.54 | 0.100                            | 0.004     | 0.0150                           | 0.0001    | 0.0486                            | 0.0020    | 97.1  | 3.9       | 95.88   | 0.91      | 247                                 | 61        | 3.7      |

**Appendix 6.** U-Pb ratio of Manwolsan Tuff of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-8-19 | 0.88 | 0.100                            | 0.003     | 0.0150                           | 0.0001    | 0.0483                            | 0.0012    | 96.6  | 2.5       | 95.9  | 0.7       | 136                                 | 30        | 2.6      |
| 170520-8-65 | 0.78 | 0.102                            | 0.005     | 0.0150                           | 0.0002    | 0.0488                            | 0.0022    | 98.1  | 4.3       | 96  | 1.1       | 219                                 | 46        | 3.4      |
| 170520-8-25 | 0.63 | 0.101                            | 0.004     | 0.0150                           | 0.0001    | 0.0487                            | 0.0022    | 97.3  | 4         | 96.05   | 0.84      | 253                                 | 59        | 3.7      |
| 170520-8-41 | 0.56 | 0.101                            | 0.004     | 0.0150                           | 0.0001    | 0.0487                            | 0.0018    | 97.2  | 3.5       | 96.17   | 0.72      | 209                                 | 41        | 3.3      |
| 170520-8-54 | 0.69 | 0.101                            | 0.006     | 0.0150                           | 0.0001    | 0.0495                            | 0.0033    | 97.9  | 5.8       | 96.21   | 0.81      | 227                                 | 70        | 5.1      |
| 170520-8-21 | 0.93 | 0.099                            | 0.011     | 0.0151                           | 0.0003    | 0.0477                            | 0.0053    | 96  | 10        | 96.3  | 1.7       | 240                                 | 250       | 12.5     |
| 170520-8-48 | 0.60 | 0.102                            | 0.004     | 0.0151                           | 0.0002    | 0.0492                            | 0.0018    | 98.5  | 3.7       | 96.4  | 1.1       | 219                                 | 56        | 2.8      |
| 170520-8-70 | 0.88 | 0.102                            | 0.007     | 0.0151                           | 0.0004    | 0.0495                            | 0.0034    | 98.4  | 6.3       | 96.5  | 2.3       | 186                                 | 80        | 6.9      |
| 170520-8-17 | 0.56 | 0.100                            | 0.004     | 0.0151                           | 0.0001    | 0.0488                            | 0.0022    | 96.7  | 3.8       | 96.58   | 0.79      | 231                                 | 42        | 4.6      |
| 170520-8-32 | 0.57 | 0.100                            | 0.004     | 0.0151                           | 0.0001    | 0.0483                            | 0.0019    | 97  | 3.7       | 96.58   | 0.64      | 142                                 | 31        | 4.1      |
| 170520-8-9  | 0.98 | 0.107                            | 0.010     | 0.0151                           | 0.0002    | 0.0515                            | 0.0046    | 102.8   | 8.9       | 96.6  | 1.5       | 325                                 | 45        | 4.3      |
| 170520-8-62 | 0.65 | 0.101                            | 0.003     | 0.0151                           | 0.0001    | 0.0486                            | 0.0016    | 97.9  | 3         | 96.6  | 0.57      | 196                                 | 52        | 2.3      |
| 170520-8-55 | 0.87 | 0.100                            | 0.009     | 0.0151                           | 0.0002    | 0.0480                            | 0.0042    | 96.8  | 8         | 96.8  | 1.3       | 372                                 | 98        | 9.6      |
| 170520-8-30 | 0.82 | 0.100                            | 0.002     | 0.0151                           | 0.0001    | 0.0480                            | 0.0010    | 96.7  | 2         | 96.81   | 0.82      | 107                                 | 28        | 3.0      |
| 170520-8-33 | 0.55 | 0.102                            | 0.003     | 0.0151                           | 0.0001    | 0.0483                            | 0.0014    | 98.2  | 2.4       | 96.81   | 0.62      | 209                                 | 38        | 1.7      |
| 170520-8-35 | 0.50 | 0.102                            | 0.003     | 0.0151                           | 0.0001    | 0.0490                            | 0.0016    | 98.6  | 3.1       | 96.84   | 0.64      | 214                                 | 40        | 2.0      |
| 170520-8-49 | 0.62 | 0.103                            | 0.013     | 0.0152                           | 0.0004    | 0.0492                            | 0.0064    | 99  | 12        | 96.9  | 2.5       | 330                                 | 150       | 12.8     |
| 170520-8-23 | 0.56 | 0.099                            | 0.003     | 0.0152                           | 0.0002    | 0.0477                            | 0.0017    | 96.1  | 2.8       | 96.93   | 0.94      | 196                                 | 69        | 4.7      |
| 170520-8-27 | 0.62 | 0.102                            | 0.005     | 0.0152                           | 0.0001    | 0.0484                            | 0.0023    | 98  | 4.4       | 96.94   | 0.69      | 229                                 | 53        | 4.2      |
| 170520-8-50 | 0.74 | 0.101                            | 0.006     | 0.0152                           | 0.0002    | 0.0486                            | 0.0027    | 98.4  | 4.9       | 97  | 1.5       | 296                                 | 57        | 5.2      |

**Appendix 6.** U-Pb ratio of Manwolsan Tuff of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-8-63 | 0.83 | 0.108                            | 0.008     | 0.0152                           | 0.0002    | 0.0513                            | 0.0039    | 103.8   | 7.6       | 97.1  | 1.5       | 380                                 | 110       | 2.5      |
| 170520-8-16 | 0.54 | 0.101                            | 0.004     | 0.0152                           | 0.0002    | 0.0483                            | 0.0020    | 98.5  | 3.4       | 97.23   | 0.95      | 227                                 | 43        | 3.2      |
| 170520-8-61 | 0.88 | 0.101                            | 0.003     | 0.0152                           | 0.0001    | 0.0480                            | 0.0012    | 97.9  | 2.4       | 97.49   | 0.69      | 125                                 | 26        | 2.7      |
| 170520-8-2  | 0.65 | 0.104                            | 0.005     | 0.0153                           | 0.0002    | 0.0495                            | 0.0024    | 100.1   | 4.6       | 97.6  | 1.1       | 225                                 | 64        | 3.3      |
| 170520-8-52 | 0.97 | 0.104                            | 0.007     | 0.0153                           | 0.0003    | 0.0495                            | 0.0032    | 100.5   | 6.3       | 97.8  | 1.6       | 520                                 | 260       | 5.3      |
| 170520-8-8  | 0.64 | 0.105                            | 0.005     | 0.0153                           | 0.0002    | 0.0499                            | 0.0022    | 100.9   | 4.1       | 98  | 1.5       | 247                                 | 45        | 2.8      |
| 170520-8-29 | 0.86 | 0.104                            | 0.013     | 0.0153                           | 0.0003    | 0.0520                            | 0.0083    | 100   | 12        | 98  | 1.8       | 620                                 | 440       | 12.0     |
| 170520-8-39 | 0.73 | 0.103                            | 0.004     | 0.0153                           | 0.0002    | 0.0485                            | 0.0018    | 99.4  | 3.8       | 98  | 1.2       | 199                                 | 59        | 3.7      |
| 170520-8-3  | 0.70 | 0.104                            | 0.005     | 0.0153                           | 0.0002    | 0.0497                            | 0.0022    | 100   | 4.7       | 98.2  | 1.1       | 235                                 | 63        | 4.1      |
| 170520-8-34 | 0.77 | 0.102                            | 0.004     | 0.0153                           | 0.0002    | 0.0487                            | 0.0022    | 98.9  | 4         | 98.2  | 1.3       | 259                                 | 52        | 4.7      |
| 170520-8-75 | 0.51 | 0.105                            | 0.012     | 0.0154                           | 0.0003    | 0.0499                            | 0.0062    | 101   | 11        | 98.2  | 2.1       | 350                                 | 200       | 10.5     |
| 170520-8-4  | 0.61 | 0.101                            | 0.004     | 0.0154                           | 0.0002    | 0.0481                            | 0.0020    | 98  | 3.9       | 98.4  | 1         | 169                                 | 45        | 5.4      |
| 170520-8-38 | 0.38 | 0.199                            | 0.002     | 0.0290                           | 0.0002    | 0.0499                            | 0.0005    | 184   | 1.8       | 184.52  | 0.98      | 189                                 | 13        | 1.8      |
| 170520-8-46 | 0.57 | 0.202                            | 0.002     | 0.0294                           | 0.0002    | 0.0499                            | 0.0006    | 187   | 1.4       | 186.69  | 0.97      | 204                                 | 22        | 1.1      |
| 170520-8-56 | 0.60 | 0.207                            | 0.004     | 0.0298                           | 0.0002    | 0.0504                            | 0.0009    | 191.4   | 3         | 189.4   | 1.5       | 222                                 | 24        | 1.3      |
| 170520-8-24 | 0.72 | 0.210                            | 0.007     | 0.0303                           | 0.0003    | 0.0504                            | 0.0017    | 193.6   | 6.1       | 192.1   | 1.8       | 294                                 | 82        | 3.3      |
| 170520-8-57 | 0.56 | 0.213                            | 0.004     | 0.0305                           | 0.0002    | 0.0502                            | 0.0009    | 196   | 3.3       | 193.8   | 1.4       | 201                                 | 26        | 1.3      |
| 170520-8-44 | 0.39 | 0.211                            | 0.007     | 0.0306                           | 0.0002    | 0.0501                            | 0.0018    | 194.4   | 5.8       | 194.5   | 1.2       | 263                                 | 90        | 3.7      |
| 170520-8-53 | 0.07 | 3.883                            | 0.053     | 0.2524                           | 0.0032    | 0.1112                            | 0.0003    | 1609  | 11        | 1451  | 16        | 1819.7                              | 3         | -24.1    |
| 170520-8-42 | 0.89 | 11.700                           | 0.320     | 0.4900                           | 0.0110    | 0.1737                            | 0.0018    | 2588  | 26        | 2570  | 48        | 2593                                | 12        | 1.4      |

**Appendix 7.** U-Pb ratio of Jangdong Tuff(matrix of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-9-1  | 0.53 | 7.192                            | 0.076     | 0.3619                           | 0.0031    | 0.1462                            | 0.0011    | 2135.5                                      | 9.4       | 1991  | 15        | 2304                                | 10        | -14.5    |
| 170520-9-2  | 0.56 | 0.208                            | 0.008     | 0.0303                           | 0.0002    | 0.0504                            | 0.0017    | 189.2                                       | 4.6       | 192.6                                       | 1.4       | 234                                 | 37        | 4.9      |
| 170520-9-3  | 0.01 | 4.542                            | 0.025     | 0.2954                           | 0.0013    | 0.1134                            | 0.0004    | 1738.6                                      | 4.6       | 1668.6                                      | 6.4       | 1853.8                              | 2.8       | -10.5    |
| 170520-9-4  | 0.25 | 9.610                            | 0.160     | 0.4506                           | 0.0060    | 0.1576                            | 0.0007    | 2398  | 15        | 2397  | 27        | 2429.4                              | 6.3       | 0.0      |
| 170520-9-5  | 0.06 | 5.183                            | 0.024     | 0.3395                           | 0.0016    | 0.1121                            | 0.0002    | 1849.8                                      | 3.9       | 1884.5                                      | 7.9       | 1832.2                              | 3.4       | 3.4      |
| 170520-9-6  | 0.94 | 0.206                            | 0.007     | 0.0302                           | 0.0004    | 0.0497                            | 0.0014    | 190.3                                       | 6         | 191.6                                       | 2.2       | 214                                 | 42        | 5.0      |
| 170520-9-7  | 0.76 | 0.205                            | 0.007     | 0.0301                           | 0.0004    | 0.0505                            | 0.0019    | 189   | 6.1       | 191.3                                       | 2.2       | 167                                 | 38        | 5.5      |
| 170520-9-8  | 0.26 | 5.235                            | 0.047     | 0.3339                           | 0.0022    | 0.1155                            | 0.0006    | 1858.2                                      | 7.6       | 1857  | 11        | 1885.8                              | 7         | -0.6     |
| 170520-9-9  | 0.39 | 0.255                            | 0.010     | 0.0315                           | 0.0003    | 0.0600                            | 0.0022    | 230.7                                       | 7.9       | 200.1                                       | 2         | 603                                 | 60        | -10.3    |
| 170520-9-10 | 0.57 | 0.211                            | 0.006     | 0.0305                           | 0.0005    | 0.0505                            | 0.0016    | 194.1                                       | 5.3       | 193.8                                       | 3         | 221                                 | 47        | 4.1      |
| 170520-9-11 | 0.35 | 0.206                            | 0.005     | 0.0301                           | 0.0003    | 0.0499                            | 0.0013    | 190.3                                       | 4.6       | 191.1                                       | 1.7       | 202                                 | 33        | 3.7      |
| 170520-9-12 | 0.42 | 0.369                            | 0.018     | 0.0491                           | 0.0027    | 0.0552                            | 0.0018    | 319   | 13        | 309   | 17        | 530                                 | 83        | 6.5      |
| 170520-9-13 | 0.23 | 5.255                            | 0.066     | 0.3346                           | 0.0028    | 0.1137                            | 0.0006    | 1861  | 11        | 1861  | 13        | 1863                                | 5.1       | 0.9      |
| 170520-9-14 | 0.59 | 0.210                            | 0.006     | 0.0308                           | 0.0002    | 0.0499                            | 0.0011    | 195.2                                       | 4.5       | 195.3                                       | 1.4       | 194                                 | 34        | 3.1      |
| 170520-9-15 | 0.52 | 0.227                            | 0.014     | 0.0315                           | 0.0006    | 0.0521                            | 0.0029    | 207   | 11        | 199.7                                       | 3.6       | 301                                 | 69        | 3.7      |
| 170520-9-16 | 0.56 | 0.209                            | 0.007     | 0.0304                           | 0.0004    | 0.0495                            | 0.0016    | 192.3                                       | 5.9       | 193.1                                       | 2.2       | 214                                 | 46        | 4.6      |
| 170520-9-17 | 0.25 | 0.207                            | 0.005     | 0.0299                           | 0.0002    | 0.0498                            | 0.0011    | 190.8                                       | 4         | 189.7                                       | 1.4       | 228                                 | 30        | 2.3      |
| 170520-9-18 | 0.76 | 0.208                            | 0.004     | 0.0302                           | 0.0002    | 0.0495                            | 0.0008    | 191.5                                       | 3         | 191.9                                       | 1.3       | 200                                 | 22        | 2.4      |
| 170520-9-19 | 0.33 | 0.211                            | 0.006     | 0.0305                           | 0.0003    | 0.0498                            | 0.0014    | 194.6                                       | 5.1       | 194.1                                       | 1.5       | 180                                 | 29        | 3.1      |
| 170520-9-20 | 0.32 | 0.210                            | 0.008     | 0.0306                           | 0.0004    | 0.0497                            | 0.0016    | 193.7                                       | 6.7       | 194.4                                       | 2.8       | 179                                 | 40        | 5.2      |

**Appendix 7.** U-Pb ratio of Jangdong Tuff(matrix of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | <sup>207</sup> Pb/ <sup>235</sup> U | 2σ    | <sup>206</sup> Pb/ <sup>238</sup> U | 2σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | 2σ     | <sup>235</sup> U- <sup>207</sup> Pb<br>age(Ma) | 2σ  | <sup>238</sup> U- <sup>206</sup> Pb<br>age(Ma) | 2σ  | <sup>207</sup> / <sup>206</sup> Pb<br>age(Ma) | 2σ  | disc.(%) |
|-------------|------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|--------|--|-----|--|-----|---|-----|----------|
| 170520-9-21 | 0.46 | 0.209                               | 0.006 | 0.0302                              | 0.0003 | 0.0498                               | 0.0011 | 192.6  | 4.8 | 191.5  | 1.9 | 193   | 30  | 2.9      |
| 170520-9-22 | 0.61 | 0.209                               | 0.005 | 0.0303                              | 0.0003 | 0.0496                               | 0.0011 | 193.6  | 3.7 | 192.4  | 2   | 182   | 29  | 2.3      |
| 170520-9-23 | 0.52 | 0.211                               | 0.004 | 0.0302                              | 0.0002 | 0.0508                               | 0.0011 | 195.1  | 3.9 | 191.9  | 1.4 | 220   | 19  | 1.1      |
| 170520-9-24 | 0.51 | 0.208                               | 0.009 | 0.0300                              | 0.0006 | 0.0504                               | 0.0018 | 193.3  | 7.8 | 190.3  | 3.7 | 213   | 38  | 4.5      |
| 170520-9-25 | 0.57 | 0.209                               | 0.006 | 0.0300                              | 0.0002 | 0.0503                               | 0.0016 | 192.4  | 5   | 190.7  | 1.5 | 201   | 37  | 2.5      |
| 170520-9-26 | 0.50 | 0.207                               | 0.006 | 0.0301                              | 0.0003 | 0.0495                               | 0.0014 | 190.5  | 4.7 | 191.1  | 1.6 | 205   | 44  | 3.6      |
| 170520-9-27 | 0.58 | 0.209                               | 0.007 | 0.0302                              | 0.0003 | 0.0497                               | 0.0015 | 192.4  | 5.4 | 191.8  | 1.9 | 202   | 36  | 3.5      |
| 170520-9-28 | 0.79 | 0.204                               | 0.009 | 0.0296                              | 0.0003 | 0.0506                               | 0.0021 | 188.1  | 7.9 | 188  | 1.8 | 322   | 71  | 5.1      |
| 170520-9-29 | 0.10 | 7.430                               | 0.320 | 0.3990                              | 0.0120 | 0.1338                               | 0.0022 | 2163   | 39  | 2164   | 54  | 2146  | 25  | 4.5      |
| 170520-9-30 | 0.53 | 0.220                               | 0.017 | 0.0303                              | 0.0004 | 0.0525                               | 0.0038 | 202  | 14  | 192.4  | 2.4 | 333   | 69  | 3.5      |
| 170520-9-31 | 0.31 | 0.290                               | 0.007 | 0.0356                              | 0.0004 | 0.0589                               | 0.0014 | 258.8  | 5.1 | 225.4  | 2.3 | 552   | 50  | -11.5    |
| 170520-9-32 | 0.59 | 0.211                               | 0.003 | 0.0305                              | 0.0002 | 0.0498                               | 0.0008 | 194.5  | 2.5 | 193.6  | 1.3 | 203   | 20  | 1.5      |
| 170520-9-33 | 0.41 | 0.216                               | 0.006 | 0.0306                              | 0.0002 | 0.0507                               | 0.0015 | 198.3  | 5.3 | 194.5  | 1.1 | 250   | 23  | 1.3      |
| 170520-9-34 | 0.81 | 0.208                               | 0.009 | 0.0299                              | 0.0003 | 0.0515                               | 0.0034 | 191.5  | 7.4 | 190  | 1.9 | 253   | 78  | 4.1      |
| 170520-9-35 | 0.52 | 0.207                               | 0.006 | 0.0301                              | 0.0002 | 0.0494                               | 0.0015 | 191.1  | 5.2 | 191.5  | 1.3 | 186   | 32  | 3.6      |
| 170520-9-36 | 0.61 | 0.204                               | 0.008 | 0.0291                              | 0.0003 | 0.0509                               | 0.0023 | 188.2  | 6.9 | 184.6  | 1.8 | 287   | 76  | 2.8      |
| 170520-9-37 | 0.53 | 0.236                               | 0.010 | 0.0294                              | 0.0004 | 0.0576                               | 0.0027 | 214.7  | 7.8 | 186.7  | 2.2 | 557   | 90  | -9.6     |
| 170520-9-38 | 0.06 | 2.203                               | 0.026 | 0.1469                              | 0.0011 | 0.1086                               | 0.0005 | 1181.8   | 8.2 | 883.7  | 6   | 1771.9  | 5.8 | -99.2    |
| 170520-9-39 | 0.05 | 2.833                               | 0.030 | 0.1892                              | 0.0019 | 0.1079                               | 0.0005 | 1364.2   | 8   | 1117   | 10  | 1762.8  | 4.4 | -56.5    |
| 170520-9-40 | 0.54 | 8.400                               | 0.200 | 0.3959                              | 0.0055 | 0.1529                               | 0.0025 | 2274   | 22  | 2150   | 25  | 2378  | 19  | -8.6     |

Appendix 7. U-Pb ratio of Jangdong Tuff(matrix of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-9-41 | 0.27 | 0.207                            | 0.004     | 0.0296                           | 0.0003    | 0.0503                            | 0.0008    | 190.6                                       | 3.2       | 188.2                                       | 2.1       | 187                                 | 49        | 1.5      |
| 170520-9-42 | 0.02 | 1.734                            | 0.047     | 0.1110                           | 0.0013    | 0.1114                            | 0.0022    | 1021  | 18        | 678.7                                       | 7.4       | 1826                                | 34        | -162.9   |
| 170520-9-43 | 0.61 | 0.232                            | 0.006     | 0.0294                           | 0.0003    | 0.0571                            | 0.0014    | 212.5                                       | 5.4       | 186.6                                       | 1.8       | 515                                 | 35        | -10.0    |
| 170520-9-44 | 0.56 | 0.206                            | 0.010     | 0.0294                           | 0.0005    | 0.0498                            | 0.0029    | 190   | 8.4       | 186.8                                       | 3.1       | 185                                 | 57        | 4.4      |
| 170520-9-45 | 0.61 | 0.203                            | 0.009     | 0.0292                           | 0.0003    | 0.0505                            | 0.0021    | 187.7                                       | 7.7       | 185.5                                       | 2         | 259                                 | 68        | 4.0      |
| 170520-9-46 | 0.07 | 5.149                            | 0.072     | 0.3314                           | 0.0038    | 0.1125                            | 0.0005    | 1844  | 12        | 1845  | 18        | 1840.6                              | 4.7       | 1.5      |
| 170520-9-47 | 0.49 | 0.253                            | 0.012     | 0.0295                           | 0.0006    | 0.0623                            | 0.0024    | 229   | 10        | 187.4                                       | 3.5       | 711                                 | 47        | -15.0    |
| 170520-9-48 | 0.56 | 0.192                            | 0.005     | 0.0280                           | 0.0002    | 0.0500                            | 0.0014    | 178.3                                       | 4.4       | 178   | 1.3       | 215                                 | 37        | 3.0      |
| 170520-9-49 | 0.07 | 3.682                            | 0.021     | 0.2381                           | 0.0012    | 0.1122                            | 0.0004    | 1567.4                                      | 4.6       | 1376.8                                      | 6.4       | 1835.6                              | 3.7       | -32.6    |
| 170520-9-50 | 0.50 | 3.490                            | 0.100     | 0.2124                           | 0.0037    | 0.1200                            | 0.0021    | 1524  | 23        | 1241  | 19        | 1953                                | 28        | -53.6    |
| 170520-9-51 | 0.55 | 0.201                            | 0.004     | 0.0296                           | 0.0002    | 0.0495                            | 0.0011    | 186.3                                       | 3.7       | 187.9                                       | 1.2       | 170                                 | 25        | 3.5      |
| 170520-9-52 | 0.39 | 0.201                            | 0.003     | 0.0293                           | 0.0002    | 0.0499                            | 0.0007    | 185.9                                       | 2.6       | 185.9                                       | 1.5       | 194                                 | 18        | 2.2      |
| 170520-9-53 | 0.75 | 0.201                            | 0.009     | 0.0293                           | 0.0004    | 0.0496                            | 0.0023    | 186   | 7.5       | 186.3                                       | 2.5       | 278                                 | 44        | 5.5      |
| 170520-9-54 | 0.57 | 0.207                            | 0.006     | 0.0298                           | 0.0003    | 0.0513                            | 0.0014    | 192.9                                       | 4.9       | 189   | 1.8       | 249                                 | 32        | 1.5      |
| 170520-9-55 | 0.47 | 0.204                            | 0.004     | 0.0298                           | 0.0002    | 0.0500                            | 0.0010    | 188.9                                       | 3.4       | 189.2                                       | 1.3       | 178                                 | 24        | 2.6      |
| 170520-9-56 | 0.60 | 0.197                            | 0.007     | 0.0288                           | 0.0003    | 0.0496                            | 0.0017    | 182.6                                       | 5.9       | 183.2                                       | 2.1       | 214                                 | 46        | 4.7      |
| 170520-9-57 | 0.60 | 0.204                            | 0.006     | 0.0297                           | 0.0002    | 0.0499                            | 0.0014    | 188.4                                       | 5.1       | 188.6                                       | 1.4       | 216                                 | 34        | 3.6      |
| 170520-9-58 | 0.51 | 0.203                            | 0.007     | 0.0293                           | 0.0003    | 0.0502                            | 0.0015    | 187.6                                       | 5.5       | 186   | 1.7       | 203                                 | 39        | 3.0      |
| 170520-9-59 | 0.29 | 0.211                            | 0.002     | 0.0301                           | 0.0003    | 0.0507                            | 0.0007    | 194   | 1.3       | 191   | 1.9       | 229                                 | 34        | 0.1      |
| 170520-9-60 | 0.50 | 0.200                            | 0.006     | 0.0291                           | 0.0002    | 0.0498                            | 0.0013    | 185.3                                       | 4.7       | 184.8                                       | 1.1       | 193                                 | 34        | 2.9      |

**Appendix 7.** U-Pb ratio of Jangdong Tuff(matrix of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-9-61 | 0.09 | 2.846                            | 0.053     | 0.1853                           | 0.0012    | 0.1107                            | 0.0014    | 1368  | 14        | 1095.7                                      | 6.7       | 1811                                | 11        | -63.7    |
| 170520-9-62 | 0.43 | 0.201                            | 0.004     | 0.0295                           | 0.0002    | 0.0495                            | 0.0009    | 186.2                                       | 3.6       | 187.1                                       | 1.1       | 200                                 | 27        | 3.0      |
| 170520-9-63 | 0.58 | 0.209                            | 0.009     | 0.0299                           | 0.0003    | 0.0504                            | 0.0020    | 192.3                                       | 7.4       | 189.8                                       | 2         | 226                                 | 52        | 3.6      |
| 170520-9-64 | 0.15 | 5.700                            | 0.078     | 0.3497                           | 0.0039    | 0.1179                            | 0.0004    | 1931  | 12        | 1933  | 19        | 1925.5                              | 5.5       | 1.7      |
| 170520-9-65 | 0.47 | 0.173                            | 0.003     | 0.0130                           | 0.0002    | 0.0946                            | 0.0013    | 161.7                                       | 2.5       | 83.4  | 1.3       | 1521                                | 23        | -89.3    |
| 170520-9-66 | 0.55 | 0.207                            | 0.006     | 0.0296                           | 0.0003    | 0.0515                            | 0.0018    | 192.3                                       | 5.5       | 187.8                                       | 1.9       | 266                                 | 53        | 1.5      |
| 170520-9-67 | 0.35 | 4.236                            | 0.056     | 0.2639                           | 0.0033    | 0.1174                            | 0.0007    | 1681  | 11        | 1509  | 17        | 1916.8                              | 6.2       | -25.5    |
| 170520-9-68 | 0.74 | 0.207                            | 0.009     | 0.0297                           | 0.0004    | 0.0508                            | 0.0021    | 190.9                                       | 7.2       | 188.8                                       | 2.3       | 346                                 | 66        | 3.9      |
| 170520-9-69 | 0.34 | 0.204                            | 0.005     | 0.0296                           | 0.0002    | 0.0501                            | 0.0011    | 188.6                                       | 4.2       | 188.2                                       | 1.1       | 195                                 | 29        | 2.6      |
| 170520-9-70 | 0.50 | 0.204                            | 0.006     | 0.0295                           | 0.0003    | 0.0508                            | 0.0016    | 188.6                                       | 5.3       | 187.2                                       | 1.8       | 258                                 | 45        | 3.0      |
| 170520-9-71 | 0.49 | 0.202                            | 0.006     | 0.0292                           | 0.0003    | 0.0499                            | 0.0013    | 187.1                                       | 4.9       | 185.8                                       | 1.6       | 243                                 | 57        | 2.8      |
| 170520-9-72 | 0.63 | 0.202                            | 0.005     | 0.0292                           | 0.0002    | 0.0496                            | 0.0012    | 186.3                                       | 4.4       | 185.6                                       | 1.3       | 191                                 | 28        | 2.7      |
| 170520-9-73 | 0.46 | 0.200                            | 0.005     | 0.0291                           | 0.0003    | 0.0496                            | 0.0012    | 184.9                                       | 4.6       | 184.9                                       | 1.6       | 170                                 | 34        | 3.4      |
| 170520-9-74 | 0.52 | 0.206                            | 0.017     | 0.0294                           | 0.0007    | 0.0504                            | 0.0035    | 190   | 14        | 187   | 4.2       | 255                                 | 95        | 8.1      |
| 170520-9-75 | 0.56 | 0.200                            | 0.004     | 0.0291                           | 0.0002    | 0.0497                            | 0.0009    | 185.2                                       | 3.1       | 184.9                                       | 1.1       | 178                                 | 22        | 2.1      |
| 170520-9-76 | 0.60 | 0.201                            | 0.004     | 0.0293                           | 0.0001    | 0.0496                            | 0.0009    | 186.2                                       | 3.5       | 185.85                                      | 0.88      | 184                                 | 22        | 2.2      |
| 170520-9-77 | 0.75 | 0.197                            | 0.004     | 0.0285                           | 0.0002    | 0.0503                            | 0.0012    | 182.5                                       | 3.5       | 181.1                                       | 1         | 190                                 | 41        | 1.7      |
| 170520-9-78 | 0.02 | 5.236                            | 0.055     | 0.3337                           | 0.0035    | 0.1135                            | 0.0002    | 1858.3                                      | 8.8       | 1856  | 17        | 1856.4                              | 1.9       | 1.0      |
| 170520-9-79 | 0.56 | 0.239                            | 0.009     | 0.0307                           | 0.0004    | 0.0562                            | 0.0016    | 217.8                                       | 7         | 194.7                                       | 2.2       | 538                                 | 80        | -7.1     |
| 170520-9-80 | 0.58 | 0.198                            | 0.006     | 0.0291                           | 0.0002    | 0.0492                            | 0.0014    | 182.8                                       | 4.9       | 184.8                                       | 1.2       | 240                                 | 37        | 4.4      |



**Appendix 7.** U-Pb ratio of Jangdong Tuff(matrix of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 170520-9-81  | 0.33 | 0.256                            | 0.008     | 0.0309                           | 0.0003    | 0.0604                            | 0.0020    | 231.7                                       | 6         | 196   | 1.9       | 613                                 | 70        | -14.2    |
| 170520-9-82  | 0.27 | 0.200                            | 0.014     | 0.0289                           | 0.0005    | 0.0516                            | 0.0020    | 185   | 12        | 183.7                                       | 3         | 214                                 | 66        | 7.5      |
| 170520-9-83  | 0.46 | 22.980                           | 0.140     | 0.6176                           | 0.0031    | 0.2705                            | 0.0008    | 3226.2                                      | 6.1       | 3100  | 12        | 3307.8                              | 3.5       | -6.2     |
| 170520-9-84  | 0.31 | 0.199                            | 0.005     | 0.0286                           | 0.0002    | 0.0502                            | 0.0010    | 183.8                                       | 4.1       | 181.9                                       | 1.4       | 223                                 | 35        | 2.0      |
| 170520-9-85  | 0.05 | 3.983                            | 0.055     | 0.2559                           | 0.0033    | 0.1126                            | 0.0004    | 1630  | 11        | 1469  | 17        | 1845.1                              | 3.4       | -24.2    |
| 170520-9-86  | 0.56 | 0.202                            | 0.004     | 0.0292                           | 0.0002    | 0.0501                            | 0.0012    | 186.9                                       | 3.7       | 185.5                                       | 1.4       | 215                                 | 30        | 2.0      |
| 170520-9-87  | 0.58 | 0.198                            | 0.006     | 0.0290                           | 0.0003    | 0.0498                            | 0.0016    | 183.4                                       | 5.5       | 184.4                                       | 2.1       | 203                                 | 34        | 4.7      |
| 170520-9-88  | 0.58 | 0.203                            | 0.008     | 0.0292                           | 0.0003    | 0.0506                            | 0.0019    | 187.6                                       | 6.7       | 185.5                                       | 2.1       | 302                                 | 46        | 3.6      |
| 170520-9-89  | 0.34 | 7.622                            | 0.067     | 0.3788                           | 0.0022    | 0.1456                            | 0.0008    | 2187.1                                      | 8         | 2070  | 10        | 2295.4                              | 8.4       | -10.0    |
| 170520-9-90  | 0.84 | 0.197                            | 0.004     | 0.0288                           | 0.0004    | 0.0498                            | 0.0008    | 182.8                                       | 3.7       | 183.2                                       | 2.2       | 185                                 | 29        | 3.4      |
| 170520-9-91  | 0.53 | 0.204                            | 0.016     | 0.0292                           | 0.0004    | 0.0499                            | 0.0039    | 188   | 13        | 185.7                                       | 2.6       | 244                                 | 98        | 7.2      |
| 170520-9-92  | 0.57 | 0.198                            | 0.006     | 0.0290                           | 0.0002    | 0.0497                            | 0.0016    | 183.6                                       | 5.4       | 184   | 1.5       | 198                                 | 48        | 4.0      |
| 170520-9-93  | 0.55 | 0.201                            | 0.005     | 0.0292                           | 0.0002    | 0.0501                            | 0.0014    | 185.6                                       | 4.4       | 185.7                                       | 1.5       | 206                                 | 20        | 3.2      |
| 170520-9-94  | 0.56 | 6.882                            | 0.096     | 0.3146                           | 0.0034    | 0.1589                            | 0.0009    | 2096  | 12        | 1763  | 17        | 2442.9                              | 5.8       | -37.3    |
| 170520-9-95  | 0.55 | 0.201                            | 0.008     | 0.0288                           | 0.0002    | 0.0515                            | 0.0024    | 186.2                                       | 6.8       | 182.8                                       | 1.5       | 241                                 | 54        | 2.7      |
| 170520-9-96  | 0.54 | 0.198                            | 0.004     | 0.0289                           | 0.0002    | 0.0496                            | 0.0010    | 183.4                                       | 2.9       | 183.8                                       | 1.2       | 186                                 | 29        | 2.4      |
| 170520-9-97  | 0.60 | 0.203                            | 0.007     | 0.0292                           | 0.0003    | 0.0500                            | 0.0016    | 187.2                                       | 6.2       | 185.8                                       | 2.1       | 212                                 | 35        | 3.7      |
| 170520-9-98  | 0.59 | 0.197                            | 0.013     | 0.0289                           | 0.0004    | 0.0493                            | 0.0033    | 182   | 11        | 183.6                                       | 2.6       | 220                                 | 120       | 8.3      |
| 170520-9-99  | 0.52 | 0.210                            | 0.011     | 0.0294                           | 0.0002    | 0.0515                            | 0.0028    | 193.7                                       | 9.5       | 186.8                                       | 1.1       | 291                                 | 41        | 2.0      |
| 170520-9-100 | 0.16 | 4.265                            | 0.021     | 0.2757                           | 0.0011    | 0.1119                            | 0.0002    | 1686.6                                      | 4         | 1569.8                                      | 5.5       | 1830.3                              | 2.5       | -16.1    |

**Appendix 8.** U-Pb ratio of Jangdong Tuff(boulder of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-10-66 | 0.65 | 0.203                            | 0.009     | 0.0253                           | 0.0005    | 0.0576                            | 0.0024    | 187.2                                       | 7.5       | 161   | 3.2       | 493                              | 47        | -9.6     |
| 170520-10-24 | 0.48 | 0.239                            | 0.003     | 0.0261                           | 0.0003    | 0.0666                            | 0.0016    | 217.7                                       | 2.7       | 166.2                                       | 2.1       | 861                              | 59        | -28.1    |
| 170520-10-59 | 0.67 | 0.193                            | 0.005     | 0.0282                           | 0.0002    | 0.0499                            | 0.0011    | 179.1                                       | 4         | 179   | 1.4       | 210                              | 33        | 3.0      |
| 170520-10-75 | 0.52 | 0.198                            | 0.008     | 0.0283                           | 0.0003    | 0.0508                            | 0.0021    | 183.6                                       | 6.6       | 180   | 2         | 260                              | 46        | 2.8      |
| 170520-10-88 | 0.56 | 0.199                            | 0.006     | 0.0286                           | 0.0003    | 0.0501                            | 0.0013    | 183.9                                       | 4.7       | 182   | 1.7       | 231                              | 39        | 2.5      |
| 170520-10-81 | 0.69 | 0.204                            | 0.012     | 0.0286                           | 0.0006    | 0.0516                            | 0.0031    | 188   | 10        | 182   | 3.8       | 345                              | 63        | 4.3      |
| 170520-10-87 | 0.53 | 0.198                            | 0.002     | 0.0287                           | 0.0002    | 0.0500                            | 0.0006    | 183.2                                       | 1.9       | 182.55                                      | 0.99      | 195                              | 16        | 1.2      |
| 170520-10-92 | 0.11 | 0.230                            | 0.006     | 0.0288                           | 0.0004    | 0.0576                            | 0.0016    | 210.2                                       | 4.7       | 183.2                                       | 2.3       | 539                              | 60        | -10.9    |
| 170520-10-71 | 0.81 | 0.203                            | 0.008     | 0.0289                           | 0.0003    | 0.0504                            | 0.0018    | 187.2                                       | 6.4       | 183.3                                       | 1.6       | 268                              | 35        | 2.2      |
| 170520-10-61 | 0.60 | 0.197                            | 0.004     | 0.0289                           | 0.0002    | 0.0495                            | 0.0010    | 183.4                                       | 3.3       | 183.35                                      | 0.99      | 204                              | 29        | 2.3      |
| 170520-10-73 | 0.48 | 0.198                            | 0.005     | 0.0289                           | 0.0003    | 0.0494                            | 0.0011    | 182.4                                       | 3.8       | 183.4                                       | 1.6       | 199                              | 24        | 3.5      |
| 170520-10-11 | 0.84 | 0.202                            | 0.007     | 0.0289                           | 0.0003    | 0.0507                            | 0.0019    | 186.7                                       | 6.2       | 183.6                                       | 1.6       | 278                              | 37        | 2.6      |
| 170520-10-91 | 0.89 | 0.199                            | 0.005     | 0.0289                           | 0.0003    | 0.0505                            | 0.0013    | 184.3                                       | 4.5       | 183.6                                       | 2         | 194                              | 30        | 3.2      |
| 170520-10-63 | 0.48 | 0.199                            | 0.003     | 0.0289                           | 0.0002    | 0.0496                            | 0.0007    | 184.4                                       | 2.6       | 183.7                                       | 1         | 185                              | 16        | 1.6      |
| 170520-10-57 | 0.58 | 0.200                            | 0.008     | 0.0289                           | 0.0003    | 0.0500                            | 0.0018    | 185.1                                       | 6.6       | 183.8                                       | 1.7       | 248                              | 42        | 3.8      |
| 170520-10-18 | 0.57 | 0.202                            | 0.004     | 0.0290                           | 0.0002    | 0.0506                            | 0.0010    | 186.3                                       | 3.4       | 184.1                                       | 1.3       | 251                              | 28        | 1.4      |
| 170520-10-82 | 0.53 | 0.201                            | 0.008     | 0.0290                           | 0.0004    | 0.0493                            | 0.0018    | 185.6                                       | 7.1       | 184.1                                       | 2.4       | 202                              | 39        | 4.3      |
| 170520-10-64 | 0.52 | 0.202                            | 0.005     | 0.0290                           | 0.0002    | 0.0504                            | 0.0013    | 186.5                                       | 4.5       | 184.3                                       | 1.5       | 204                              | 31        | 2.1      |
| 170520-10-79 | 0.48 | 0.203                            | 0.007     | 0.0290                           | 0.0002    | 0.0505                            | 0.0016    | 187.6                                       | 5.9       | 184.3                                       | 1.4       | 241                              | 36        | 2.2      |
| 170520-10-67 | 0.98 | 0.199                            | 0.005     | 0.0290                           | 0.0002    | 0.0495                            | 0.0011    | 184.3                                       | 4.4       | 184.4                                       | 1.3       | 177                              | 30        | 3.1      |

**Appendix 8.** U-Pb ratio of Jangdong Tuff(boulder of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-10-68 | 0.65 | 0.205                            | 0.009     | 0.0291                           | 0.0004    | 0.0512                            | 0.0023    | 188.8                                       | 7.7       | 184.8                                       | 2.2       | 346                              | 64        | 3.2      |
| 170520-10-97 | 0.42 | 0.202                            | 0.006     | 0.0291                           | 0.0004    | 0.0507                            | 0.0014    | 186.6                                       | 4.9       | 185.1                                       | 2.3       | 217                              | 32        | 3.1      |
| 170520-10-10 | 0.60 | 0.204                            | 0.008     | 0.0291                           | 0.0005    | 0.0506                            | 0.0020    | 188.2                                       | 6.5       | 185.2                                       | 3         | 239                              | 54        | 3.5      |
| 170520-10-35 | 0.50 | 0.202                            | 0.004     | 0.0292                           | 0.0002    | 0.0505                            | 0.0008    | 187   | 3.1       | 185.3                                       | 1.1       | 227                              | 30        | 1.3      |
| 170520-10-7  | 0.59 | 0.205                            | 0.009     | 0.0292                           | 0.0003    | 0.0508                            | 0.0023    | 189.1                                       | 7.3       | 185.3                                       | 2.1       | 301                              | 57        | 3.0      |
| 170520-10-77 | 0.63 | 0.203                            | 0.009     | 0.0292                           | 0.0004    | 0.0505                            | 0.0022    | 187.8                                       | 7.2       | 185.3                                       | 2.6       | 316                              | 43        | 3.9      |
| 170520-10-86 | 0.56 | 0.198                            | 0.009     | 0.0292                           | 0.0003    | 0.0491                            | 0.0022    | 184.2                                       | 7.2       | 185.3                                       | 2.1       | 301                              | 45        | 5.6      |
| 170520-10-78 | 0.45 | 0.206                            | 0.010     | 0.0292                           | 0.0003    | 0.0506                            | 0.0024    | 189.5                                       | 8         | 185.5                                       | 1.7       | 267                              | 47        | 3.1      |
| 170520-10-89 | 0.63 | 0.200                            | 0.005     | 0.0292                           | 0.0002    | 0.0500                            | 0.0012    | 185.2                                       | 4.4       | 185.5                                       | 1.5       | 188                              | 32        | 3.3      |
| 170520-10-52 | 0.50 | 0.203                            | 0.010     | 0.0292                           | 0.0004    | 0.0504                            | 0.0026    | 187.1                                       | 8.8       | 185.6                                       | 2.7       | 345                              | 57        | 5.4      |
| 170520-10-41 | 0.43 | 0.202                            | 0.014     | 0.0292                           | 0.0007    | 0.0509                            | 0.0038    | 186   | 12        | 185.6                                       | 4.2       | 252                              | 68        | 8.5      |
| 170520-10-76 | 0.54 | 0.201                            | 0.006     | 0.0292                           | 0.0006    | 0.0487                            | 0.0014    | 185.6                                       | 4.7       | 185.7                                       | 3.5       | 127                              | 62        | 4.5      |
| 170520-10-84 | 0.54 | 0.202                            | 0.005     | 0.0293                           | 0.0003    | 0.0501                            | 0.0012    | 186.6                                       | 3.8       | 185.9                                       | 1.9       | 224                              | 40        | 2.7      |
| 170520-10-96 | 0.59 | 0.200                            | 0.007     | 0.0293                           | 0.0003    | 0.0493                            | 0.0018    | 185.1                                       | 6         | 185.9                                       | 1.7       | 175                              | 28        | 4.6      |
| 170520-10-54 | 0.48 | 0.202                            | 0.006     | 0.0293                           | 0.0003    | 0.0491                            | 0.0013    | 187.1                                       | 4.9       | 186.1                                       | 1.8       | 212                              | 42        | 3.1      |
| 170520-10-34 | 0.50 | 0.199                            | 0.004     | 0.0293                           | 0.0002    | 0.0496                            | 0.0009    | 184.3                                       | 3         | 186.1                                       | 1         | 172                              | 21        | 3.1      |
| 170520-10-39 | 0.59 | 0.205                            | 0.005     | 0.0293                           | 0.0003    | 0.0504                            | 0.0012    | 189.1                                       | 4.5       | 186.2                                       | 1.6       | 202                              | 28        | 1.7      |
| 170520-10-85 | 0.55 | 0.201                            | 0.009     | 0.0293                           | 0.0004    | 0.0491                            | 0.0019    | 185.7                                       | 7.9       | 186.3                                       | 2.4       | 211                              | 47        | 5.9      |
| 170520-10-55 | 0.49 | 0.208                            | 0.011     | 0.0294                           | 0.0010    | 0.0503                            | 0.0021    | 191.8                                       | 9.4       | 186.5                                       | 6.1       | 237                              | 41        | 5.5      |
| 170520-10-42 | 0.56 | 0.199                            | 0.004     | 0.0294                           | 0.0002    | 0.0488                            | 0.0011    | 184.1                                       | 3.8       | 186.6                                       | 1.4       | 138                              | 22        | 4.1      |

**Appendix 8.** U-Pb ratio of Jangdong Tuff(boulder of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name   | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|---------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-10-31  | 0.40 | 0.203                            | 0.004     | 0.0294                           | 0.0002    | 0.0504                            | 0.0009    | 187.9                                       | 3.4       | 186.7                                       | 1.2       | 228                              | 25        | 1.8      |
| 170520-10-74  | 0.53 | 0.205                            | 0.006     | 0.0294                           | 0.0003    | 0.0503                            | 0.0015    | 188.9                                       | 4.8       | 186.7                                       | 1.6       | 219                              | 43        | 2.2      |
| 170520-10-58  | 0.42 | 0.205                            | 0.007     | 0.0294                           | 0.0003    | 0.0510                            | 0.0019    | 190.4                                       | 6.3       | 186.7                                       | 1.9       | 273                              | 52        | 2.4      |
| 170520-10-46  | 0.57 | 0.204                            | 0.005     | 0.0294                           | 0.0005    | 0.0501                            | 0.0010    | 188   | 4.3       | 186.9                                       | 2.8       | 226                              | 22        | 3.2      |
| 170520-10-80  | 0.54 | 0.203                            | 0.007     | 0.0294                           | 0.0003    | 0.0496                            | 0.0016    | 187.3                                       | 5.7       | 186.9                                       | 1.6       | 224                              | 36        | 3.7      |
| 170520-10-12  | 0.49 | 0.207                            | 0.007     | 0.0294                           | 0.0005    | 0.0506                            | 0.0013    | 190.9                                       | 6         | 187   | 2.9       | 152                              | 78        | 2.7      |
| 170520-10-22  | 0.60 | 0.204                            | 0.004     | 0.0295                           | 0.0002    | 0.0504                            | 0.0010    | 188.8                                       | 3.1       | 187.1                                       | 1.3       | 249                              | 29        | 1.4      |
| 170520-10-37  | 0.48 | 0.200                            | 0.004     | 0.0294                           | 0.0003    | 0.0493                            | 0.0010    | 184.6                                       | 3.4       | 187.1                                       | 1.6       | 185                              | 19        | 4.0      |
| 170520-10-100 | 0.63 | 0.207                            | 0.008     | 0.0295                           | 0.0005    | 0.0513                            | 0.0020    | 190.8                                       | 6.4       | 187.2                                       | 2.9       | 255                              | 43        | 3.0      |
| 170520-10-8   | 0.57 | 0.205                            | 0.005     | 0.0295                           | 0.0002    | 0.0500                            | 0.0012    | 188.8                                       | 4.4       | 187.3                                       | 1.2       | 206                              | 29        | 2.2      |
| 170520-10-20  | 0.56 | 0.204                            | 0.003     | 0.0295                           | 0.0002    | 0.0503                            | 0.0007    | 188.5                                       | 2.5       | 187.36                                      | 0.99      | 211                              | 20        | 1.3      |
| 170520-10-70  | 0.58 | 0.206                            | 0.005     | 0.0295                           | 0.0002    | 0.0504                            | 0.0011    | 189.8                                       | 3.9       | 187.4                                       | 1.2       | 231                              | 27        | 1.4      |
| 170520-10-44  | 0.44 | 0.209                            | 0.011     | 0.0295                           | 0.0007    | 0.0519                            | 0.0029    | 194.4                                       | 9.9       | 187.4                                       | 4.2       | 309                              | 81        | 3.8      |
| 170520-10-26  | 0.59 | 0.205                            | 0.006     | 0.0295                           | 0.0003    | 0.0505                            | 0.0015    | 189.3                                       | 5.2       | 187.5                                       | 1.8       | 247                              | 39        | 2.8      |
| 170520-10-93  | 0.50 | 0.204                            | 0.007     | 0.0295                           | 0.0004    | 0.0500                            | 0.0018    | 188.6                                       | 6.3       | 187.5                                       | 2.5       | 220                              | 34        | 4.1      |
| 170520-10-50  | 0.53 | 0.205                            | 0.006     | 0.0295                           | 0.0003    | 0.0492                            | 0.0013    | 189.4                                       | 5.4       | 187.6                                       | 1.7       | 201                              | 34        | 2.8      |
| 170520-10-13  | 0.66 | 0.205                            | 0.004     | 0.0295                           | 0.0002    | 0.0498                            | 0.0009    | 188.9                                       | 3.1       | 187.68                                      | 0.97      | 198                              | 26        | 1.5      |
| 170520-10-27  | 0.55 | 0.207                            | 0.006     | 0.0296                           | 0.0003    | 0.0508                            | 0.0013    | 191   | 4.9       | 187.8                                       | 1.7       | 260                              | 31        | 1.8      |
| 170520-10-25  | 0.51 | 0.202                            | 0.004     | 0.0296                           | 0.0002    | 0.0496                            | 0.0011    | 186.4                                       | 3.4       | 187.9                                       | 1.5       | 181                              | 26        | 3.4      |
| 170520-10-95  | 0.67 | 0.205                            | 0.007     | 0.0296                           | 0.0003    | 0.0506                            | 0.0016    | 188.9                                       | 5.6       | 187.9                                       | 2.1       | 249                              | 46        | 3.6      |

**Appendix 8.** U-Pb ratio of Jangdong Tuff(boulder of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-10-17 | 0.58 | 0.206                            | 0.011     | 0.0296                           | 0.0004    | 0.0505                            | 0.0027    | 190.4                                       | 9.3       | 187.9                                       | 2.6       | 260                              | 72        | 5.0      |
| 170520-10-98 | 0.47 | 0.203                            | 0.003     | 0.0296                           | 0.0003    | 0.0501                            | 0.0006    | 187.3                                       | 2.7       | 188.3                                       | 1.6       | 184                              | 22        | 2.8      |
| 170520-10-21 | 0.54 | 0.207                            | 0.004     | 0.0297                           | 0.0002    | 0.0507                            | 0.0010    | 191   | 3.4       | 188.4                                       | 1.4       | 229                              | 23        | 1.2      |
| 170520-10-9  | 0.49 | 0.203                            | 0.003     | 0.0297                           | 0.0002    | 0.0496                            | 0.0007    | 187.7                                       | 2.7       | 188.4                                       | 1.2       | 174                              | 22        | 2.4      |
| 170520-10-48 | 0.46 | 0.205                            | 0.004     | 0.0297                           | 0.0002    | 0.0498                            | 0.0009    | 189.5                                       | 3.2       | 188.7                                       | 1.3       | 201                              | 25        | 2.0      |
| 170520-10-2  | 0.54 | 0.204                            | 0.004     | 0.0297                           | 0.0002    | 0.0499                            | 0.0010    | 188.7                                       | 3.4       | 188.8                                       | 1.3       | 213                              | 26        | 2.5      |
| 170520-10-28 | 0.40 | 0.205                            | 0.005     | 0.0297                           | 0.0003    | 0.0504                            | 0.0012    | 189.4                                       | 3.9       | 188.9                                       | 1.7       | 218                              | 31        | 2.7      |
| 170520-10-49 | 0.74 | 0.204                            | 0.003     | 0.0298                           | 0.0002    | 0.0493                            | 0.0009    | 188.3                                       | 2.8       | 189   | 1         | 178                              | 22        | 2.4      |
| 170520-10-32 | 0.24 | 0.214                            | 0.011     | 0.0298                           | 0.0007    | 0.0525                            | 0.0027    | 197.3                                       | 9         | 189   | 4.6       | 305                              | 61        | 2.8      |
| 170520-10-1  | 0.63 | 0.205                            | 0.008     | 0.0298                           | 0.0005    | 0.0500                            | 0.0019    | 189.4                                       | 6.5       | 189.2                                       | 3.3       | 254                              | 38        | 5.1      |
| 170520-10-4  | 0.55 | 0.207                            | 0.005     | 0.0298                           | 0.0002    | 0.0503                            | 0.0011    | 191.2                                       | 4.5       | 189.4                                       | 1.5       | 192                              | 22        | 2.2      |
| 170520-10-47 | 0.55 | 0.210                            | 0.008     | 0.0298                           | 0.0004    | 0.0507                            | 0.0019    | 193.4                                       | 6.3       | 189.5                                       | 2.5       | 272                              | 37        | 2.6      |
| 170520-10-69 | 0.57 | 0.203                            | 0.010     | 0.0298                           | 0.0004    | 0.0496                            | 0.0027    | 187.7                                       | 8.7       | 189.5                                       | 2.3       | 263                              | 88        | 6.8      |
| 170520-10-16 | 0.40 | 0.211                            | 0.009     | 0.0300                           | 0.0003    | 0.0508                            | 0.0020    | 194   | 7.6       | 190.3                                       | 2         | 282                              | 61        | 3.1      |
| 170520-10-53 | 0.56 | 0.207                            | 0.010     | 0.0300                           | 0.0003    | 0.0493                            | 0.0027    | 190.8                                       | 8.9       | 190.3                                       | 2.1       | 211                              | 55        | 5.5      |
| 170520-10-30 | 0.56 | 0.205                            | 0.005     | 0.0300                           | 0.0002    | 0.0498                            | 0.0010    | 189.3                                       | 3.8       | 190.4                                       | 1.2       | 216                              | 43        | 3.2      |
| 170520-10-6  | 0.52 | 0.204                            | 0.008     | 0.0301                           | 0.0003    | 0.0485                            | 0.0020    | 188.4                                       | 6.9       | 191.3                                       | 2.2       | 177                              | 50        | 6.3      |
| 170520-10-15 | 0.55 | 0.211                            | 0.009     | 0.0304                           | 0.0004    | 0.0509                            | 0.0025    | 194.2                                       | 7.5       | 192.7                                       | 2.3       | 239                              | 73        | 4.3      |
| 170520-10-51 | 0.60 | 0.213                            | 0.019     | 0.0304                           | 0.0007    | 0.0497                            | 0.0044    | 196   | 16        | 193.1                                       | 4.3       | 376                              | 85        | 9.0      |
| 170520-10-23 | 0.63 | 0.210                            | 0.007     | 0.0306                           | 0.0004    | 0.0497                            | 0.0014    | 193.5                                       | 5.6       | 194.4                                       | 2.6       | 238                              | 46        | 4.7      |

**Appendix 8.** U-Pb ratio of Jangdong Tuff(boulder of conglomerate, Southwest area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 170520-10-19 | 0.31 | 0.212                            | 0.002     | 0.0308                           | 0.0001    | 0.0499                            | 0.0002    | 195.6                                       | 1.3       | 195.6                                       | 0.88      | 197.8                            | 6.9       | 1.1      |
| 170520-10-72 | 0.36 | 0.219                            | 0.009     | 0.0309                           | 0.0006    | 0.0521                            | 0.0020    | 200.6                                       | 7.7       | 196   | 3.8       | 322                              | 72        | 3.5      |
| 170520-10-83 | 0.34 | 0.216                            | 0.004     | 0.0309                           | 0.0003    | 0.0508                            | 0.0010    | 198.6                                       | 3.6       | 196.3                                       | 1.7       | 248                              | 38        | 1.5      |
| 170520-10-99 | 0.59 | 0.220                            | 0.008     | 0.0314                           | 0.0004    | 0.0513                            | 0.0018    | 201.6                                       | 6.9       | 199   | 2.5       | 254                              | 71        | 3.4      |
| 170520-10-36 | 0.53 | 0.554                            | 0.016     | 0.0315                           | 0.0005    | 0.1286                            | 0.0030    | 447   | 11        | 199.6                                       | 3.1       | 2080                             | 32        | -116.9   |
| 170520-10-33 | 0.45 | 0.305                            | 0.006     | 0.0327                           | 0.0005    | 0.0683                            | 0.0012    | 270.3                                       | 4.7       | 207.2                                       | 2.8       | 882                              | 34        | -26.8    |
| 170520-10-38 | 0.31 | 0.237                            | 0.007     | 0.0327                           | 0.0014    | 0.0509                            | 0.0023    | 215.9                                       | 5.7       | 207.4                                       | 8.6       | 227                              | 36        | 2.8      |
| 170520-10-90 | 0.43 | 1.332                            | 0.015     | 0.0914                           | 0.0006    | 0.1052                            | 0.0007    | 859.8                                       | 6.3       | 563.8                                       | 3.5       | 1719.4                           | 9.1       | -50.8    |
| 170520-10-3  | 0.34 | 1.329                            | 0.035     | 0.0933                           | 0.0015    | 0.1028                            | 0.0009    | 858   | 15        | 574.9                                       | 8.8       | 1680                             | 14        | -45.1    |
| 170520-10-40 | 0.01 | 3.757                            | 0.034     | 0.2414                           | 0.0022    | 0.1126                            | 0.0007    | 1583.5                                      | 7.3       | 1394  | 11        | 1845                             | 8.7       | -30.9    |
| 170520-10-56 | 0.02 | 3.937                            | 0.027     | 0.2510                           | 0.0015    | 0.1129                            | 0.0003    | 1621  | 5.6       | 1443.3                                      | 7.7       | 1847.4                           | 3.2       | -27.2    |
| 170520-10-94 | 0.06 | 3.885                            | 0.077     | 0.2533                           | 0.0043    | 0.1117                            | 0.0007    | 1610  | 16        | 1455  | 22        | 1824.7                           | 7.5       | -23.4    |
| 170520-10-29 | 0.07 | 3.950                            | 0.023     | 0.2543                           | 0.0012    | 0.1128                            | 0.0005    | 1624  | 4.8       | 1460.5                                      | 6.3       | 1847                             | 7.6       | -25.5    |
| 170520-10-62 | 0.02 | 4.553                            | 0.040     | 0.2787                           | 0.0019    | 0.1184                            | 0.0005    | 1740.5                                      | 7.4       | 1585  | 9.5       | 1932.5                           | 6         | -20.9    |
| 170520-10-14 | 0.10 | 4.572                            | 0.059     | 0.2906                           | 0.0025    | 0.1131                            | 0.0005    | 1744  | 11        | 1644  | 13        | 1859                             | 11        | -11.6    |
| 170520-10-60 | 0.30 | 4.626                            | 0.037     | 0.2930                           | 0.0019    | 0.1141                            | 0.0006    | 1753.8                                      | 6.7       | 1656.5                                      | 9.3       | 1862.1                           | 5.4       | -11.5    |
| 170520-10-5  | 0.70 | 11.174                           | 0.066     | 0.4584                           | 0.0022    | 0.1768                            | 0.0003    | 2537.5                                      | 5.5       | 2432.2                                      | 9.8       | 2622.3                           | 2.3       | -7.3     |
| 170520-10-65 | 1.00 | 10.395                           | 0.067     | 0.4673                           | 0.0069    | 0.1601                            | 0.0017    | 2470.6                                      | 6         | 2471  | 30        | 2454.6                           | 5.3       | 2.1      |
| 170520-10-45 | 5.78 | 12.450                           | 0.360     | 0.4830                           | 0.0150    | 0.1851                            | 0.0021    | 2638  | 27        | 2541  | 65        | 2698                             | 10        | -3.2     |
| 170520-10-43 | 0.55 | 12.840                           | 0.320     | 0.5080                           | 0.0140    | 0.1792                            | 0.0016    | 2666  | 24        | 2647  | 59        | 2649                             | 14        | 2.7      |

**Appendix 9.** U-Pb ratio of Jeokbyeok Tuff(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180104-1-50 | 1.30 | 0.091                            | 0.001     | 0.0136                           | 0.0001    | 0.0486                            | 0.0007    | 88.1  | 1         | 86.79                                       | 0.63      | 126                                 | 22        | 0.4      |
| 180104-1-34 | 2.03 | 0.090                            | 0.003     | 0.0136                           | 0.0001    | 0.0485                            | 0.0019    | 87.8  | 3.1       | 86.8  | 0.92      | 148                                 | 54        | 3.5      |
| 180104-1-41 | 1.71 | 0.095                            | 0.008     | 0.0136                           | 0.0002    | 0.0511                            | 0.0042    | 92.4  | 7.1       | 87  | 1         | 274                                 | 21        | 3.1      |
| 180104-1-84 | 1.49 | 0.090                            | 0.001     | 0.0136                           | 0.0001    | 0.0485                            | 0.0009    | 87.6  | 1.3       | 87.03                                       | 0.57      | 142                                 | 24        | 1.5      |
| 180104-1-90 | 1.03 | 0.089                            | 0.002     | 0.0136                           | 0.0001    | 0.0470                            | 0.0010    | 86.8  | 2         | 87.12                                       | 0.8       | 114                                 | 25        | 3.6      |
| 180104-1-89 | 2.49 | 0.091                            | 0.002     | 0.0136                           | 0.0001    | 0.0481                            | 0.0013    | 88.3  | 1.9       | 87.15                                       | 0.85      | 114                                 | 25        | 1.8      |
| 180104-1-75 | 1.61 | 0.091                            | 0.003     | 0.0136                           | 0.0001    | 0.0495                            | 0.0011    | 88.6  | 2.3       | 87.2  | 0.86      | 195                                 | 39        | 2.0      |
| 180104-1-30 | 1.07 | 0.091                            | 0.002     | 0.0136                           | 0.0001    | 0.0485                            | 0.0012    | 88.2  | 2.1       | 87.21                                       | 0.63      | 173                                 | 27        | 2.0      |
| 180104-1-42 | 1.64 | 0.090                            | 0.001     | 0.0136                           | 0.0001    | 0.0480                            | 0.0005    | 87.16                                       | 0.99      | 87.22                                       | 0.7       | 114                                 | 11        | 2.0      |
| 180104-1-23 | 1.21 | 0.090                            | 0.003     | 0.0136                           | 0.0002    | 0.0478                            | 0.0016    | 87.8  | 2.7       | 87.3  | 1.1       | 147                                 | 30        | 3.8      |
| 180104-1-69 | 1.47 | 0.089                            | 0.004     | 0.0136                           | 0.0001    | 0.0480                            | 0.0019    | 86.6  | 3.4       | 87.33                                       | 0.85      | 205                                 | 56        | 5.7      |
| 180104-1-29 | 1.16 | 0.091                            | 0.002     | 0.0137                           | 0.0001    | 0.0480                            | 0.0010    | 88.2  | 1.7       | 87.4  | 0.59      | 115                                 | 26        | 1.7      |
| 180104-1-36 | 0.97 | 0.094                            | 0.005     | 0.0136                           | 0.0003    | 0.0500                            | 0.0024    | 91.5  | 4.8       | 87.4  | 1.8       | 249                                 | 55        | 2.9      |
| 180104-1-57 | 1.55 | 0.091                            | 0.002     | 0.0137                           | 0.0002    | 0.0479                            | 0.0009    | 88.4  | 2         | 87.5  | 1.1       | 114                                 | 23        | 2.5      |
| 180104-1-47 | 0.76 | 0.091                            | 0.003     | 0.0137                           | 0.0002    | 0.0489                            | 0.0018    | 88.2  | 3         | 87.51                                       | 0.95      | 170                                 | 44        | 3.7      |
| 180104-1-40 | 1.77 | 0.091                            | 0.001     | 0.0137                           | 0.0001    | 0.0483                            | 0.0007    | 88  | 1.3       | 87.54                                       | 0.51      | 127                                 | 19        | 1.5      |
| 180104-1-96 | 1.28 | 0.091                            | 0.002     | 0.0137                           | 0.0001    | 0.0484                            | 0.0006    | 88.1  | 1.5       | 87.54                                       | 0.81      | 111                                 | 15        | 2.0      |
| 180104-1-51 | 1.39 | 0.092                            | 0.005     | 0.0137                           | 0.0003    | 0.0484                            | 0.0024    | 89.3  | 4.3       | 87.6  | 1.7       | 165                                 | 40        | 4.9      |
| 180104-1-33 | 1.76 | 0.091                            | 0.002     | 0.0137                           | 0.0001    | 0.0485                            | 0.0009    | 88.9  | 1.6       | 87.61                                       | 0.56      | 160                                 | 24        | 1.0      |
| 180104-1-20 | 1.28 | 0.092                            | 0.003     | 0.0137                           | 0.0002    | 0.0493                            | 0.0021    | 89  | 3.1       | 87.7  | 1.5       | 134                                 | 39        | 3.8      |

**Appendix 9.** U-Pb ratio of Jeokbyeok Tuff(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180104-1-38 | 4.49 | 0.089                            | 0.002     | 0.0137                           | 0.0002    | 0.0476                            | 0.0007    | 86.9  | 1.5       | 87.7  | 1.4       | 88                                  | 17        | 4.2      |
| 180104-1-37 | 1.72 | 0.090                            | 0.002     | 0.0137                           | 0.0001    | 0.0479                            | 0.0009    | 87.7  | 1.6       | 87.73                                       | 0.46      | 127                                 | 19        | 2.4      |
| 180104-1-87 | 1.74 | 0.091                            | 0.004     | 0.0137                           | 0.0002    | 0.0498                            | 0.0020    | 88.6  | 3.6       | 87.8  | 1.2       | 211                                 | 47        | 4.6      |
| 180104-1-32 | 1.45 | 0.091                            | 0.001     | 0.0137                           | 0.0001    | 0.0481                            | 0.0006    | 88.2  | 1.1       | 87.81                                       | 0.42      | 141                                 | 15        | 1.3      |
| 180104-1-39 | 1.60 | 0.091                            | 0.002     | 0.0137                           | 0.0001    | 0.0484                            | 0.0009    | 88.3  | 1.6       | 87.81                                       | 0.53      | 159                                 | 22        | 1.9      |
| 180104-1-53 | 1.69 | 0.091                            | 0.004     | 0.0137                           | 0.0001    | 0.0497                            | 0.0020    | 88.5  | 3.4       | 87.82                                       | 0.87      | 192                                 | 40        | 4.1      |
| 180104-1-17 | 1.80 | 0.090                            | 0.001     | 0.0137                           | 0.0001    | 0.0474                            | 0.0006    | 87.3  | 1.2       | 87.85                                       | 0.5       | 99                                  | 17        | 2.6      |
| 180104-1-27 | 2.81 | 0.091                            | 0.002     | 0.0137                           | 0.0001    | 0.0479                            | 0.0008    | 88.6  | 1.7       | 87.9  | 0.83      | 115                                 | 21        | 2.1      |
| 180104-1-59 | 1.41 | 0.091                            | 0.003     | 0.0137                           | 0.0002    | 0.0492                            | 0.0014    | 88.1  | 2.7       | 87.9  | 1.5       | 163                                 | 35        | 4.6      |
| 180104-1-48 | 1.09 | 0.092                            | 0.003     | 0.0137                           | 0.0001    | 0.0487                            | 0.0014    | 89.7  | 2.5       | 87.95                                       | 0.68      | 162                                 | 34        | 1.6      |
| 180104-1-49 | 2.60 | 0.092                            | 0.001     | 0.0137                           | 0.0001    | 0.0487                            | 0.0007    | 89.2  | 1.2       | 88.02                                       | 0.49      | 136                                 | 16        | 0.6      |
| 180104-1-22 | 1.84 | 0.090                            | 0.001     | 0.0138                           | 0.0001    | 0.0476                            | 0.0007    | 87.5  | 1.3       | 88.03                                       | 0.66      | 141                                 | 19        | 2.8      |
| 180104-1-91 | 1.41 | 0.091                            | 0.003     | 0.0138                           | 0.0001    | 0.0485                            | 0.0019    | 88.4  | 3         | 88.08                                       | 0.9       | 180                                 | 39        | 4.1      |
| 180104-1-64 | 1.52 | 0.091                            | 0.003     | 0.0138                           | 0.0002    | 0.0497                            | 0.0020    | 87.9  | 2.9       | 88.1  | 1.5       | 210                                 | 60        | 5.2      |
| 180104-1-5  | 1.04 | 0.093                            | 0.003     | 0.0138                           | 0.0002    | 0.0489                            | 0.0017    | 90  | 3.1       | 88.28                                       | 0.97      | 158                                 | 34        | 2.7      |
| 180104-1-35 | 1.67 | 0.100                            | 0.010     | 0.0138                           | 0.0003    | 0.0528                            | 0.0049    | 97  | 9.2       | 88.3  | 2.1       | 343                                 | 61        | 2.9      |
| 180104-1-95 | 1.57 | 0.091                            | 0.001     | 0.0138                           | 0.0001    | 0.0487                            | 0.0006    | 88.7  | 1.1       | 88.35                                       | 0.71      | 139                                 | 13        | 1.7      |
| 180104-1-2  | 2.16 | 0.091                            | 0.001     | 0.0138                           | 0.0001    | 0.0477                            | 0.0007    | 88.4  | 1.3       | 88.4  | 0.77      | 113                                 | 16        | 2.3      |
| 180104-1-83 | 1.78 | 0.091                            | 0.002     | 0.0138                           | 0.0001    | 0.0485                            | 0.0011    | 88.5  | 1.9       | 88.53                                       | 0.5       | 140                                 | 24        | 2.7      |
| 180104-1-4  | 1.02 | 0.126                            | 0.028     | 0.0138                           | 0.0002    | 0.0660                            | 0.0150    | 120   | 25        | 88.6  | 1.4       | 670                                 | 220       | -5.6     |



**Appendix 9.** U-Pb ratio of Jeokbyeok Tuff(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180104-1-16 | 1.71 | 0.093                            | 0.006     | 0.0138                           | 0.0003    | 0.0505                            | 0.0046    | 89.8  | 5.5       | 88.6  | 1.7       | 260                                 | 120       | 6.8      |
| 180104-1-43 | 2.25 | 0.090                            | 0.005     | 0.0138                           | 0.0002    | 0.0477                            | 0.0023    | 87.7  | 4.3       | 88.6  | 1.3       | 168                                 | 52        | 7.3      |
| 180104-1-56 | 1.81 | 0.096                            | 0.012     | 0.0138                           | 0.0003    | 0.0505                            | 0.0054    | 93  | 11        | 88.6  | 1.6       | 263                                 | 76        | 9.3      |
| 180104-1-78 | 1.29 | 0.088                            | 0.004     | 0.0138                           | 0.0003    | 0.0478                            | 0.0021    | 85.9  | 4.1       | 88.6  | 2.1       | 180                                 | 110       | 10.0     |
| 180104-1-97 | 1.35 | 0.091                            | 0.002     | 0.0139                           | 0.0001    | 0.0481                            | 0.0008    | 88.8  | 1.4       | 88.68                                       | 0.48      | 143                                 | 21        | 2.0      |
| 180104-1-70 | 2.02 | 0.091                            | 0.001     | 0.0139                           | 0.0001    | 0.0481                            | 0.0005    | 88.58                                       | 0.97      | 88.69                                       | 0.57      | 107                                 | 10        | 1.9      |
| 180104-1-60 | 1.17 | 0.091                            | 0.003     | 0.0139                           | 0.0002    | 0.0485                            | 0.0014    | 88.3  | 2.6       | 88.7  | 1.2       | 140                                 | 28        | 4.7      |
| 180104-1-65 | 2.52 | 0.091                            | 0.003     | 0.0139                           | 0.0002    | 0.0491                            | 0.0018    | 88.5  | 3.1       | 88.7  | 1.3       | 212                                 | 47        | 5.2      |
| 180104-1-76 | 1.54 | 0.086                            | 0.007     | 0.0139                           | 0.0003    | 0.0468                            | 0.0038    | 84  | 6.4       | 88.7  | 1.8       | 83                                  | 50        | 14.5     |
| 180104-1-26 | 1.49 | 0.091                            | 0.003     | 0.0139                           | 0.0002    | 0.0481                            | 0.0016    | 88.3  | 2.9       | 88.79                                       | 0.95      | 139                                 | 46        | 4.9      |
| 180104-1-86 | 1.21 | 0.094                            | 0.004     | 0.0139                           | 0.0003    | 0.0492                            | 0.0020    | 91.6  | 4.1       | 88.8  | 1.7       | 166                                 | 31        | 3.4      |
| 180104-1-14 | 2.27 | 0.092                            | 0.002     | 0.0139                           | 0.0002    | 0.0479                            | 0.0010    | 89  | 1.8       | 88.82                                       | 0.93      | 118                                 | 22        | 2.9      |
| 180104-1-62 | 1.93 | 0.090                            | 0.002     | 0.0139                           | 0.0002    | 0.0479                            | 0.0008    | 87.7  | 1.7       | 88.9  | 1.1       | 121                                 | 21        | 4.5      |
| 180104-1-73 | 1.22 | 0.089                            | 0.004     | 0.0139                           | 0.0003    | 0.0487                            | 0.0022    | 86.8  | 3.6       | 88.9  | 1.6       | 146                                 | 37        | 8.2      |
| 180104-1-67 | 1.83 | 0.091                            | 0.004     | 0.0139                           | 0.0002    | 0.0485                            | 0.0020    | 88.6  | 3.9       | 88.92                                       | 0.96      | 186                                 | 65        | 5.8      |
| 180104-1-25 | 1.76 | 0.091                            | 0.002     | 0.0139                           | 0.0001    | 0.0477                            | 0.0011    | 88.2  | 2         | 88.95                                       | 0.72      | 140                                 | 23        | 3.9      |
| 180104-1-31 | 3.04 | 0.092                            | 0.001     | 0.0139                           | 0.0001    | 0.0482                            | 0.0007    | 89.7  | 1.1       | 88.97                                       | 0.6       | 113                                 | 20        | 1.1      |
| 180104-1-63 | 1.27 | 0.089                            | 0.003     | 0.0139                           | 0.0003    | 0.0483                            | 0.0017    | 86.9  | 3.1       | 89  | 1.6       | 121                                 | 41        | 7.6      |
| 180104-1-66 | 1.59 | 0.090                            | 0.008     | 0.0139                           | 0.0007    | 0.0481                            | 0.0038    | 87.5  | 7.5       | 89  | 4.7       | 123                                 | 81        | 15.4     |
| 180104-1-88 | 1.35 | 0.091                            | 0.002     | 0.0139                           | 0.0001    | 0.0476                            | 0.0008    | 88.8  | 1.5       | 89.09                                       | 0.58      | 142                                 | 18        | 2.7      |

**Appendix 9.** U-Pb ratio of Jeokbyeok Tuff(tuff) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180104-1-3  | 1.21 | 0.092                            | 0.003     | 0.0139                           | 0.0003    | 0.0474                            | 0.0009    | 89.1  | 2.6       | 89.1  | 2         | 81                                  | 23        | 5.2      |
| 180104-1-54 | 1.53 | 0.091                            | 0.003     | 0.0139                           | 0.0001    | 0.0491                            | 0.0015    | 88.5  | 2.7       | 89.12                                       | 0.83      | 155                                 | 39        | 4.7      |
| 180104-1-58 | 1.72 | 0.093                            | 0.003     | 0.0139                           | 0.0001    | 0.0494                            | 0.0015    | 89.9  | 2.8       | 89.13                                       | 0.87      | 193                                 | 35        | 3.3      |
| 180104-1-8  | 1.45 | 0.093                            | 0.003     | 0.0139                           | 0.0002    | 0.0479                            | 0.0015    | 89.8  | 2.7       | 89.2  | 1.3       | 101                                 | 36        | 3.8      |
| 180104-1-6  | 1.40 | 0.091                            | 0.002     | 0.0139                           | 0.0001    | 0.0479                            | 0.0014    | 88.6  | 2.1       | 89.25                                       | 0.71      | 133                                 | 29        | 3.9      |
| 180104-1-19 | 1.51 | 0.091                            | 0.003     | 0.0139                           | 0.0001    | 0.0475                            | 0.0014    | 88.8  | 2.5       | 89.26                                       | 0.55      | 177                                 | 32        | 3.9      |
| 180104-1-85 | 0.77 | 0.106                            | 0.015     | 0.0140                           | 0.0004    | 0.0554                            | 0.0090    | 102   | 14        | 89.3  | 2.4       | 463                                 | 95        | 4.1      |
| 180104-1-11 | 1.63 | 0.093                            | 0.003     | 0.0140                           | 0.0001    | 0.0484                            | 0.0016    | 90  | 3         | 89.4  | 0.65      | 140                                 | 45        | 3.4      |
| 180104-1-15 | 1.37 | 0.095                            | 0.006     | 0.0140                           | 0.0002    | 0.0489                            | 0.0027    | 91.8  | 5.1       | 89.4  | 1.4       | 131                                 | 58        | 4.6      |
| 180104-1-18 | 1.90 | 0.092                            | 0.003     | 0.0140                           | 0.0002    | 0.0494                            | 0.0015    | 89.6  | 2.9       | 89.5  | 1.4       | 181                                 | 46        | 4.7      |
| 180104-1-79 | 1.48 | 0.096                            | 0.007     | 0.0140                           | 0.0004    | 0.0499                            | 0.0041    | 93.2  | 6         | 89.5  | 2.8       | 193                                 | 76        | 5.7      |
| 180104-1-61 | 1.95 | 0.092                            | 0.002     | 0.0140                           | 0.0001    | 0.0479                            | 0.0008    | 89.6  | 1.5       | 89.55                                       | 0.68      | 105                                 | 28        | 2.4      |
| 180104-1-68 | 1.53 | 0.121                            | 0.004     | 0.0140                           | 0.0002    | 0.0636                            | 0.0019    | 116.2                                       | 3.3       | 89.57                                       | 0.97      | 709                                 | 30        | -25.0    |
| 180104-1-44 | 1.53 | 0.093                            | 0.002     | 0.0140                           | 0.0001    | 0.0483                            | 0.0012    | 89.9  | 2.1       | 89.66                                       | 0.67      | 164                                 | 20        | 2.8      |
| 180104-1-21 | 1.46 | 0.093                            | 0.003     | 0.0140                           | 0.0001    | 0.0472                            | 0.0011    | 90  | 2.4       | 89.68                                       | 0.83      | 129                                 | 30        | 3.2      |
| 180104-1-81 | 1.38 | 0.093                            | 0.001     | 0.0140                           | 0.0001    | 0.0480                            | 0.0005    | 89.9  | 1         | 89.75                                       | 0.5       | 107                                 | 12        | 1.5      |
| 180104-1-82 | 1.76 | 0.092                            | 0.002     | 0.0140                           | 0.0002    | 0.0487                            | 0.0008    | 89.7  | 1.5       | 89.76                                       | 0.95      | 137                                 | 24        | 2.8      |
| 180104-1-80 | 1.42 | 0.094                            | 0.004     | 0.0140                           | 0.0001    | 0.0496                            | 0.0024    | 92.2  | 3.8       | 89.77                                       | 0.9       | 194                                 | 49        | 2.5      |
| 180104-1-98 | 0.92 | 0.091                            | 0.002     | 0.0140                           | 0.0001    | 0.0470                            | 0.0012    | 88  | 2.2       | 89.83                                       | 0.69      | 152                                 | 34        | 5.3      |
| 180104-1-10 | 1.15 | 0.093                            | 0.002     | 0.0140                           | 0.0001    | 0.0487                            | 0.0011    | 90.6  | 2.1       | 89.88                                       | 0.64      | 151                                 | 28        | 2.2      |

**Appendix 9.** U-Pb ratio of Jeokbyeok Tuff(tuff) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180104-1-77  | 1.63 | 0.093                            | 0.003     | 0.0140                           | 0.0001    | 0.0471                            | 0.0019    | 89.8  | 2.8       | 89.88                                       | 0.89      | 124                                 | 47        | 4.2      |
| 180104-1-7   | 1.69 | 0.092                            | 0.001     | 0.0140                           | 0.0001    | 0.0477                            | 0.0006    | 89.19                                       | 0.96      | 89.9  | 0.49      | 105                                 | 14        | 2.4      |
| 180104-1-74  | 1.06 | 0.097                            | 0.010     | 0.0141                           | 0.0005    | 0.0504                            | 0.0056    | 94.3  | 9.4       | 89.9  | 2.8       | 390                                 | 140       | 8.7      |
| 180104-1-92  | 2.06 | 0.092                            | 0.004     | 0.0140                           | 0.0002    | 0.0480                            | 0.0019    | 89.6  | 3.4       | 89.91                                       | 0.92      | 155                                 | 34        | 5.1      |
| 180104-1-55  | 2.11 | 0.094                            | 0.004     | 0.0141                           | 0.0001    | 0.0504                            | 0.0024    | 91.3  | 4.1       | 89.92                                       | 0.64      | 206                                 | 70        | 3.7      |
| 180104-1-71  | 0.77 | 0.093                            | 0.002     | 0.0141                           | 0.0001    | 0.0491                            | 0.0010    | 89.8  | 1.9       | 89.93                                       | 0.67      | 131                                 | 26        | 3.0      |
| 180104-1-12  | 1.28 | 0.093                            | 0.009     | 0.0141                           | 0.0002    | 0.0474                            | 0.0048    | 89.9  | 8.1       | 90  | 1.1       | 101                                 | 61        | 10.3     |
| 180104-1-9   | 2.56 | 0.090                            | 0.004     | 0.0141                           | 0.0001    | 0.0460                            | 0.0019    | 87.5  | 3.5       | 90.02                                       | 0.67      | 152                                 | 49        | 7.4      |
| 180104-1-45  | 1.52 | 0.093                            | 0.002     | 0.0141                           | 0.0002    | 0.0481                            | 0.0009    | 90.2  | 1.5       | 90.1  | 1         | 113                                 | 18        | 2.7      |
| 180104-1-24  | 1.23 | 0.094                            | 0.003     | 0.0141                           | 0.0001    | 0.0483                            | 0.0011    | 91.3  | 2.3       | 90.22                                       | 0.66      | 161                                 | 31        | 2.1      |
| 180104-1-13  | 0.89 | 0.090                            | 0.004     | 0.0141                           | 0.0001    | 0.0466                            | 0.0020    | 87.8  | 3.4       | 90.28                                       | 0.91      | 137                                 | 37        | 7.5      |
| 180104-1-93  | 1.44 | 0.091                            | 0.003     | 0.0141                           | 0.0001    | 0.0467                            | 0.0013    | 88.7  | 2.4       | 90.32                                       | 0.81      | 207                                 | 33        | 5.3      |
| 180104-1-72  | 0.78 | 0.095                            | 0.004     | 0.0141                           | 0.0002    | 0.0501                            | 0.0022    | 92.2  | 3.5       | 90.4  | 1.3       | 213                                 | 59        | 3.3      |
| 180104-1-46  | 1.58 | 0.094                            | 0.003     | 0.0141                           | 0.0001    | 0.0481                            | 0.0016    | 91  | 3.1       | 90.42                                       | 0.87      | 128                                 | 42        | 3.7      |
| 180104-1-28  | 1.83 | 0.093                            | 0.004     | 0.0141                           | 0.0003    | 0.0479                            | 0.0017    | 90.5  | 3.7       | 90.5  | 1.9       | 178                                 | 47        | 6.2      |
| 180104-1-1   | 1.32 | 0.098                            | 0.004     | 0.0143                           | 0.0002    | 0.0495                            | 0.0025    | 94.4  | 4.1       | 91.4  | 1.4       | 224                                 | 53        | 2.7      |
| 180104-1-52  | 1.64 | 0.095                            | 0.004     | 0.0143                           | 0.0003    | 0.0490                            | 0.0018    | 91.8  | 3.5       | 91.7  | 1.6       | 150                                 | 44        | 5.5      |
| 180104-1-99  | 1.00 | 0.096                            | 0.002     | 0.0145                           | 0.0001    | 0.0491                            | 0.0010    | 93  | 2         | 92.68                                       | 0.8       | 145                                 | 22        | 2.7      |
| 180104-1-94  | 0.90 | 0.155                            | 0.013     | 0.0145                           | 0.0003    | 0.0788                            | 0.0064    | 146   | 12        | 92.7  | 1.6       | 1210                                | 110       | -42.8    |
| 180104-1-100 | 1.20 | 4.730                            | 0.530     | 0.0536                           | 0.0045    | 0.6360                            | 0.0190    | 1748  | 99        | 336   | 27        | 4582                                | 18        | -382.7   |

**Appendix 10.** U-Pb ratio of Yeonhwari Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180220-4-62 | 1.50 | 0.095                            | 0.004     | 0.0140                           | 0.0002    | 0.0495                            | 0.0020    | 92.1  | 3.7       | 89.4  | 1.1       | 306                                 | 40        | 2.3      |
| 180220-4-1  | 1.15 | 0.093                            | 0.003     | 0.0140                           | 0.0001    | 0.0477                            | 0.0017    | 89.9  | 2.9       | 89.83   | 0.91      | 260                                 | 34        | 4.2      |
| 180220-4-11 | 0.76 | 0.094                            | 0.003     | 0.0141                           | 0.0002    | 0.0474                            | 0.0015    | 90.7  | 2.7       | 90.25   | 0.99      | 210                                 | 41        | 3.6      |
| 180220-4-51 | 1.01 | 0.096                            | 0.004     | 0.0144                           | 0.0001    | 0.0485                            | 0.0018    | 93.3  | 3.3       | 92.22   | 0.87      | 269                                 | 39        | 3.4      |
| 180220-4-83 | 1.53 | 0.099                            | 0.006     | 0.0155                           | 0.0004    | 0.0473                            | 0.0029    | 95.8  | 5.8       | 99.1  | 2.3       | 268                                 | 74        | 11.5     |
| 180220-4-21 | 0.49 | 0.192                            | 0.005     | 0.0270                           | 0.0003    | 0.0511                            | 0.0015    | 178.3   | 4.2       | 171.6   | 1.8       | 255                                 | 31        | -0.4     |
| 180220-4-79 | 0.58 | 0.196                            | 0.005     | 0.0277                           | 0.0003    | 0.0510                            | 0.0011    | 181.1   | 4.4       | 176   | 1.7       | 225                                 | 27        | 0.6      |
| 180220-4-40 | 0.67 | 0.194                            | 0.004     | 0.0280                           | 0.0002    | 0.0507                            | 0.0010    | 180   | 3.7       | 177.9   | 1.5       | 234                                 | 23        | 1.7      |
| 180220-4-2  | 0.78 | 0.196                            | 0.002     | 0.0282                           | 0.0001    | 0.0502                            | 0.0004    | 182   | 1.6       | 179.09  | 0.79      | 217.3                               | 9.7       | -0.3     |
| 180220-4-12 | 0.76 | 0.195                            | 0.005     | 0.0282                           | 0.0003    | 0.0503                            | 0.0010    | 180.9   | 3.9       | 179.1   | 1.8       | 229                                 | 26        | 2.2      |
| 180220-4-15 | 0.78 | 0.197                            | 0.003     | 0.0283                           | 0.0002    | 0.0505                            | 0.0007    | 182.5   | 2.2       | 179.7   | 1.3       | 210                                 | 18        | 0.4      |
| 180220-4-39 | 0.64 | 0.195                            | 0.002     | 0.0284                           | 0.0002    | 0.0503                            | 0.0005    | 181.2   | 1.9       | 180.2   | 1.2       | 206                                 | 14        | 1.2      |
| 180220-4-66 | 1.01 | 0.195                            | 0.002     | 0.0284                           | 0.0002    | 0.0499                            | 0.0005    | 181.3   | 2         | 180.4   | 1         | 191                                 | 13        | 1.2      |
| 180220-4-31 | 0.58 | 0.197                            | 0.004     | 0.0284                           | 0.0002    | 0.0505                            | 0.0010    | 182.7   | 3.6       | 180.7   | 1.4       | 257                                 | 22        | 1.7      |
| 180220-4-58 | 0.58 | 0.196                            | 0.006     | 0.0284                           | 0.0004    | 0.0500                            | 0.0014    | 181.3   | 5         | 180.7   | 2.4       | 312                                 | 31        | 3.8      |
| 180220-4-36 | 0.60 | 0.198                            | 0.004     | 0.0285                           | 0.0003    | 0.0507                            | 0.0010    | 182.9   | 3.7       | 180.9   | 1.9       | 254                                 | 26        | 2.0      |
| 180220-4-46 | 0.83 | 0.195                            | 0.004     | 0.0285                           | 0.0002    | 0.0501                            | 0.0009    | 181   | 3.5       | 180.9   | 1.5       | 205                                 | 22        | 2.7      |
| 180220-4-42 | 0.36 | 0.196                            | 0.003     | 0.0285                           | 0.0002    | 0.0499                            | 0.0006    | 181.7   | 2.2       | 181   | 1.1       | 190                                 | 17        | 1.4      |
| 180220-4-7  | 0.54 | 0.196                            | 0.010     | 0.0285                           | 0.0006    | 0.0501                            | 0.0026    | 182   | 8.2       | 181.3   | 4         | 314                                 | 48        | 6.3      |
| 180220-4-44 | 0.40 | 0.196                            | 0.002     | 0.0286                           | 0.0002    | 0.0500                            | 0.0006    | 181.3   | 1.9       | 181.6   | 1.1       | 193                                 | 14        | 1.8      |

**Appendix 10.** U-Pb ratio of Yeonhwari Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}$ - $^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}$ - $^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180220-4-41 | 0.60 | 0.203                            | 0.012     | 0.0287                           | 0.0008    | 0.0511                            | 0.0027    | 188   | 10        | 182.2   | 4.7       | 443                                 | 48        | 4.9      |
| 180220-4-94 | 0.68 | 0.196                            | 0.005     | 0.0288                           | 0.0003    | 0.0496                            | 0.0011    | 181.5   | 3.8       | 182.8   | 1.9       | 224                                 | 25        | 3.8      |
| 180220-4-85 | 0.53 | 0.198                            | 0.004     | 0.0288                           | 0.0003    | 0.0502                            | 0.0010    | 183.6   | 3.5       | 182.9   | 2.1       | 216                                 | 24        | 2.7      |
| 180220-4-75 | 0.78 | 0.198                            | 0.004     | 0.0288                           | 0.0003    | 0.0496                            | 0.0007    | 183.1   | 3         | 183.3   | 1.8       | 196                                 | 17        | 2.7      |
| 180220-4-35 | 0.57 | 0.198                            | 0.002     | 0.0289                           | 0.0002    | 0.0499                            | 0.0005    | 183.6   | 2         | 183.5   | 1.5       | 193                                 | 13        | 1.9      |
| 180220-4-49 | 0.99 | 0.198                            | 0.002     | 0.0289                           | 0.0002    | 0.0501                            | 0.0005    | 183.6   | 1.7       | 183.5   | 1.1       | 200                                 | 12        | 1.5      |
| 180220-4-72 | 0.38 | 0.200                            | 0.002     | 0.0290                           | 0.0003    | 0.0497                            | 0.0005    | 185.2   | 2         | 184   | 1.6       | 177                                 | 13        | 1.3      |
| 180220-4-76 | 0.66 | 0.201                            | 0.003     | 0.0290                           | 0.0003    | 0.0502                            | 0.0008    | 186   | 3         | 184.1   | 1.8       | 195                                 | 22        | 1.6      |
| 180220-4-19 | 0.48 | 0.207                            | 0.005     | 0.0290                           | 0.0003    | 0.0517                            | 0.0013    | 190.5   | 4.4       | 184.4   | 1.6       | 286                                 | 29        | -0.1     |
| 180220-4-96 | 0.94 | 0.199                            | 0.006     | 0.0290                           | 0.0004    | 0.0500                            | 0.0013    | 185.3   | 5         | 184.5   | 2.8       | 256                                 | 27        | 3.8      |
| 180220-4-91 | 0.71 | 0.200                            | 0.005     | 0.0292                           | 0.0004    | 0.0498                            | 0.0011    | 186   | 4.1       | 185.3   | 2.3       | 224                                 | 22        | 3.1      |
| 180220-4-57 | 0.64 | 0.202                            | 0.003     | 0.0292                           | 0.0003    | 0.0503                            | 0.0007    | 187   | 2.8       | 185.7   | 1.7       | 203                                 | 18        | 1.7      |
| 180220-4-97 | 0.62 | 0.202                            | 0.005     | 0.0292                           | 0.0004    | 0.0502                            | 0.0012    | 186.9   | 4.6       | 185.7   | 2.4       | 234                                 | 23        | 3.1      |
| 180220-4-71 | 0.60 | 0.204                            | 0.006     | 0.0293                           | 0.0004    | 0.0498                            | 0.0013    | 187.7   | 5.3       | 186.4   | 2.2       | 264                                 | 31        | 3.3      |
| 180220-4-34 | 0.42 | 0.206                            | 0.003     | 0.0295                           | 0.0002    | 0.0506                            | 0.0007    | 189.7   | 2.9       | 187.2   | 1.4       | 213                                 | 18        | 1.0      |
| 180220-4-77 | 0.84 | 0.308                            | 0.015     | 0.0305                           | 0.0003    | 0.0727                            | 0.0031    | 271   | 11        | 193.7   | 2.1       | 980                                 | 75        | -33.1    |
| 180220-4-92 | 0.43 | 0.209                            | 0.004     | 0.0306                           | 0.0004    | 0.0496                            | 0.0007    | 193.2   | 3.1       | 194.2   | 2.3       | 193                                 | 16        | 3.3      |
| 180220-4-65 | 0.52 | 0.222                            | 0.002     | 0.0324                           | 0.0003    | 0.0500                            | 0.0005    | 203.6   | 1.7       | 205.4   | 1.6       | 192                                 | 12        | 2.5      |
| 180220-4-3  | 0.94 | 0.235                            | 0.003     | 0.0327                           | 0.0002    | 0.0523                            | 0.0005    | 214.2   | 2.2       | 207.4   | 1.3       | 289                                 | 12        | -1.6     |
| 180220-4-80 | 0.68 | 0.239                            | 0.006     | 0.0327                           | 0.0006    | 0.0523                            | 0.0010    | 217.3   | 5.2       | 207.7   | 3.4       | 283                                 | 28        | -0.5     |

**Appendix 10.** U-Pb ratio of Yeonhwari Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180220-4-24 | 0.31 | 0.233                            | 0.004     | 0.0328                           | 0.0003    | 0.0511                            | 0.0007    | 212.6                                       | 2.9       | 207.9                                       | 1.8       | 243                              | 18        | 0.0      |
| 180220-4-25 | 0.39 | 0.231                            | 0.002     | 0.0328                           | 0.0003    | 0.0504                            | 0.0004    | 210.7                                       | 1.9       | 207.9                                       | 1.6       | 214.2                            | 8.6       | 0.3      |
| 180220-4-27 | 0.71 | 0.234                            | 0.003     | 0.0328                           | 0.0003    | 0.0512                            | 0.0006    | 213.3                                       | 2.7       | 208.1                                       | 1.6       | 257                              | 16        | -0.4     |
| 180220-4-22 | 0.29 | 0.234                            | 0.003     | 0.0332                           | 0.0003    | 0.0507                            | 0.0006    | 213.5                                       | 2.7       | 210.3                                       | 1.8       | 231                              | 15        | 0.6      |
| 180220-4-33 | 0.66 | 0.235                            | 0.002     | 0.0334                           | 0.0002    | 0.0507                            | 0.0004    | 213.9                                       | 1.8       | 211.8                                       | 1.5       | 226.9                            | 8.3       | 0.6      |
| 180220-4-26 | 1.01 | 0.235                            | 0.002     | 0.0334                           | 0.0002    | 0.0508                            | 0.0002    | 214.3                                       | 1.5       | 212   | 1.4       | 226.7                            | 4.7       | 0.3      |
| 180220-4-30 | 0.60 | 0.234                            | 0.002     | 0.0335                           | 0.0002    | 0.0505                            | 0.0003    | 213.6                                       | 1.6       | 212.1                                       | 1.3       | 217.8                            | 7.2       | 0.7      |
| 180220-4-47 | 0.93 | 0.237                            | 0.004     | 0.0335                           | 0.0003    | 0.0516                            | 0.0010    | 216   | 3.6       | 212.2                                       | 1.5       | 264                              | 23        | 0.6      |
| 180220-4-23 | 0.13 | 0.245                            | 0.004     | 0.0336                           | 0.0004    | 0.0525                            | 0.0010    | 222.1                                       | 3.5       | 212.8                                       | 2.2       | 306                              | 38        | -1.7     |
| 180220-4-61 | 0.52 | 0.239                            | 0.003     | 0.0338                           | 0.0002    | 0.0509                            | 0.0005    | 217.1                                       | 2.3       | 214.5                                       | 1.4       | 237                              | 13        | 0.5      |
| 180220-4-59 | 0.42 | 0.240                            | 0.002     | 0.0340                           | 0.0002    | 0.0509                            | 0.0003    | 218   | 1.7       | 215.3                                       | 1.2       | 233.6                            | 9.6       | 0.1      |
| 180220-4-13 | 0.41 | 0.238                            | 0.003     | 0.0341                           | 0.0003    | 0.0506                            | 0.0006    | 216.8                                       | 2.6       | 215.9                                       | 1.9       | 224                              | 16        | 1.7      |
| 180220-4-28 | 0.61 | 0.242                            | 0.003     | 0.0341                           | 0.0003    | 0.0512                            | 0.0005    | 220   | 2.3       | 216   | 1.6       | 251                              | 16        | 0.0      |
| 180220-4-29 | 0.38 | 0.239                            | 0.002     | 0.0341                           | 0.0003    | 0.0510                            | 0.0003    | 217.7                                       | 2         | 216.1                                       | 1.6       | 238.7                            | 9         | 0.9      |
| 180220-4-81 | 0.67 | 0.241                            | 0.003     | 0.0342                           | 0.0003    | 0.0514                            | 0.0006    | 219.4                                       | 2.6       | 216.5                                       | 2         | 248                              | 14        | 0.8      |
| 180220-4-54 | 0.38 | 0.240                            | 0.003     | 0.0342                           | 0.0002    | 0.0507                            | 0.0005    | 218.1                                       | 2.1       | 216.9                                       | 1.5       | 231                              | 13        | 1.1      |
| 180220-4-32 | 0.57 | 0.241                            | 0.004     | 0.0342                           | 0.0003    | 0.0507                            | 0.0006    | 219.4                                       | 2.9       | 217   | 1.8       | 233                              | 16        | 1.1      |
| 180220-4-8  | 0.58 | 0.239                            | 0.002     | 0.0342                           | 0.0002    | 0.0506                            | 0.0003    | 217.4                                       | 1.5       | 217   | 1.3       | 223.7                            | 7.3       | 1.1      |
| 180220-4-38 | 0.22 | 0.243                            | 0.006     | 0.0343                           | 0.0004    | 0.0517                            | 0.0011    | 221.3                                       | 4.9       | 217.4                                       | 2.4       | 286                              | 26        | 1.6      |
| 180220-4-90 | 0.39 | 0.239                            | 0.004     | 0.0344                           | 0.0005    | 0.0508                            | 0.0003    | 217.7                                       | 2.9       | 217.7                                       | 2.8       | 223.4                            | 8.1       | 2.6      |

**Appendix 10.** U-Pb ratio of Yeonhwari Fm. of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180220-4-37 | 0.30 | 0.242                            | 0.003     | 0.0344                           | 0.0003    | 0.0513                            | 0.0005    | 220.3                                       | 2.5       | 217.8                                       | 1.9       | 247                                 | 13        | 0.9      |
| 180220-4-70 | 0.70 | 0.244                            | 0.007     | 0.0344                           | 0.0005    | 0.0513                            | 0.0014    | 220.9                                       | 5.5       | 217.9                                       | 2.8       | 264                                 | 32        | 2.4      |
| 180220-4-68 | 0.88 | 0.244                            | 0.007     | 0.0344                           | 0.0005    | 0.0515                            | 0.0013    | 221.6                                       | 5.4       | 218.3                                       | 2.8       | 278                                 | 28        | 2.2      |
| 180220-4-14 | 0.33 | 0.241                            | 0.003     | 0.0345                           | 0.0003    | 0.0506                            | 0.0005    | 219.7                                       | 2.6       | 218.5                                       | 1.6       | 219                                 | 15        | 1.4      |
| 180220-4-9  | 0.49 | 0.252                            | 0.006     | 0.0345                           | 0.0003    | 0.0532                            | 0.0010    | 228.3                                       | 4.9       | 218.6                                       | 1.9       | 341                                 | 34        | -1.3     |
| 180220-4-63 | 0.59 | 0.241                            | 0.002     | 0.0345                           | 0.0002    | 0.0505                            | 0.0003    | 219   | 1.4       | 218.8                                       | 1.1       | 224.8                               | 7.6       | 1.1      |
| 180220-4-56 | 0.54 | 0.244                            | 0.003     | 0.0346                           | 0.0004    | 0.0509                            | 0.0005    | 221.3                                       | 2.7       | 219.2                                       | 2.3       | 238                                 | 12        | 1.3      |
| 180220-4-84 | 0.51 | 0.243                            | 0.003     | 0.0346                           | 0.0003    | 0.0511                            | 0.0005    | 220.5                                       | 2.5       | 219.4                                       | 1.7       | 244                                 | 12        | 1.4      |
| 180220-4-17 | 0.39 | 0.244                            | 0.003     | 0.0346                           | 0.0003    | 0.0511                            | 0.0006    | 221.6                                       | 2.8       | 219.5                                       | 1.7       | 246                                 | 16        | 1.1      |
| 180220-4-53 | 0.79 | 0.241                            | 0.002     | 0.0346                           | 0.0002    | 0.0505                            | 0.0003    | 219.2                                       | 1.5       | 219.5                                       | 1.4       | 217.7                               | 6.8       | 1.5      |
| 180220-4-45 | 0.41 | 0.240                            | 0.003     | 0.0347                           | 0.0003    | 0.0505                            | 0.0004    | 218.4                                       | 2.1       | 219.6                                       | 1.6       | 222                                 | 11        | 2.2      |
| 180220-4-4  | 0.36 | 0.244                            | 0.001     | 0.0347                           | 0.0002    | 0.0509                            | 0.0002    | 221.5                                       | 1.2       | 219.8                                       | 1.1       | 231.9                               | 5.1       | 0.3      |
| 180220-4-98 | 0.55 | 0.244                            | 0.003     | 0.0348                           | 0.0003    | 0.0511                            | 0.0006    | 221.4                                       | 2.7       | 220.4                                       | 2.1       | 245                                 | 15        | 1.7      |
| 180220-4-82 | 0.62 | 0.244                            | 0.004     | 0.0348                           | 0.0003    | 0.0509                            | 0.0006    | 221.2                                       | 2.9       | 220.6                                       | 2.1       | 240                                 | 15        | 2.0      |
| 180220-4-86 | 0.39 | 0.247                            | 0.004     | 0.0348                           | 0.0004    | 0.0512                            | 0.0008    | 223.6                                       | 3.6       | 220.7                                       | 2.2       | 256                                 | 19        | 1.3      |
| 180220-4-6  | 0.54 | 0.242                            | 0.002     | 0.0349                           | 0.0002    | 0.0505                            | 0.0002    | 220.3                                       | 1.4       | 220.8                                       | 1.4       | 220.1                               | 4.5       | 1.5      |
| 180220-4-10 | 0.57 | 0.243                            | 0.002     | 0.0349                           | 0.0002    | 0.0507                            | 0.0004    | 220.8                                       | 2         | 221.1                                       | 1.5       | 220                                 | 11        | 1.7      |
| 180220-4-93 | 0.44 | 0.241                            | 0.004     | 0.0349                           | 0.0004    | 0.0509                            | 0.0006    | 219.5                                       | 2.9       | 220.9                                       | 2.6       | 227                                 | 13        | 3.1      |
| 180220-4-50 | 0.45 | 0.243                            | 0.002     | 0.0351                           | 0.0002    | 0.0504                            | 0.0003    | 221.1                                       | 1.7       | 222.3                                       | 1.4       | 217.2                               | 7.9       | 1.9      |
| 180220-4-43 | 0.47 | 0.244                            | 0.002     | 0.0351                           | 0.0002    | 0.0509                            | 0.0003    | 222.1                                       | 1.5       | 222.5                                       | 1.2       | 235.7                               | 9.6       | 1.4      |

**Appendix 10.** U-Pb ratio of Yeonhwari Fm. of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207}/^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|-------------------------------------|-----------|----------|
| 180220-4-78  | 0.43 | 0.248                            | 0.003     | 0.0351                           | 0.0006    | 0.0512                            | 0.0008    | 225.2                                       | 2.4       | 222.6                                       | 3.4       | 242                                 | 19        | 1.4      |
| 180220-4-48  | 0.60 | 0.247                            | 0.002     | 0.0353                           | 0.0002    | 0.0512                            | 0.0003    | 224.3                                       | 1.6       | 223.4                                       | 1.2       | 244.7                               | 7.6       | 0.9      |
| 180220-4-88  | 0.25 | 0.254                            | 0.006     | 0.0354                           | 0.0004    | 0.0521                            | 0.0012    | 229.2                                       | 4.8       | 224   | 2.3       | 280                                 | 27        | 0.8      |
| 180220-4-20  | 0.22 | 0.253                            | 0.005     | 0.0354                           | 0.0003    | 0.0516                            | 0.0010    | 229.3                                       | 4.3       | 224.2                                       | 1.7       | 283                                 | 22        | 0.4      |
| 180220-4-60  | 0.47 | 0.249                            | 0.003     | 0.0354                           | 0.0002    | 0.0508                            | 0.0005    | 226   | 2.3       | 224.5                                       | 1.4       | 237                                 | 15        | 1.0      |
| 180220-4-64  | 0.79 | 0.249                            | 0.002     | 0.0355                           | 0.0002    | 0.0506                            | 0.0003    | 225.8                                       | 1.5       | 225.1                                       | 1.1       | 233                                 | 6.2       | 0.8      |
| 180220-4-69  | 0.53 | 0.250                            | 0.002     | 0.0357                           | 0.0002    | 0.0509                            | 0.0004    | 226.9                                       | 1.9       | 225.9                                       | 1.2       | 240.2                               | 8.4       | 0.9      |
| 180220-4-52  | 0.60 | 0.250                            | 0.003     | 0.0358                           | 0.0004    | 0.0508                            | 0.0004    | 226.3                                       | 2.7       | 226.6                                       | 2.4       | 235                                 | 13        | 2.4      |
| 180220-4-74  | 0.47 | 0.250                            | 0.002     | 0.0359                           | 0.0003    | 0.0505                            | 0.0003    | 226.7                                       | 1.9       | 227   | 1.6       | 218.3                               | 8.4       | 1.7      |
| 180220-4-5   | 0.57 | 0.252                            | 0.002     | 0.0359                           | 0.0002    | 0.0509                            | 0.0003    | 228   | 1.7       | 227.3                                       | 1.3       | 233.6                               | 7.9       | 1.0      |
| 180220-4-67  | 0.62 | 0.252                            | 0.002     | 0.0361                           | 0.0002    | 0.0507                            | 0.0003    | 228.5                                       | 1.5       | 228.5                                       | 1         | 225.1                               | 7.8       | 1.1      |
| 180220-4-73  | 0.52 | 0.284                            | 0.006     | 0.0361                           | 0.0007    | 0.0572                            | 0.0014    | 253.5                                       | 4.6       | 228.6                                       | 4.3       | 504                                 | 19        | -7.0     |
| 180220-4-99  | 0.54 | 0.256                            | 0.004     | 0.0362                           | 0.0003    | 0.0515                            | 0.0007    | 231.5                                       | 3.1       | 229   | 1.7       | 271                                 | 17        | 1.0      |
| 180220-4-87  | 0.94 | 0.256                            | 0.002     | 0.0365                           | 0.0002    | 0.0510                            | 0.0003    | 231.4                                       | 2         | 230.8                                       | 1.2       | 242                                 | 12        | 1.1      |
| 180220-4-95  | 0.26 | 0.255                            | 0.006     | 0.0365                           | 0.0004    | 0.0510                            | 0.0012    | 230.2                                       | 4.7       | 231.2                                       | 2.5       | 259                                 | 34        | 3.5      |
| 180220-4-55  | 0.64 | 0.354                            | 0.027     | 0.0365                           | 0.0004    | 0.0700                            | 0.0046    | 305   | 19        | 231.3                                       | 2.6       | 910                                 | 130       | -22.5    |
| 180220-4-18  | 0.55 | 0.261                            | 0.003     | 0.0368                           | 0.0003    | 0.0512                            | 0.0003    | 235.6                                       | 2         | 232.9                                       | 1.7       | 252.7                               | 8.2       | 0.4      |
| 180220-4-89  | 0.63 | 0.257                            | 0.003     | 0.0368                           | 0.0004    | 0.0507                            | 0.0004    | 232.4                                       | 2.5       | 233.1                                       | 2.3       | 226                                 | 11        | 2.4      |
| 180220-4-16  | 0.61 | 0.272                            | 0.006     | 0.0371                           | 0.0006    | 0.0533                            | 0.0005    | 244.3                                       | 4.7       | 234.8                                       | 3.4       | 342                                 | 13        | -0.6     |
| 180220-4-100 | 0.54 | 0.277                            | 0.002     | 0.0397                           | 0.0003    | 0.0507                            | 0.0003    | 247.9                                       | 1.8       | 251   | 1.6       | 228.6                               | 7.8       | 2.6      |



**Appendix 11.** U-Pb ratio of Jandong Fm. (South area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-1-93 | 1.02 | 0.095                            | 0.007     | 0.0138                           | 0.0004    | 0.0475                            | 0.0034    | 92.3  | 6.4       | 88  | 2.2       | 245                              | 57        | 4.9      |
| 180426-1-1  | 1.14 | 0.097                            | 0.005     | 0.0144                           | 0.0003    | 0.0493                            | 0.0024    | 93.4  | 4.5       | 91.9  | 1.6       | 294                              | 50        | 5.0      |
| 180426-1-45 | 1.16 | 0.094                            | 0.004     | 0.0144                           | 0.0002    | 0.0486                            | 0.0019    | 90.7  | 3.4       | 91.9  | 1.1       | 250                              | 33        | 6.2      |
| 180426-1-46 | 1.07 | 0.097                            | 0.005     | 0.0144                           | 0.0002    | 0.0499                            | 0.0028    | 93.7  | 4.9       | 92.1  | 1         | 382                              | 60        | 4.7      |
| 180426-1-28 | 0.93 | 0.099                            | 0.008     | 0.0144                           | 0.0003    | 0.0495                            | 0.0040    | 95.2  | 7.6       | 92.2  | 2.2       | 313                              | 87        | 7.4      |
| 180426-1-38 | 1.07 | 0.094                            | 0.003     | 0.0144                           | 0.0002    | 0.0473                            | 0.0015    | 91.3  | 3         | 92.3  | 1         | 239                              | 35        | 5.4      |
| 180426-1-41 | 1.14 | 0.096                            | 0.004     | 0.0144                           | 0.0002    | 0.0492                            | 0.0019    | 92.7  | 3.6       | 92.3  | 1.2       | 274                              | 41        | 4.8      |
| 180426-1-58 | 1.09 | 0.096                            | 0.004     | 0.0145                           | 0.0002    | 0.0493                            | 0.0021    | 93.5  | 3.4       | 92.7  | 1.2       | 324                              | 46        | 4.1      |
| 180426-1-64 | 1.45 | 0.096                            | 0.011     | 0.0145                           | 0.0004    | 0.0472                            | 0.0053    | 92  | 10        | 92.7  | 2.4       | 621                              | 91        | 14.1     |
| 180426-1-91 | 0.91 | 0.101                            | 0.006     | 0.0145                           | 0.0002    | 0.0511                            | 0.0032    | 97.7  | 6         | 92.7  | 1.5       | 489                              | 64        | 2.7      |
| 180426-1-44 | 0.93 | 0.097                            | 0.004     | 0.0145                           | 0.0002    | 0.0492                            | 0.0021    | 94  | 3.8       | 92.8  | 1.3       | 296                              | 42        | 4.2      |
| 180426-1-23 | 1.15 | 0.095                            | 0.003     | 0.0145                           | 0.0002    | 0.0474                            | 0.0012    | 92.3  | 2.5       | 92.8  | 1.3       | 162                              | 26        | 4.6      |
| 180426-1-54 | 1.08 | 0.094                            | 0.004     | 0.0145                           | 0.0002    | 0.0483                            | 0.0021    | 91.3  | 4         | 92.9  | 1.2       | 314                              | 39        | 7.3      |
| 180426-1-9  | 1.22 | 0.097                            | 0.004     | 0.0145                           | 0.0002    | 0.0479                            | 0.0017    | 94.1  | 3.3       | 93.02                                       | 0.98      | 248                              | 39        | 3.4      |
| 180426-1-68 | 1.15 | 0.097                            | 0.004     | 0.0146                           | 0.0002    | 0.0477                            | 0.0019    | 93.7  | 3.5       | 93.3  | 1.1       | 260                              | 43        | 4.5      |
| 180426-1-25 | 1.12 | 0.097                            | 0.003     | 0.0146                           | 0.0002    | 0.0484                            | 0.0016    | 93.9  | 3.1       | 93.66                                       | 0.93      | 228                              | 31        | 4.0      |
| 180426-1-2  | 1.24 | 0.099                            | 0.007     | 0.0148                           | 0.0003    | 0.0491                            | 0.0033    | 95.4  | 6         | 94.4  | 1.7       | 445                              | 68        | 7.1      |
| 180426-1-29 | 1.18 | 0.101                            | 0.006     | 0.0148                           | 0.0003    | 0.0484                            | 0.0030    | 97.3  | 5.7       | 94.5  | 1.8       | 238                              | 67        | 5.0      |
| 180426-1-90 | 0.97 | 0.112                            | 0.019     | 0.0148                           | 0.0005    | 0.0554                            | 0.0095    | 110   | 18        | 94.7  | 3         | 830                              | 150       | 6.0      |
| 180426-1-49 | 0.99 | 0.110                            | 0.014     | 0.0148                           | 0.0004    | 0.0496                            | 0.0057    | 105   | 13        | 94.8  | 2.6       | 310                              | 120       | 5.7      |

**Appendix 11.** U-Pb ratio of Jandong Fm. (South area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-1-7  | 0.92 | 0.101                            | 0.005     | 0.0148                           | 0.0002    | 0.0498                            | 0.0025    | 97.9  | 4.5       | 94.9  | 1.2       | 394                              | 50        | 2.8      |
| 180426-1-22 | 1.03 | 0.097                            | 0.005     | 0.0149                           | 0.0002    | 0.0466                            | 0.0021    | 94  | 4.3       | 95  | 1.4       | 262                              | 37        | 7.1      |
| 180426-1-92 | 0.43 | 0.107                            | 0.004     | 0.0157                           | 0.0002    | 0.0487                            | 0.0016    | 102.9                                       | 3.7       | 100.1                                       | 1.3       | 145                              | 20        | 2.2      |
| 180426-1-70 | 0.88 | 0.286                            | 0.034     | 0.0169                           | 0.0007    | 0.1250                            | 0.0150    | 252   | 27        | 107.7                                       | 4.3       | 1980                             | 190       | -104.9   |
| 180426-1-65 | 0.53 | 0.196                            | 0.009     | 0.0281                           | 0.0005    | 0.0506                            | 0.0017    | 183.4                                       | 6.4       | 178.7                                       | 3.4       | 252                              | 45        | 2.9      |
| 180426-1-97 | 0.60 | 0.203                            | 0.008     | 0.0286                           | 0.0004    | 0.0503                            | 0.0020    | 186.9                                       | 7         | 181.7                                       | 2.8       | 303                              | 41        | 2.5      |
| 180426-1-30 | 0.62 | 0.198                            | 0.005     | 0.0287                           | 0.0003    | 0.0501                            | 0.0011    | 184.3                                       | 4.2       | 182.6                                       | 1.6       | 238                              | 25        | 2.2      |
| 180426-1-80 | 0.45 | 0.204                            | 0.008     | 0.0289                           | 0.0004    | 0.0511                            | 0.0018    | 187.9                                       | 6.5       | 183.4                                       | 2.4       | 293                              | 50        | 2.4      |
| 180426-1-69 | 0.34 | 0.198                            | 0.003     | 0.0290                           | 0.0003    | 0.0499                            | 0.0006    | 183.3                                       | 2.7       | 184   | 1.8       | 191                              | 16        | 2.8      |
| 180426-1-42 | 0.66 | 0.202                            | 0.005     | 0.0290                           | 0.0004    | 0.0503                            | 0.0012    | 186.6                                       | 4.1       | 184.1                                       | 2.2       | 237                              | 31        | 2.1      |
| 180426-1-89 | 0.87 | 0.198                            | 0.008     | 0.0290                           | 0.0005    | 0.0504                            | 0.0018    | 184.3                                       | 6.6       | 184.3                                       | 3.1       | 267                              | 40        | 5.3      |
| 180426-1-71 | 0.81 | 0.202                            | 0.005     | 0.0290                           | 0.0003    | 0.0504                            | 0.0011    | 186.4                                       | 4         | 184.4                                       | 1.8       | 237                              | 23        | 2.1      |
| 180426-1-55 | 0.36 | 0.199                            | 0.005     | 0.0290                           | 0.0003    | 0.0502                            | 0.0010    | 184.2                                       | 3.8       | 184.5                                       | 1.6       | 222                              | 26        | 3.1      |
| 180426-1-40 | 0.48 | 0.201                            | 0.004     | 0.0291                           | 0.0003    | 0.0496                            | 0.0007    | 185.9                                       | 3.5       | 185.1                                       | 1.8       | 186                              | 19        | 2.4      |
| 180426-1-79 | 0.72 | 0.203                            | 0.008     | 0.0292                           | 0.0006    | 0.0517                            | 0.0019    | 188.3                                       | 6.2       | 185.7                                       | 3.5       | 254                              | 45        | 3.8      |
| 180426-1-17 | 0.73 | 0.203                            | 0.005     | 0.0295                           | 0.0004    | 0.0516                            | 0.0010    | 187.7                                       | 4.4       | 187.2                                       | 2.5       | 246                              | 24        | 3.4      |
| 180426-1-59 | 0.67 | 0.201                            | 0.018     | 0.0295                           | 0.0007    | 0.0497                            | 0.0044    | 184   | 15        | 187.4                                       | 4.6       | 504                              | 68        | 12.3     |
| 180426-1-27 | 0.68 | 0.203                            | 0.006     | 0.0295                           | 0.0005    | 0.0488                            | 0.0011    | 187.6                                       | 4.8       | 187.5                                       | 2.8       | 174                              | 29        | 4.0      |
| 180426-1-31 | 0.81 | 0.203                            | 0.005     | 0.0296                           | 0.0003    | 0.0497                            | 0.0012    | 187.4                                       | 4.2       | 187.9                                       | 2.1       | 196                              | 32        | 3.6      |
| 180426-1-6  | 0.74 | 0.204                            | 0.005     | 0.0298                           | 0.0003    | 0.0497                            | 0.0011    | 187.8                                       | 4.2       | 189.1                                       | 1.8       | 229                              | 26        | 3.9      |

**Appendix 11.** U-Pb ratio of Jandong Fm. (South area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-1-47 | 0.94 | 0.212                            | 0.004     | 0.0304                           | 0.0003    | 0.0508                            | 0.0008    | 194.9                                       | 3.4       | 193.1                                       | 1.7       | 226                              | 23        | 1.7      |
| 180426-1-77 | 0.83 | 0.232                            | 0.010     | 0.0304                           | 0.0006    | 0.0551                            | 0.0025    | 211.4                                       | 8.4       | 193.3                                       | 3.6       | 436                              | 57        | -3.2     |
| 180426-1-4  | 0.19 | 3.747                            | 0.046     | 0.2553                           | 0.0032    | 0.1064                            | 0.0004    | 1581  | 9.9       | 1466  | 16        | 1742                             | 4.2       | -6.1     |
| 180426-1-50 | 0.01 | 4.234                            | 0.087     | 0.2867                           | 0.0054    | 0.1096                            | 0.0008    | 1680  | 17        | 1632  | 30        | 1793.3                           | 9.9       | -0.1     |
| 180426-1-32 | 0.42 | 4.417                            | 0.066     | 0.2909                           | 0.0040    | 0.1142                            | 0.0005    | 1715  | 12        | 1646  | 20        | 1866.7                           | 4.8       | -2.2     |
| 180426-1-16 | 0.01 | 4.674                            | 0.064     | 0.3146                           | 0.0045    | 0.1115                            | 0.0004    | 1762  | 11        | 1763  | 22        | 1825.5                           | 4.4       | 1.9      |
| 180426-1-10 | 0.03 | 4.759                            | 0.094     | 0.3168                           | 0.0058    | 0.1146                            | 0.0011    | 1777  | 17        | 1774  | 29        | 1869                             | 9.3       | 2.4      |
| 180426-1-43 | 0.04 | 4.774                            | 0.098     | 0.3179                           | 0.0065    | 0.1129                            | 0.0007    | 1779  | 17        | 1779  | 32        | 1852.5                           | 6.3       | 2.8      |
| 180426-1-12 | 0.04 | 4.796                            | 0.063     | 0.3190                           | 0.0051    | 0.1110                            | 0.0002    | 1783  | 11        | 1784  | 25        | 1818.3                           | 2.1       | 2.1      |
| 180426-1-13 | 0.40 | 4.970                            | 0.130     | 0.3196                           | 0.0064    | 0.1186                            | 0.0009    | 1814  | 23        | 1788  | 31        | 1934.1                           | 7.7       | 1.6      |
| 180426-1-5  | 0.05 | 4.940                            | 0.110     | 0.3238                           | 0.0068    | 0.1142                            | 0.0007    | 1807  | 19        | 1807  | 33        | 1867.5                           | 7.8       | 2.9      |
| 180426-1-3  | 0.30 | 4.947                            | 0.093     | 0.3243                           | 0.0053    | 0.1144                            | 0.0006    | 1811  | 15        | 1810  | 26        | 1871.7                           | 4.3       | 2.2      |
| 180426-1-35 | 0.01 | 4.965                            | 0.068     | 0.3254                           | 0.0042    | 0.1144                            | 0.0004    | 1815  | 12        | 1816  | 20        | 1871.4                           | 3.3       | 1.8      |
| 180426-1-51 | 0.21 | 4.974                            | 0.089     | 0.3263                           | 0.0056    | 0.1126                            | 0.0006    | 1819  | 15        | 1824  | 26        | 1842.6                           | 6.2       | 2.5      |
| 180426-1-39 | 0.03 | 5.068                            | 0.080     | 0.3276                           | 0.0054    | 0.1109                            | 0.0003    | 1830  | 13        | 1827  | 26        | 1813                             | 2.5       | 2.0      |
| 180426-1-15 | 0.12 | 5.030                            | 0.059     | 0.3279                           | 0.0026    | 0.1140                            | 0.0005    | 1823  | 10        | 1828  | 13        | 1862                             | 3.9       | 1.5      |
| 180426-1-52 | 0.37 | 5.163                            | 0.064     | 0.3315                           | 0.0039    | 0.1144                            | 0.0007    | 1848  | 10        | 1845  | 19        | 1873.2                           | 5.4       | 1.4      |
| 180426-1-20 | 0.03 | 5.177                            | 0.056     | 0.3325                           | 0.0034    | 0.1173                            | 0.0004    | 1849.6                                      | 9.4       | 1850  | 16        | 1916.1                           | 3.4       | 1.4      |
| 180426-1-63 | 0.04 | 5.181                            | 0.041     | 0.3329                           | 0.0025    | 0.1140                            | 0.0004    | 1849.8                                      | 6.8       | 1852  | 12        | 1863.7                           | 2.8       | 1.1      |
| 180426-1-74 | 0.03 | 5.192                            | 0.064     | 0.3337                           | 0.0037    | 0.1138                            | 0.0004    | 1851  | 11        | 1856  | 18        | 1859.3                           | 2.8       | 1.8      |

**Appendix 11.** U-Pb ratio of Jandong Fm. (South area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U  | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|-------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-1-33 | 0.03  | 5.513                            | 0.079     | 0.3340                           | 0.0049    | 0.1143                            | 0.0005    | 1902  | 12        | 1858  | 24        | 1865.6                           | 4.7       | -0.4     |
| 180426-1-83 | 0.04  | 5.232                            | 0.046     | 0.3345                           | 0.0032    | 0.1127                            | 0.0004    | 1857.4                                      | 7.6       | 1860  | 15        | 1843                             | 4.1       | 1.4      |
| 180426-1-53 | 0.08  | 5.248                            | 0.049     | 0.3346                           | 0.0029    | 0.1156                            | 0.0003    | 1860.3                                      | 8         | 1860  | 14        | 1887.7                           | 3.9       | 1.2      |
| 180426-1-36 | 3.58  | 5.501                            | 0.073     | 0.3350                           | 0.0040    | 0.1157                            | 0.0008    | 1901  | 11        | 1862  | 19        | 1888.8                           | 7.6       | -0.5     |
| 180426-1-94 | 0.01  | 5.261                            | 0.066     | 0.3355                           | 0.0044    | 0.1146                            | 0.0003    | 1862  | 11        | 1868  | 22        | 1873                             | 2.7       | 2.1      |
| 180426-1-24 | 0.03  | 5.283                            | 0.057     | 0.3362                           | 0.0030    | 0.1143                            | 0.0003    | 1866  | 9.1       | 1868  | 15        | 1867.6                           | 3         | 1.4      |
| 180426-1-84 | -0.13 | 5.281                            | 0.053     | 0.3362                           | 0.0032    | 0.1143                            | 0.0004    | 1865.1                                      | 8.5       | 1868  | 16        | 1870.5                           | 3.5       | 1.5      |
| 180426-1-81 | -0.17 | 5.302                            | 0.064     | 0.3367                           | 0.0041    | 0.1145                            | 0.0004    | 1869  | 11        | 1870  | 20        | 1871.3                           | 4         | 1.7      |
| 180426-1-99 | 0.21  | 5.301                            | 0.095     | 0.3367                           | 0.0063    | 0.1146                            | 0.0010    | 1871  | 14        | 1870  | 30        | 1876.6                           | 8.5       | 2.3      |
| 180426-1-75 | 0.05  | 5.334                            | 0.062     | 0.3382                           | 0.0037    | 0.1144                            | 0.0006    | 1875  | 10        | 1877  | 18        | 1871.1                           | 6.1       | 1.6      |
| 180426-1-66 | 0.25  | 5.356                            | 0.078     | 0.3387                           | 0.0050    | 0.1155                            | 0.0008    | 1876  | 12        | 1879  | 24        | 1889.6                           | 7.8       | 2.1      |
| 180426-1-95 | 0.29  | 5.417                            | 0.075     | 0.3395                           | 0.0045    | 0.1152                            | 0.0006    | 1886  | 12        | 1883  | 22        | 1879.5                           | 6.3       | 1.6      |
| 180426-1-73 | 0.01  | 5.430                            | 0.110     | 0.3403                           | 0.0066    | 0.1135                            | 0.0005    | 1888  | 17        | 1887  | 31        | 1856.9                           | 4.6       | 2.5      |
| 180426-1-56 | 0.02  | 5.380                            | 0.079     | 0.3407                           | 0.0053    | 0.1148                            | 0.0008    | 1881  | 13        | 1890  | 25        | 1871.9                           | 7.4       | 2.5      |
| 180426-1-88 | 0.03  | 5.470                            | 0.160     | 0.3407                           | 0.0097    | 0.1149                            | 0.0006    | 1892  | 25        | 1888  | 47        | 1875.2                           | 6.7       | 3.6      |
| 180426-1-37 | 0.31  | 5.473                            | 0.072     | 0.3413                           | 0.0032    | 0.1144                            | 0.0004    | 1895  | 11        | 1892  | 15        | 1869.1                           | 2.9       | 1.2      |
| 180426-1-14 | 0.02  | 5.450                            | 0.110     | 0.3415                           | 0.0047    | 0.1137                            | 0.0006    | 1891  | 16        | 1893  | 23        | 1858                             | 5.9       | 2.2      |
| 180426-1-98 | 0.03  | 5.456                            | 0.067     | 0.3418                           | 0.0049    | 0.1155                            | 0.0006    | 1893  | 10        | 1895  | 23        | 1888.4                           | 5.5       | 1.8      |
| 180426-1-8  | 0.13  | 5.488                            | 0.081     | 0.3421                           | 0.0035    | 0.1150                            | 0.0005    | 1899  | 13        | 1896  | 17        | 1875.7                           | 4         | 1.4      |
| 180426-1-11 | 0.32  | 5.493                            | 0.063     | 0.3427                           | 0.0043    | 0.1165                            | 0.0003    | 1900  | 9.6       | 1899  | 21        | 1902.7                           | 2.4       | 1.6      |

**Appendix 11.** U-Pb ratio of Jandong Fm. (South area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U  | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|-------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-1-18  | 0.59  | 5.489                            | 0.057     | 0.3429                           | 0.0035    | 0.1208                            | 0.0003    | 1898.4                                      | 8.9       | 1900  | 17        | 1969.2                           | 2.2       | 1.4      |
| 180426-1-87  | 0.03  | 5.449                            | 0.080     | 0.3435                           | 0.0048    | 0.1136                            | 0.0007    | 1892  | 13        | 1903  | 23        | 1859.2                           | 5.6       | 2.5      |
| 180426-1-62  | 0.14  | 5.560                            | 0.110     | 0.3438                           | 0.0065    | 0.1162                            | 0.0006    | 1909  | 17        | 1904  | 31        | 1901.8                           | 4.4       | 2.3      |
| 180426-1-85  | 0.06  | 5.460                            | 0.120     | 0.3453                           | 0.0052    | 0.1174                            | 0.0017    | 1894  | 19        | 1912  | 25        | 1917                             | 20        | 3.2      |
| 180426-1-21  | 0.47  | 5.605                            | 0.065     | 0.3465                           | 0.0032    | 0.1221                            | 0.0008    | 1917.8                                      | 9.6       | 1918  | 15        | 1989.9                           | 5         | 1.3      |
| 180426-1-78  | 0.07  | 5.763                            | 0.070     | 0.3524                           | 0.0035    | 0.1204                            | 0.0006    | 1947  | 11        | 1949  | 17        | 1961.1                           | 5.4       | 1.5      |
| 180426-1-61  | 0.58  | 6.096                            | 0.076     | 0.3623                           | 0.0042    | 0.1217                            | 0.0006    | 1989  | 11        | 1992  | 20        | 1983.4                           | 5.2       | 1.7      |
| 180426-1-100 | 0.25  | 6.157                            | 0.071     | 0.3647                           | 0.0042    | 0.1201                            | 0.0003    | 1998  | 10        | 2004  | 20        | 1958.6                           | 2.5       | 1.8      |
| 180426-1-48  | 0.13  | 6.286                            | 0.064     | 0.3663                           | 0.0039    | 0.1282                            | 0.0005    | 2015.8                                      | 8.9       | 2012  | 18        | 2075                             | 5.3       | 1.1      |
| 180426-1-19  | 0.09  | 6.629                            | 0.083     | 0.3769                           | 0.0041    | 0.1319                            | 0.0008    | 2062  | 11        | 2061  | 19        | 2123.4                           | 6.5       | 1.4      |
| 180426-1-26  | 0.41  | 7.270                            | 0.270     | 0.3880                           | 0.0160    | 0.1372                            | 0.0016    | 2144  | 33        | 2111  | 75        | 2188.4                           | 8.8       | 3.6      |
| 180426-1-76  | -1.00 | 7.930                            | 0.290     | 0.3950                           | 0.0120    | 0.1445                            | 0.0011    | 2222  | 33        | 2146  | 58        | 2271.7                           | 8.2       | 0.7      |
| 180426-1-34  | 0.83  | 7.360                            | 0.160     | 0.3954                           | 0.0068    | 0.1344                            | 0.0009    | 2159  | 18        | 2146  | 31        | 2162.1                           | 7         | 1.7      |
| 180426-1-82  | 0.70  | 7.600                            | 0.190     | 0.4013                           | 0.0088    | 0.1388                            | 0.0016    | 2189  | 20        | 2173  | 40        | 2207                             | 12        | 2.0      |
| 180426-1-86  | 0.78  | 7.510                            | 0.150     | 0.4021                           | 0.0079    | 0.1364                            | 0.0010    | 2172  | 18        | 2177  | 36        | 2183                             | 6.2       | 2.7      |
| 180426-1-96  | 0.63  | 7.663                            | 0.071     | 0.4059                           | 0.0044    | 0.1365                            | 0.0004    | 2191.4                                      | 8.3       | 2195  | 20        | 2183.3                           | 2.7       | 1.5      |
| 180426-1-60  | 0.17  | 8.950                            | 0.140     | 0.4358                           | 0.0064    | 0.1532                            | 0.0010    | 2332  | 15        | 2331  | 29        | 2381.6                           | 5.5       | 1.8      |
| 180426-1-67  | 0.39  | 8.997                            | 0.093     | 0.4387                           | 0.0049    | 0.1482                            | 0.0006    | 2338.9                                      | 9.4       | 2346  | 22        | 2323                             | 4         | 1.6      |
| 180426-1-72  | 0.46  | 10.360                           | 0.250     | 0.4640                           | 0.0110    | 0.1620                            | 0.0008    | 2466  | 22        | 2458  | 47        | 2478.5                           | 4.8       | 2.5      |
| 180426-1-57  | 0.43  | 15.230                           | 0.150     | 0.5508                           | 0.0057    | 0.2034                            | 0.0007    | 2828.9                                      | 9.7       | 2830  | 24        | 2854.5                           | 3.3       | 1.2      |

**Appendix 12.** U-Pb ratio of Jandong Fm. (West area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-4-93  | 0.85 | 0.095                            | 0.006     | 0.0139                           | 0.0002    | 0.0498                            | 0.0032    | 92  | 5.4       | 89  | 1.4       | 283                              | 62        | 4.3      |
| 180426-4-54  | 0.48 | 0.096                            | 0.010     | 0.0139                           | 0.0003    | 0.0500                            | 0.0052    | 93.5  | 9.4       | 89.1  | 2.1       | 506                              | 79        | 8.0      |
| 180426-4-34  | 1.64 | 0.092                            | 0.003     | 0.0140                           | 0.0001    | 0.0483                            | 0.0014    | 89.6  | 2.4       | 89.4  | 0.76      | 199                              | 28        | 3.3      |
| 180426-4-40  | 0.67 | 0.095                            | 0.004     | 0.0140                           | 0.0002    | 0.0488                            | 0.0023    | 91.5  | 4         | 89.8  | 1.2       | 367                              | 45        | 3.9      |
| 180426-4-24  | 0.61 | 0.096                            | 0.005     | 0.0141                           | 0.0003    | 0.0480                            | 0.0024    | 93.7  | 4.3       | 90.1  | 1.6       | 231                              | 45        | 2.6      |
| 180426-4-91  | 0.86 | 0.107                            | 0.014     | 0.0141                           | 0.0004    | 0.0546                            | 0.0075    | 103   | 13        | 90.1  | 2.2       | 483                              | 93        | 2.6      |
| 180426-4-25  | 0.82 | 0.098                            | 0.006     | 0.0141                           | 0.0003    | 0.0504                            | 0.0034    | 96  | 6.1       | 90.2  | 2.1       | 269                              | 60        | 2.7      |
| 180426-4-30  | 0.94 | 0.096                            | 0.005     | 0.0141                           | 0.0002    | 0.0495                            | 0.0028    | 93.2  | 5         | 90.2  | 1.3       | 321                              | 50        | 3.7      |
| 180426-4-87  | 0.70 | 0.093                            | 0.004     | 0.0141                           | 0.0002    | 0.0476                            | 0.0021    | 90.2  | 4         | 90.3  | 1.2       | 306                              | 48        | 5.9      |
| 180426-4-32  | 0.67 | 0.097                            | 0.006     | 0.0141                           | 0.0002    | 0.0502                            | 0.0029    | 94  | 5.1       | 90.4  | 1.5       | 416                              | 62        | 3.3      |
| 180426-4-15  | 0.71 | 0.194                            | 0.010     | 0.0141                           | 0.0002    | 0.1014                            | 0.0048    | 180.1                                       | 8.3       | 90.5  | 1.4       | 1609                             | 63        | -88.3    |
| 180426-4-84  | 1.04 | 0.096                            | 0.005     | 0.0142                           | 0.0002    | 0.0492                            | 0.0026    | 92.9  | 4.6       | 90.6  | 1.3       | 295                              | 44        | 4.0      |
| 180426-4-100 | 0.61 | 0.095                            | 0.006     | 0.0142                           | 0.0002    | 0.0487                            | 0.0029    | 92.8  | 5.2       | 90.9  | 1.3       | 335                              | 61        | 5.1      |
| 180426-4-89  | 1.19 | 0.096                            | 0.003     | 0.0143                           | 0.0002    | 0.0484                            | 0.0015    | 93.4  | 2.9       | 91.3  | 1         | 222                              | 35        | 2.0      |
| 180426-4-67  | 0.57 | 0.099                            | 0.008     | 0.0143                           | 0.0003    | 0.0500                            | 0.0041    | 95.5  | 7.7       | 91.4  | 2.1       | 344                              | 87        | 6.2      |
| 180426-4-75  | 0.56 | 0.096                            | 0.009     | 0.0143                           | 0.0004    | 0.0486                            | 0.0042    | 92.7  | 8         | 91.4  | 2.3       | 361                              | 63        | 9.8      |
| 180426-4-80  | 0.52 | 0.092                            | 0.006     | 0.0143                           | 0.0002    | 0.0465                            | 0.0029    | 89.2  | 5.6       | 91.4  | 1.4       | 315                              | 64        | 10.1     |
| 180426-4-52  | 0.55 | 0.096                            | 0.008     | 0.0143                           | 0.0003    | 0.0470                            | 0.0037    | 92.6  | 7.4       | 91.5  | 1.8       | 482                              | 62        | 8.9      |
| 180426-4-90  | 0.51 | 0.095                            | 0.004     | 0.0143                           | 0.0002    | 0.0475                            | 0.0020    | 91.7  | 3.6       | 91.5  | 1.2       | 294                              | 44        | 5.0      |
| 180426-4-33  | 1.37 | 0.094                            | 0.004     | 0.0143                           | 0.0001    | 0.0470                            | 0.0016    | 91  | 3.2       | 91.53                                       | 0.89      | 217                              | 39        | 5.0      |

**Appendix 12.** U-Pb ratio of Jandong Fm. (West area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-4-12 | 0.54 | 0.096                            | 0.003     | 0.0143                           | 0.0002    | 0.0483                            | 0.0016    | 92.7  | 3.1       | 91.56                                       | 0.98      | 282                              | 37        | 3.2      |
| 180426-4-97 | 0.75 | 0.097                            | 0.006     | 0.0143                           | 0.0002    | 0.0493                            | 0.0028    | 93.6  | 5.3       | 91.6  | 1.4       | 270                              | 60        | 5.1      |
| 180426-4-19 | 0.76 | 0.093                            | 0.003     | 0.0143                           | 0.0002    | 0.0471                            | 0.0017    | 89.8  | 3.2       | 91.66                                       | 0.99      | 244                              | 35        | 6.6      |
| 180426-4-83 | 0.62 | 0.101                            | 0.014     | 0.0143                           | 0.0005    | 0.0542                            | 0.0064    | 101   | 12        | 91.8  | 3.3       | 406                              | 99        | 6.6      |
| 180426-4-37 | 0.82 | 0.096                            | 0.004     | 0.0144                           | 0.0002    | 0.0490                            | 0.0025    | 93.8  | 4.2       | 91.9  | 1.3       | 379                              | 56        | 3.9      |
| 180426-4-81 | 0.55 | 0.097                            | 0.006     | 0.0144                           | 0.0002    | 0.0493                            | 0.0030    | 93.9  | 5.5       | 91.9  | 1.5       | 392                              | 63        | 5.4      |
| 180426-4-9  | 0.85 | 0.096                            | 0.003     | 0.0144                           | 0.0002    | 0.0478                            | 0.0015    | 92.6  | 2.9       | 91.97                                       | 0.95      | 219                              | 34        | 3.5      |
| 180426-4-16 | 0.65 | 0.096                            | 0.006     | 0.0144                           | 0.0002    | 0.0495                            | 0.0031    | 93.1  | 5.8       | 92  | 1.5       | 373                              | 59        | 6.7      |
| 180426-4-36 | 0.66 | 0.116                            | 0.024     | 0.0144                           | 0.0004    | 0.0580                            | 0.0120    | 111   | 21        | 92  | 2.4       | 850                              | 310       | 4.8      |
| 180426-4-79 | 0.63 | 0.099                            | 0.006     | 0.0144                           | 0.0002    | 0.0494                            | 0.0029    | 95.8  | 5.5       | 92.2  | 1.5       | 402                              | 59        | 3.7      |
| 180426-4-3  | 0.77 | 0.098                            | 0.005     | 0.0144                           | 0.0002    | 0.0490                            | 0.0024    | 94.5  | 4.5       | 92.3  | 1.2       | 277                              | 48        | 3.8      |
| 180426-4-17 | 1.37 | 0.098                            | 0.009     | 0.0144                           | 0.0004    | 0.0517                            | 0.0046    | 95.6  | 8.2       | 92.3  | 2.7       | 579                              | 73        | 8.2      |
| 180426-4-26 | 0.66 | 0.102                            | 0.009     | 0.0144                           | 0.0003    | 0.0511                            | 0.0045    | 98.6  | 8.3       | 92.3  | 1.8       | 415                              | 87        | 4.1      |
| 180426-4-85 | 0.74 | 0.098                            | 0.006     | 0.0144                           | 0.0002    | 0.0489                            | 0.0031    | 95.5  | 5.2       | 92.3  | 1.5       | 348                              | 52        | 3.8      |
| 180426-4-53 | 0.66 | 0.100                            | 0.008     | 0.0144                           | 0.0004    | 0.0512                            | 0.0041    | 96.6  | 7         | 92.4  | 2.6       | 386                              | 71        | 5.8      |
| 180426-4-55 | 1.01 | 0.097                            | 0.005     | 0.0144                           | 0.0002    | 0.0482                            | 0.0023    | 93.4  | 4.5       | 92.4  | 1.1       | 318                              | 51        | 5.0      |
| 180426-4-68 | 0.51 | 0.097                            | 0.007     | 0.0144                           | 0.0003    | 0.0477                            | 0.0035    | 92.2  | 6.4       | 92.4  | 1.6       | 426                              | 66        | 8.9      |
| 180426-4-98 | 2.71 | 0.095                            | 0.004     | 0.0144                           | 0.0002    | 0.0478                            | 0.0018    | 92.1  | 3.4       | 92.4  | 1.2       | 188                              | 50        | 5.3      |
| 180426-4-22 | 0.59 | 0.100                            | 0.007     | 0.0145                           | 0.0002    | 0.0499                            | 0.0031    | 97.5  | 6.3       | 92.6  | 1.4       | 422                              | 65        | 3.0      |
| 180426-4-31 | 0.67 | 0.096                            | 0.006     | 0.0145                           | 0.0002    | 0.0481                            | 0.0027    | 93.3  | 5         | 92.7  | 1.5       | 383                              | 54        | 6.4      |

**Appendix 12.** U-Pb ratio of Jandong Fm. (West area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-4-29 | 0.67 | 0.095                            | 0.005     | 0.0145                           | 0.0002    | 0.0477                            | 0.0023    | 92.7  | 4.3       | 92.8  | 1.2       | 361                              | 45        | 6.0      |
| 180426-4-82 | 0.62 | 0.094                            | 0.005     | 0.0145                           | 0.0002    | 0.0469                            | 0.0023    | 92.2  | 4.4       | 92.8  | 1.2       | 268                              | 43        | 6.7      |
| 180426-4-86 | 0.41 | 0.105                            | 0.010     | 0.0145                           | 0.0005    | 0.0526                            | 0.0050    | 101.7                                       | 9.4       | 92.8  | 2.9       | 600                              | 110       | 3.7      |
| 180426-4-42 | 0.52 | 0.098                            | 0.005     | 0.0145                           | 0.0002    | 0.0484                            | 0.0027    | 94.7  | 5         | 92.9  | 1.5       | 384                              | 51        | 5.1      |
| 180426-4-74 | 0.74 | 0.097                            | 0.005     | 0.0145                           | 0.0002    | 0.0470                            | 0.0023    | 94  | 4.5       | 92.9  | 1.3       | 307                              | 62        | 5.1      |
| 180426-4-88 | 0.59 | 0.096                            | 0.003     | 0.0145                           | 0.0002    | 0.0479                            | 0.0012    | 93.2  | 2.4       | 92.9  | 1.1       | 206                              | 29        | 3.4      |
| 180426-4-99 | 0.80 | 0.099                            | 0.004     | 0.0145                           | 0.0002    | 0.0492                            | 0.0022    | 95.2  | 3.9       | 92.9  | 1.2       | 304                              | 51        | 3.0      |
| 180426-4-5  | 0.57 | 0.099                            | 0.010     | 0.0145                           | 0.0005    | 0.0474                            | 0.0046    | 95.6  | 9.1       | 93  | 2.9       | 247                              | 93        | 10.1     |
| 180426-4-57 | 0.58 | 0.094                            | 0.005     | 0.0145                           | 0.0002    | 0.0468                            | 0.0024    | 91.2  | 4.7       | 93  | 1.4       | 328                              | 62        | 8.5      |
| 180426-4-59 | 0.67 | 0.098                            | 0.004     | 0.0145                           | 0.0002    | 0.0487                            | 0.0020    | 94.3  | 3.8       | 93  | 1.1       | 249                              | 41        | 3.9      |
| 180426-4-95 | 0.57 | 0.097                            | 0.005     | 0.0146                           | 0.0002    | 0.0481                            | 0.0022    | 94.2  | 4.2       | 93.1  | 1.2       | 312                              | 43        | 4.6      |
| 180426-4-21 | 0.67 | 0.100                            | 0.010     | 0.0146                           | 0.0003    | 0.0509                            | 0.0051    | 98.2  | 9.3       | 93.2  | 2.1       | 424                              | 79        | 6.9      |
| 180426-4-6  | 0.70 | 0.098                            | 0.005     | 0.0146                           | 0.0002    | 0.0477                            | 0.0024    | 94.2  | 4.6       | 93.3  | 1.5       | 291                              | 42        | 5.6      |
| 180426-4-48 | 0.63 | 0.100                            | 0.006     | 0.0146                           | 0.0002    | 0.0496                            | 0.0026    | 97.4  | 5.1       | 93.3  | 1.3       | 351                              | 50        | 2.5      |
| 180426-4-71 | 0.70 | 0.098                            | 0.005     | 0.0146                           | 0.0002    | 0.0487                            | 0.0026    | 95.3  | 4.8       | 93.3  | 1.5       | 348                              | 46        | 4.6      |
| 180426-4-18 | 0.70 | 0.097                            | 0.007     | 0.0146                           | 0.0002    | 0.0489                            | 0.0035    | 93.4  | 6.4       | 93.4  | 1.5       | 387                              | 73        | 8.5      |
| 180426-4-35 | 0.55 | 0.099                            | 0.007     | 0.0146                           | 0.0003    | 0.0490                            | 0.0035    | 94.3  | 6.5       | 93.4  | 1.7       | 416                              | 69        | 7.8      |
| 180426-4-51 | 0.63 | 0.099                            | 0.007     | 0.0146                           | 0.0003    | 0.0486                            | 0.0035    | 95  | 6.7       | 93.4  | 1.8       | 444                              | 62        | 7.4      |
| 180426-4-58 | 0.65 | 0.099                            | 0.006     | 0.0146                           | 0.0002    | 0.0481                            | 0.0028    | 95.1  | 5.3       | 93.4  | 1.5       | 384                              | 60        | 5.5      |
| 180426-4-11 | 0.87 | 0.101                            | 0.010     | 0.0146                           | 0.0004    | 0.0516                            | 0.0050    | 98.2  | 9.4       | 93.5  | 2.4       | 583                              | 92        | 7.6      |



**Appendix 12.** U-Pb ratio of Jandong Fm. (West area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-4-20 | 0.59 | 0.096                            | 0.004     | 0.0146                           | 0.0002    | 0.0477                            | 0.0022    | 93.1  | 4.1       | 93.5  | 1.2       | 319                              | 46        | 6.1      |
| 180426-4-38 | 0.71 | 0.097                            | 0.005     | 0.0146                           | 0.0002    | 0.0479                            | 0.0022    | 93.4  | 4.1       | 93.5  | 1.2       | 278                              | 39        | 5.8      |
| 180426-4-77 | 0.66 | 0.097                            | 0.005     | 0.0146                           | 0.0002    | 0.0483                            | 0.0027    | 93.5  | 4.9       | 93.5  | 1.4       | 370                              | 51        | 6.7      |
| 180426-4-10 | 0.76 | 0.099                            | 0.004     | 0.0146                           | 0.0002    | 0.0495                            | 0.0019    | 95.6  | 3.8       | 93.6  | 1.1       | 269                              | 37        | 3.1      |
| 180426-4-44 | 0.67 | 0.099                            | 0.005     | 0.0146                           | 0.0002    | 0.0493                            | 0.0025    | 95.3  | 4.7       | 93.7  | 1.2       | 398                              | 54        | 4.6      |
| 180426-4-8  | 0.73 | 0.098                            | 0.001     | 0.0147                           | 0.0001    | 0.0477                            | 0.0008    | 94.7  | 1.3       | 93.8  | 0.41      | 103                              | 21        | 0.9      |
| 180426-4-39 | 0.59 | 0.098                            | 0.006     | 0.0147                           | 0.0002    | 0.0488                            | 0.0030    | 95.5  | 5.5       | 93.8  | 1.4       | 436                              | 64        | 5.5      |
| 180426-4-41 | 0.68 | 0.099                            | 0.006     | 0.0147                           | 0.0002    | 0.0491                            | 0.0030    | 95.3  | 5.6       | 93.8  | 1.4       | 328                              | 49        | 5.9      |
| 180426-4-49 | 0.53 | 0.098                            | 0.005     | 0.0146                           | 0.0002    | 0.0487                            | 0.0026    | 95.4  | 4.7       | 93.8  | 1.2       | 360                              | 55        | 4.6      |
| 180426-4-70 | 0.71 | 0.101                            | 0.006     | 0.0147                           | 0.0002    | 0.0489                            | 0.0030    | 96.8  | 5.9       | 93.8  | 1.5       | 378                              | 67        | 4.7      |
| 180426-4-92 | 0.64 | 0.102                            | 0.007     | 0.0147                           | 0.0003    | 0.0490                            | 0.0039    | 97.9  | 6.8       | 93.8  | 2.1       | 349                              | 58        | 5.1      |
| 180426-4-14 | 0.59 | 0.093                            | 0.007     | 0.0147                           | 0.0003    | 0.0470                            | 0.0035    | 89.9  | 6.4       | 93.9  | 1.8       | 431                              | 84        | 13.0     |
| 180426-4-50 | 1.12 | 0.098                            | 0.004     | 0.0147                           | 0.0002    | 0.0485                            | 0.0021    | 95.3  | 3.9       | 93.9  | 1.2       | 337                              | 49        | 3.9      |
| 180426-4-62 | 0.99 | 0.099                            | 0.008     | 0.0147                           | 0.0003    | 0.0495                            | 0.0039    | 96.4  | 7.5       | 93.9  | 1.9       | 362                              | 73        | 7.3      |
| 180426-4-65 | 0.63 | 0.097                            | 0.005     | 0.0147                           | 0.0002    | 0.0480                            | 0.0024    | 93.8  | 4.4       | 93.9  | 1.3       | 367                              | 43        | 6.2      |
| 180426-4-45 | 0.64 | 0.101                            | 0.007     | 0.0147                           | 0.0002    | 0.0509                            | 0.0036    | 97.7  | 6.7       | 94  | 1.5       | 383                              | 69        | 4.8      |
| 180426-4-60 | 0.57 | 0.101                            | 0.007     | 0.0147                           | 0.0003    | 0.0517                            | 0.0033    | 96.9  | 6.3       | 94  | 1.7       | 367                              | 74        | 5.4      |
| 180426-4-43 | 0.61 | 0.099                            | 0.008     | 0.0147                           | 0.0003    | 0.0491                            | 0.0038    | 95.2  | 7.1       | 94.2  | 1.8       | 454                              | 76        | 8.4      |
| 180426-4-76 | 0.82 | 0.095                            | 0.004     | 0.0147                           | 0.0002    | 0.0469                            | 0.0021    | 91.8  | 4.1       | 94.2  | 1.3       | 282                              | 45        | 8.3      |
| 180426-4-94 | 0.62 | 0.097                            | 0.004     | 0.0147                           | 0.0002    | 0.0474                            | 0.0021    | 94.8  | 3.6       | 94.2  | 1.4       | 342                              | 52        | 4.7      |

**Appendix 12.** U-Pb ratio of Jandong Fm. (West area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-4-27 | 0.78 | 0.096                            | 0.010     | 0.0147                           | 0.0004    | 0.0462                            | 0.0046    | 92  | 8.8       | 94.3  | 2.3       | 560                              | 120       | 14.2     |
| 180426-4-73 | 0.75 | 0.102                            | 0.009     | 0.0147                           | 0.0004    | 0.0506                            | 0.0050    | 98.9  | 8.2       | 94.3  | 2.3       | 496                              | 96        | 6.3      |
| 180426-4-4  | 0.64 | 0.101                            | 0.007     | 0.0148                           | 0.0003    | 0.0492                            | 0.0034    | 97.6  | 6.3       | 94.4  | 1.7       | 386                              | 59        | 5.1      |
| 180426-4-23 | 0.83 | 0.103                            | 0.010     | 0.0148                           | 0.0004    | 0.0519                            | 0.0048    | 99.3  | 9.1       | 94.4  | 2.5       | 407                              | 87        | 7.1      |
| 180426-4-64 | 0.68 | 0.095                            | 0.005     | 0.0148                           | 0.0002    | 0.0463                            | 0.0024    | 92.2  | 4.7       | 94.4  | 1.2       | 301                              | 49        | 8.6      |
| 180426-4-78 | 0.61 | 0.099                            | 0.005     | 0.0148                           | 0.0002    | 0.0482                            | 0.0022    | 95.9  | 4.3       | 94.4  | 1.1       | 317                              | 48        | 4.1      |
| 180426-4-1  | 0.92 | 0.099                            | 0.004     | 0.0148                           | 0.0002    | 0.0478                            | 0.0017    | 95.7  | 3.3       | 94.5  | 0.93      | 208                              | 33        | 3.2      |
| 180426-4-69 | 0.85 | 0.094                            | 0.005     | 0.0148                           | 0.0003    | 0.0445                            | 0.0026    | 90.8  | 4.7       | 94.5  | 1.6       | 155                              | 52        | 10.6     |
| 180426-4-66 | 0.69 | 0.094                            | 0.006     | 0.0147                           | 0.0003    | 0.0455                            | 0.0031    | 91.1  | 5.7       | 94.7  | 1.9       | 293                              | 66        | 11.8     |
| 180426-4-47 | 0.64 | 0.124                            | 0.007     | 0.0148                           | 0.0002    | 0.0596                            | 0.0029    | 118.3                                       | 6.1       | 94.9  | 1.4       | 660                              | 63        | -16.8    |
| 180426-4-63 | 1.12 | 0.103                            | 0.012     | 0.0148                           | 0.0004    | 0.0482                            | 0.0054    | 102   | 10        | 94.9  | 2.5       | 529                              | 92        | 5.7      |
| 180426-4-13 | 0.63 | 0.113                            | 0.033     | 0.0149                           | 0.0008    | 0.0550                            | 0.0150    | 108   | 29        | 95.5  | 5         | 490                              | 300       | 22.5     |
| 180426-4-56 | 0.64 | 0.103                            | 0.008     | 0.0149                           | 0.0004    | 0.0498                            | 0.0036    | 98.8  | 7.5       | 95.5  | 2.4       | 418                              | 68        | 6.9      |
| 180426-4-72 | 0.71 | 0.101                            | 0.006     | 0.0149                           | 0.0002    | 0.0497                            | 0.0032    | 97.4  | 5.7       | 95.5  | 1.4       | 343                              | 57        | 5.4      |
| 180426-4-96 | 0.65 | 0.103                            | 0.006     | 0.0150                           | 0.0003    | 0.0489                            | 0.0026    | 98.2  | 5.3       | 95.8  | 1.9       | 390                              | 63        | 5.0      |
| 180426-4-46 | 0.91 | 0.103                            | 0.008     | 0.0152                           | 0.0003    | 0.0496                            | 0.0035    | 100.1                                       | 7         | 97.5  | 1.6       | 409                              | 61        | 6.2      |
| 180426-4-28 | 0.34 | 0.197                            | 0.004     | 0.0286                           | 0.0002    | 0.0498                            | 0.0009    | 182.8                                       | 3.3       | 181.5                                       | 1.5       | 208                              | 20        | 1.9      |
| 180426-4-7  | 0.30 | 0.197                            | 0.003     | 0.0286                           | 0.0002    | 0.0491                            | 0.0006    | 182.7                                       | 2.6       | 182   | 1         | 161                              | 17        | 1.6      |
| 180426-4-61 | 0.21 | 5.235                            | 0.069     | 0.3339                           | 0.0042    | 0.1148                            | 0.0007    | 1858  | 11        | 1857  | 20        | 1879.3                           | 5.4       | 1.6      |
| 180426-4-2  | 0.17 | 5.850                            | 0.049     | 0.3539                           | 0.0030    | 0.1188                            | 0.0004    | 1954.4                                      | 7.5       | 1953  | 14        | 1936.9                           | 3.3       | 1.0      |

**Appendix 13.** U-Pb ratio of Jandong Fm. (Center area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-7-11 | 1.21 | 0.091                            | 0.004     | 0.0133                           | 0.0002    | 0.0498                            | 0.0020    | 88.3  | 3.8       | 85.1  | 1.1       | 301                              | 50        | 2.0      |
| 180426-7-6  | 0.47 | 0.090                            | 0.005     | 0.0138                           | 0.0002    | 0.0475                            | 0.0028    | 87.4  | 5         | 88.2  | 1.3       | 296                              | 57        | 8.0      |
| 180426-7-18 | 0.56 | 0.155                            | 0.020     | 0.0138                           | 0.0003    | 0.0795                            | 0.0098    | 146   | 17        | 88.6  | 1.6       | 1160                             | 150       | -43.8    |
| 180426-7-19 | 0.76 | 0.094                            | 0.004     | 0.0139                           | 0.0002    | 0.0490                            | 0.0019    | 91.2  | 3.9       | 88.8  | 0.94      | 278                              | 48        | 2.7      |
| 180426-7-12 | 0.57 | 0.096                            | 0.005     | 0.0139                           | 0.0002    | 0.0501                            | 0.0023    | 93  | 4.4       | 88.92                                       | 0.99      | 312                              | 47        | 1.5      |
| 180426-7-45 | 0.67 | 0.094                            | 0.005     | 0.0139                           | 0.0002    | 0.0486                            | 0.0027    | 91  | 5         | 89  | 1.1       | 315                              | 61        | 4.6      |
| 180426-7-47 | 0.49 | 0.092                            | 0.003     | 0.0139                           | 0.0001    | 0.0476                            | 0.0016    | 89.2  | 3         | 89  | 0.92      | 215                              | 30        | 4.2      |
| 180426-7-90 | 1.39 | 0.092                            | 0.006     | 0.0139                           | 0.0002    | 0.0482                            | 0.0029    | 89.1  | 5.3       | 89  | 1.3       | 400                              | 57        | 7.3      |
| 180426-7-50 | 0.55 | 0.096                            | 0.006     | 0.0139                           | 0.0002    | 0.0512                            | 0.0033    | 92.8  | 5.9       | 89.2  | 1.4       | 358                              | 71        | 4.1      |
| 180426-7-51 | 0.50 | 0.096                            | 0.006     | 0.0139                           | 0.0002    | 0.0475                            | 0.0028    | 92.9  | 5.3       | 89.2  | 1.4       | 352                              | 54        | 3.4      |
| 180426-7-54 | 0.50 | 0.102                            | 0.012     | 0.0140                           | 0.0004    | 0.0506                            | 0.0060    | 98  | 11        | 89.5  | 2.5       | 412                              | 85        | 5.6      |
| 180426-7-64 | 0.67 | 0.094                            | 0.009     | 0.0140                           | 0.0003    | 0.0472                            | 0.0045    | 90.9  | 8.2       | 89.5  | 2         | 401                              | 86        | 9.8      |
| 180426-7-68 | 0.50 | 0.094                            | 0.007     | 0.0140                           | 0.0003    | 0.0489                            | 0.0036    | 90.6  | 6.5       | 89.5  | 1.8       | 435                              | 79        | 8.0      |
| 180426-7-41 | 0.82 | 0.093                            | 0.003     | 0.0140                           | 0.0001    | 0.0479                            | 0.0012    | 90.5  | 2.4       | 89.62                                       | 0.84      | 184                              | 28        | 2.6      |
| 180426-7-20 | 0.64 | 0.093                            | 0.003     | 0.0140                           | 0.0002    | 0.0484                            | 0.0014    | 90.3  | 2.8       | 89.7  | 1         | 198                              | 27        | 3.6      |
| 180426-7-67 | 0.56 | 0.095                            | 0.009     | 0.0140                           | 0.0003    | 0.0494                            | 0.0046    | 90.9  | 8.2       | 89.7  | 1.8       | 544                              | 85        | 9.8      |
| 180426-7-17 | 0.61 | 0.094                            | 0.005     | 0.0140                           | 0.0002    | 0.0487                            | 0.0026    | 91.2  | 4.5       | 89.8  | 1.3       | 317                              | 51        | 4.9      |
| 180426-7-37 | 0.44 | 0.094                            | 0.007     | 0.0140                           | 0.0003    | 0.0494                            | 0.0037    | 91.1  | 6.6       | 89.8  | 2.1       | 238                              | 64        | 8.2      |
| 180426-7-57 | 0.69 | 0.088                            | 0.010     | 0.0140                           | 0.0004    | 0.0443                            | 0.0049    | 85.4  | 8.8       | 89.8  | 2.6       | 490                              | 100       | 17.6     |
| 180426-7-8  | 0.52 | 0.097                            | 0.006     | 0.0141                           | 0.0003    | 0.0497                            | 0.0031    | 93.7  | 5.5       | 89.9  | 1.6       | 414                              | 65        | 3.7      |

**Appendix 13.** U-Pb ratio of Jandong Fm. (Center area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-7-22 | 0.78 | 0.094                            | 0.003     | 0.0141                           | 0.0002    | 0.0488                            | 0.0014    | 91.5  | 2.7       | 89.9  | 1         | 217                              | 32        | 2.3      |
| 180426-7-42 | 0.60 | 0.090                            | 0.005     | 0.0140                           | 0.0002    | 0.0467                            | 0.0023    | 88.4  | 4.7       | 89.9  | 1.2       | 255                              | 60        | 8.2      |
| 180426-7-58 | 0.69 | 0.095                            | 0.007     | 0.0141                           | 0.0003    | 0.0494                            | 0.0035    | 92.5  | 6.1       | 89.9  | 1.7       | 504                              | 73        | 5.8      |
| 180426-7-98 | 0.62 | 0.096                            | 0.008     | 0.0141                           | 0.0003    | 0.0495                            | 0.0037    | 93  | 7.2       | 89.9  | 1.9       | 429                              | 78        | 6.7      |
| 180426-7-53 | 0.57 | 0.098                            | 0.011     | 0.0141                           | 0.0003    | 0.0474                            | 0.0051    | 96  | 9.6       | 90  | 1.8       | 430                              | 84        | 6.0      |
| 180426-7-24 | 0.65 | 0.097                            | 0.005     | 0.0141                           | 0.0003    | 0.0519                            | 0.0026    | 93.8  | 5         | 90.1  | 1.8       | 360                              | 52        | 3.4      |
| 180426-7-80 | 0.77 | 0.095                            | 0.005     | 0.0141                           | 0.0002    | 0.0489                            | 0.0022    | 91.9  | 4.1       | 90.1  | 1.1       | 312                              | 39        | 3.8      |
| 180426-7-83 | 0.58 | 0.097                            | 0.006     | 0.0141                           | 0.0002    | 0.0493                            | 0.0029    | 94.3  | 5.5       | 90.1  | 1.1       | 472                              | 68        | 2.7      |
| 180426-7-40 | 0.69 | 0.095                            | 0.002     | 0.0141                           | 0.0001    | 0.0489                            | 0.0012    | 92.2  | 2.3       | 90.12                                       | 0.88      | 191                              | 24        | 1.2      |
| 180426-7-43 | 0.47 | 0.095                            | 0.003     | 0.0141                           | 0.0002    | 0.0498                            | 0.0016    | 92.3  | 3         | 90.14                                       | 0.94      | 233                              | 39        | 2.0      |
| 180426-7-46 | 0.48 | 0.093                            | 0.006     | 0.0141                           | 0.0002    | 0.0484                            | 0.0032    | 90.2  | 5.9       | 90.2  | 1.5       | 219                              | 75        | 8.2      |
| 180426-7-48 | 0.50 | 0.096                            | 0.004     | 0.0141                           | 0.0002    | 0.0480                            | 0.0020    | 92.6  | 3.5       | 90.3  | 1         | 262                              | 46        | 2.4      |
| 180426-7-49 | 0.84 | 0.096                            | 0.005     | 0.0141                           | 0.0002    | 0.0496                            | 0.0022    | 92.8  | 4.2       | 90.3  | 1.5       | 267                              | 57        | 3.5      |
| 180426-7-65 | 0.95 | 0.096                            | 0.006     | 0.0141                           | 0.0003    | 0.0492                            | 0.0030    | 92.6  | 5.3       | 90.3  | 1.6       | 271                              | 52        | 5.1      |
| 180426-7-84 | 0.57 | 0.107                            | 0.018     | 0.0141                           | 0.0006    | 0.0590                            | 0.0100    | 108   | 18        | 90.3  | 3.6       | 650                              | 170       | 4.3      |
| 180426-7-88 | 1.43 | 0.099                            | 0.007     | 0.0141                           | 0.0002    | 0.0500                            | 0.0033    | 95.9  | 6.3       | 90.3  | 1.4       | 263                              | 69        | 2.3      |
| 180426-7-60 | 0.52 | 0.095                            | 0.010     | 0.0141                           | 0.0003    | 0.0485                            | 0.0048    | 91  | 8.8       | 90.4  | 1.7       | 502                              | 86        | 11.0     |
| 180426-7-61 | 0.49 | 0.096                            | 0.008     | 0.0141                           | 0.0003    | 0.0489                            | 0.0040    | 92  | 7.3       | 90.4  | 1.9       | 440                              | 72        | 8.4      |
| 180426-7-81 | 0.56 | 0.097                            | 0.006     | 0.0141                           | 0.0003    | 0.0516                            | 0.0034    | 94  | 5.9       | 90.4  | 1.7       | 430                              | 59        | 4.4      |
| 180426-7-34 | 0.37 | 0.100                            | 0.010     | 0.0141                           | 0.0004    | 0.0498                            | 0.0052    | 96.2  | 9.4       | 90.5  | 2.4       | 460                              | 140       | 6.7      |

**Appendix 13.** U-Pb ratio of Jandong Fm. (Center area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-7-75 | 0.53 | 0.097                            | 0.008     | 0.0141                           | 0.0003    | 0.0484                            | 0.0041    | 93.2  | 7.7       | 90.5  | 1.6       | 546                              | 73        | 7.3      |
| 180426-7-16 | 0.45 | 0.096                            | 0.006     | 0.0142                           | 0.0003    | 0.0500                            | 0.0035    | 92.6  | 5.7       | 90.7  | 1.7       | 261                              | 71        | 6.1      |
| 180426-7-78 | 0.51 | 0.097                            | 0.007     | 0.0142                           | 0.0003    | 0.0490                            | 0.0033    | 93  | 6         | 90.7  | 1.6       | 424                              | 66        | 5.8      |
| 180426-7-82 | 0.56 | 0.096                            | 0.007     | 0.0142                           | 0.0003    | 0.0481                            | 0.0032    | 93.8  | 6         | 90.7  | 1.7       | 363                              | 56        | 5.1      |
| 180426-7-33 | 0.61 | 0.097                            | 0.004     | 0.0142                           | 0.0001    | 0.0488                            | 0.0020    | 93.9  | 3.9       | 90.86                                       | 0.9       | 226                              | 44        | 1.9      |
| 180426-7-23 | 0.73 | 0.095                            | 0.004     | 0.0142                           | 0.0002    | 0.0500                            | 0.0022    | 92.5  | 3.8       | 90.9  | 1.3       | 255                              | 59        | 3.9      |
| 180426-7-73 | 0.55 | 0.097                            | 0.005     | 0.0142                           | 0.0002    | 0.0488                            | 0.0021    | 94  | 4.3       | 90.96                                       | 0.96      | 267                              | 45        | 2.4      |
| 180426-7-92 | 0.61 | 0.098                            | 0.009     | 0.0142                           | 0.0003    | 0.0492                            | 0.0044    | 93.6  | 8.1       | 91  | 1.8       | 577                              | 77        | 8.0      |
| 180426-7-63 | 0.54 | 0.092                            | 0.008     | 0.0142                           | 0.0003    | 0.0475                            | 0.0041    | 88.8  | 7.4       | 91.1  | 1.7       | 522                              | 74        | 12.5     |
| 180426-7-71 | 0.50 | 0.097                            | 0.006     | 0.0142                           | 0.0002    | 0.0488                            | 0.0028    | 93.6  | 5.4       | 91.1  | 1.4       | 334                              | 52        | 4.7      |
| 180426-7-76 | 0.59 | 0.093                            | 0.006     | 0.0142                           | 0.0002    | 0.0481                            | 0.0032    | 89.7  | 5.5       | 91.1  | 1.3       | 330                              | 59        | 9.0      |
| 180426-7-66 | 0.62 | 0.098                            | 0.007     | 0.0142                           | 0.0003    | 0.0501                            | 0.0032    | 94.8  | 6         | 91.2  | 1.8       | 548                              | 69        | 4.6      |
| 180426-7-14 | 0.57 | 0.097                            | 0.006     | 0.0143                           | 0.0003    | 0.0499                            | 0.0033    | 93.9  | 5.9       | 91.3  | 1.6       | 500                              | 77        | 5.4      |
| 180426-7-36 | 1.08 | 0.097                            | 0.005     | 0.0143                           | 0.0003    | 0.0483                            | 0.0026    | 94.3  | 4.7       | 91.3  | 1.6       | 280                              | 48        | 3.6      |
| 180426-7-79 | 0.59 | 0.097                            | 0.006     | 0.0143                           | 0.0002    | 0.0482                            | 0.0030    | 93.3  | 5.8       | 91.8  | 1.4       | 409                              | 59        | 6.2      |
| 180426-7-86 | 0.62 | 0.097                            | 0.004     | 0.0143                           | 0.0002    | 0.0490                            | 0.0021    | 93.4  | 4         | 91.8  | 1.2       | 311                              | 46        | 3.9      |
| 180426-7-99 | 0.50 | 0.097                            | 0.007     | 0.0143                           | 0.0002    | 0.0477                            | 0.0037    | 93.1  | 6.4       | 91.8  | 1.5       | 502                              | 80        | 7.2      |
| 180426-7-9  | 2.98 | 0.096                            | 0.003     | 0.0144                           | 0.0001    | 0.0483                            | 0.0016    | 93.1  | 2.9       | 91.83                                       | 0.89      | 227                              | 32        | 2.7      |
| 180426-7-30 | 0.57 | 0.097                            | 0.004     | 0.0144                           | 0.0002    | 0.0487                            | 0.0020    | 94.3  | 3.5       | 91.9  | 1.3       | 193                              | 40        | 2.6      |
| 180426-7-5  | 0.49 | 0.097                            | 0.005     | 0.0144                           | 0.0002    | 0.0484                            | 0.0021    | 93.9  | 4.2       | 92  | 1.3       | 337                              | 50        | 3.9      |

**Appendix 13.** U-Pb ratio of Jandong Fm. (Center area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|--------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-7-91  | 0.52 | 0.099                            | 0.008     | 0.0144                           | 0.0003    | 0.0499                            | 0.0037    | 96.2  | 7         | 92  | 1.7       | 441                              | 57        | 4.9      |
| 180426-7-44  | 0.48 | 0.095                            | 0.005     | 0.0144                           | 0.0002    | 0.0488                            | 0.0026    | 92.4  | 4.5       | 92.2  | 1.5       | 218                              | 44        | 6.3      |
| 180426-7-96  | 0.66 | 0.105                            | 0.011     | 0.0144                           | 0.0004    | 0.0526                            | 0.0054    | 101.4                                       | 9.8       | 92.4  | 2.4       | 535                              | 84        | 3.5      |
| 180426-7-4   | 0.48 | 0.098                            | 0.004     | 0.0145                           | 0.0002    | 0.0490                            | 0.0021    | 94.4  | 4         | 92.5  | 1.1       | 263                              | 41        | 3.5      |
| 180426-7-55  | 0.63 | 0.178                            | 0.009     | 0.0145                           | 0.0002    | 0.0841                            | 0.0041    | 165.6                                       | 7.3       | 92.6  | 1.5       | 1290                             | 48        | -69.3    |
| 180426-7-97  | 0.58 | 0.100                            | 0.007     | 0.0145                           | 0.0002    | 0.0501                            | 0.0033    | 96.7  | 6.1       | 92.9  | 1.3       | 449                              | 67        | 3.9      |
| 180426-7-28  | 1.71 | 0.102                            | 0.007     | 0.0146                           | 0.0002    | 0.0486                            | 0.0037    | 98.3  | 6.7       | 93.7  | 1.5       | 272                              | 74        | 3.8      |
| 180426-7-29  | 0.58 | 0.102                            | 0.007     | 0.0147                           | 0.0003    | 0.0522                            | 0.0035    | 98.4  | 6.6       | 93.9  | 2.1       | 311                              | 64        | 4.5      |
| 180426-7-27  | 2.91 | 0.097                            | 0.005     | 0.0147                           | 0.0003    | 0.0470                            | 0.0022    | 94.3  | 4.5       | 94.1  | 1.6       | 194                              | 49        | 6.3      |
| 180426-7-26  | 0.70 | 0.117                            | 0.004     | 0.0150                           | 0.0002    | 0.0554                            | 0.0022    | 112.2                                       | 3.7       | 96.1  | 1.5       | 453                              | 45        | -11.3    |
| 180426-7-59  | 0.44 | 0.190                            | 0.007     | 0.0281                           | 0.0004    | 0.0495                            | 0.0016    | 176.5                                       | 5.8       | 178.4                                       | 2.3       | 274                              | 34        | 5.6      |
| 180426-7-56  | 0.45 | 0.195                            | 0.007     | 0.0281                           | 0.0003    | 0.0499                            | 0.0016    | 181   | 5.5       | 178.9                                       | 1.9       | 286                              | 32        | 3.0      |
| 180426-7-72  | 0.36 | 0.204                            | 0.010     | 0.0289                           | 0.0005    | 0.0510                            | 0.0027    | 188.7                                       | 8.7       | 183.8                                       | 3.1       | 318                              | 43        | 3.8      |
| 180426-7-35  | 0.33 | 0.254                            | 0.006     | 0.0290                           | 0.0004    | 0.0626                            | 0.0015    | 229.4                                       | 4.9       | 184.3                                       | 2.3       | 675                              | 31        | -20.6    |
| 180426-7-13  | 0.42 | 0.202                            | 0.004     | 0.0292                           | 0.0003    | 0.0501                            | 0.0010    | 186.7                                       | 3.6       | 185.7                                       | 1.6       | 229                              | 23        | 2.3      |
| 180426-7-74  | 0.65 | 0.210                            | 0.012     | 0.0293                           | 0.0006    | 0.0510                            | 0.0024    | 193   | 10        | 186.2                                       | 3.8       | 244                              | 45        | 3.8      |
| 180426-7-100 | 0.54 | 0.199                            | 0.004     | 0.0293                           | 0.0004    | 0.0497                            | 0.0010    | 184.6                                       | 3.8       | 186.3                                       | 2.2       | 233                              | 25        | 4.1      |
| 180426-7-7   | 0.41 | 0.202                            | 0.003     | 0.0293                           | 0.0003    | 0.0498                            | 0.0004    | 186.3                                       | 2.1       | 186.4                                       | 1.7       | 184.9                            | 9.8       | 2.1      |
| 180426-7-70  | 0.59 | 0.207                            | 0.010     | 0.0294                           | 0.0005    | 0.0515                            | 0.0021    | 190   | 8.1       | 186.5                                       | 3         | 387                              | 45        | 4.1      |
| 180426-7-15  | 0.38 | 0.205                            | 0.003     | 0.0294                           | 0.0002    | 0.0507                            | 0.0006    | 189.8                                       | 2.5       | 186.8                                       | 1.5       | 236                              | 19        | 0.5      |

**Appendix 13.** U-Pb ratio of Jandong Fm. (Center area) of the Neungju Basin, arranged by chronological order

| sample name | Th/U | $^{207}\text{Pb}/^{235}\text{U}$ | $2\sigma$ | $^{206}\text{Pb}/^{238}\text{U}$ | $2\sigma$ | $^{207}\text{Pb}/^{206}\text{Pb}$ | $2\sigma$ | $^{235}\text{U}-^{207}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{238}\text{U}-^{206}\text{Pb}$<br>age(Ma) | $2\sigma$ | $^{207/206}\text{Pb}$<br>age(Ma) | $2\sigma$ | disc.(%) |
|-------------|------|----------------------------------|-----------|----------------------------------|-----------|-----------------------------------|-----------|---|-----------|---|-----------|----------------------------------|-----------|----------|
| 180426-7-38 | 1.13 | 0.202                            | 0.003     | 0.0294                           | 0.0002    | 0.0499                            | 0.0005    | 186.9                                       | 2.2       | 186.8                                       | 1.4       | 190                              | 12        | 1.9      |
| 180426-7-85 | 0.39 | 0.206                            | 0.007     | 0.0294                           | 0.0004    | 0.0505                            | 0.0014    | 189.6                                       | 5.7       | 186.9                                       | 2.2       | 261                              | 34        | 2.8      |
| 180426-7-89 | 0.53 | 0.204                            | 0.002     | 0.0294                           | 0.0002    | 0.0503                            | 0.0007    | 188.4                                       | 2.1       | 186.99                                      | 0.97      | 212                              | 15        | 0.9      |
| 180426-7-1  | 0.89 | 0.200                            | 0.002     | 0.0294                           | 0.0002    | 0.0499                            | 0.0002    | 185.1                                       | 1.3       | 187   | 1.2       | 196.8                            | 6.9       | 2.4      |
| 180426-7-2  | 0.46 | 0.203                            | 0.005     | 0.0294                           | 0.0002    | 0.0504                            | 0.0010    | 187.2                                       | 3.9       | 187   | 1.3       | 241                              | 27        | 2.7      |
| 180426-7-94 | 0.58 | 0.203                            | 0.005     | 0.0295                           | 0.0004    | 0.0497                            | 0.0009    | 187.5                                       | 3.8       | 187.1                                       | 2.2       | 211                              | 24        | 3.0      |
| 180426-7-95 | 0.50 | 0.201                            | 0.005     | 0.0295                           | 0.0004    | 0.0492                            | 0.0011    | 186.1                                       | 4         | 187.2                                       | 2.2       | 176                              | 22        | 3.9      |
| 180426-7-21 | 0.34 | 0.202                            | 0.004     | 0.0295                           | 0.0003    | 0.0502                            | 0.0009    | 187   | 3.3       | 187.3                                       | 1.7       | 213                              | 21        | 2.8      |
| 180426-7-93 | 0.39 | 0.210                            | 0.010     | 0.0296                           | 0.0005    | 0.0514                            | 0.0023    | 194.7                                       | 8.2       | 187.9                                       | 2.8       | 366                              | 43        | 2.2      |
| 180426-7-32 | 0.21 | 0.206                            | 0.004     | 0.0298                           | 0.0003    | 0.0499                            | 0.0009    | 190.2                                       | 3.5       | 189.1                                       | 1.7       | 200                              | 22        | 2.2      |
| 180426-7-52 | 0.62 | 0.211                            | 0.010     | 0.0299                           | 0.0006    | 0.0492                            | 0.0027    | 194.1                                       | 8.2       | 189.6                                       | 3.8       | 228                              | 55        | 4.0      |
| 180426-7-10 | 0.47 | 0.208                            | 0.003     | 0.0301                           | 0.0003    | 0.0504                            | 0.0004    | 191.8                                       | 2.7       | 190.8                                       | 1.8       | 209                              | 11        | 1.8      |
| 180426-7-31 | 0.36 | 0.206                            | 0.004     | 0.0300                           | 0.0003    | 0.0495                            | 0.0009    | 189.7                                       | 3.1       | 190.8                                       | 2.1       | 191                              | 23        | 3.3      |
| 180426-7-25 | 0.67 | 0.203                            | 0.008     | 0.0301                           | 0.0004    | 0.0492                            | 0.0014    | 187.7                                       | 6.4       | 191.3                                       | 2.6       | 162                              | 45        | 6.6      |
| 180426-7-39 | 0.36 | 0.380                            | 0.015     | 0.0317                           | 0.0006    | 0.0876                            | 0.0032    | 326   | 11        | 201.1                                       | 3.7       | 1371                             | 50        | -54.8    |
| 180426-7-62 | 0.19 | 2.739                            | 0.050     | 0.1799                           | 0.0029    | 0.1105                            | 0.0005    | 1338  | 13        | 1066  | 16        | 1804.5                           | 5.8       | -22.8    |
| 180426-7-3  | 0.11 | 4.385                            | 0.045     | 0.2748                           | 0.0024    | 0.1161                            | 0.0003    | 1709.8                                      | 8.5       | 1567  | 12        | 1898.4                           | 4         | -7.8     |
| 180426-7-77 | 0.43 | 5.433                            | 0.089     | 0.3401                           | 0.0050    | 0.1146                            | 0.0008    | 1889  | 14        | 1886  | 24        | 1883                             | 5.6       | 1.9      |
| 180426-7-87 | 0.51 | 7.970                            | 0.200     | 0.3817                           | 0.0073    | 0.1514                            | 0.0014    | 2230  | 23        | 2082  | 34        | 2364                             | 12        | -4.4     |
| 180426-7-69 | 1.25 | 7.450                            | 0.280     | 0.3900                           | 0.0120    | 0.1530                            | 0.0260    | 2182  | 49        | 2119  | 55        | 2215                             | 12        | 1.9      |

**Appendix 14.** U-Pb ratio of Jandong Fm. (North area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/<br>U | <sup>207</sup> Pb/ <sup>235</sup> U | 2σ    | <sup>206</sup> Pb/ <sup>238</sup> U | 2σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | 2σ     | <sup>235</sup> U- <sup>207</sup> Pb<br>age(Ma) | 2σ  | <sup>238</sup> U- <sup>206</sup> Pb<br>age(Ma) | 2σ   | <sup>207</sup> / <sup>206</sup> Pb<br>age(Ma) | 2σ  | disc.(%) |
|--------------|----------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|--------|--|-----|--|------|---|-----|----------|
| 180426-12-14 | 0.79     | 0.090                               | 0.001 | 0.0138                              | 0.0001 | 0.0481                               | 0.0005 | 87.8   | 1.1 | 88.06  | 0.43 | 100   | 11  | 2.0      |
| 180426-12-83 | 1.35     | 0.092                               | 0.012 | 0.0138                              | 0.0005 | 0.0483                               | 0.0059 | 91   | 10  | 88.3   | 3.2  | 561   | 94  | 11.9     |
| 180426-12-1  | 1.00     | 0.092                               | 0.004 | 0.0139                              | 0.0002 | 0.0479                               | 0.0020 | 89.4   | 3.5 | 88.9   | 1.1  | 211   | 43  | 4.6      |
| 180426-12-51 | 2.11     | 0.089                               | 0.010 | 0.0141                              | 0.0003 | 0.0433                               | 0.0050 | 85.4   | 9.3 | 90.4   | 2    | 552   | 94  | 18.0     |
| 180426-12-98 | 1.18     | 0.093                               | 0.004 | 0.0142                              | 0.0004 | 0.0479                               | 0.0018 | 89.9   | 3.8 | 90.7   | 2.2  | 254   | 40  | 7.5      |
| 180426-12-78 | 1.09     | 0.098                               | 0.006 | 0.0142                              | 0.0004 | 0.0500                               | 0.0027 | 94.8   | 5.7 | 91   | 2.5  | 401   | 53  | 4.8      |
| 180426-12-80 | 0.79     | 0.094                               | 0.008 | 0.0144                              | 0.0004 | 0.0463                               | 0.0039 | 91.3   | 7.7 | 91.9   | 2.7  | 147   | 84  | 12.0     |
| 180426-12-93 | 0.66     | 0.098                               | 0.007 | 0.0144                              | 0.0006 | 0.0504                               | 0.0023 | 95.4   | 6.1 | 92.1   | 4.1  | 290   | 44  | 7.5      |
| 180426-12-86 | 1.33     | 0.095                               | 0.005 | 0.0145                              | 0.0004 | 0.0472                               | 0.0018 | 91.7   | 4.3 | 93   | 2.4  | 216   | 31  | 8.6      |
| 180426-12-42 | 1.41     | 0.097                               | 0.005 | 0.0146                              | 0.0003 | 0.0479                               | 0.0023 | 93.4   | 4.5 | 93.3   | 1.6  | 339   | 58  | 6.4      |
| 180426-12-33 | 0.81     | 0.098                               | 0.003 | 0.0146                              | 0.0002 | 0.0480                               | 0.0013 | 94.8   | 2.6 | 93.4   | 1.1  | 171   | 26  | 2.5      |
| 180426-12-45 | 0.91     | 0.096                               | 0.003 | 0.0146                              | 0.0002 | 0.0477                               | 0.0014 | 92.7   | 3.1 | 93.6   | 1.3  | 164   | 26  | 5.7      |
| 180426-12-48 | 0.88     | 0.097                               | 0.003 | 0.0146                              | 0.0002 | 0.0483                               | 0.0011 | 93.6   | 2.4 | 93.7   | 1.2  | 125   | 23  | 3.9      |
| 180426-12-81 | 1.58     | 0.096                               | 0.007 | 0.0146                              | 0.0005 | 0.0474                               | 0.0031 | 92.4   | 6.1 | 93.7   | 2.9  | 383   | 52  | 11.0     |
| 180426-12-87 | 0.72     | 0.096                               | 0.004 | 0.0147                              | 0.0004 | 0.0483                               | 0.0014 | 92.7   | 3.5 | 93.7   | 2.5  | 220   | 32  | 7.5      |
| 180426-12-29 | 0.61     | 0.097                               | 0.002 | 0.0147                              | 0.0001 | 0.0480                               | 0.0011 | 93.8   | 2.1 | 93.97  | 0.67 | 128   | 25  | 3.1      |
| 180426-12-79 | 0.94     | 0.102                               | 0.007 | 0.0148                              | 0.0007 | 0.0493                               | 0.0025 | 98.3   | 6.5 | 94.6   | 4.5  | 362   | 73  | 7.7      |
| 180426-12-70 | 1.15     | 0.097                               | 0.017 | 0.0151                              | 0.0004 | 0.0429                               | 0.0069 | 93   | 15  | 96.5   | 2.6  | 470   | 110 | 21.9     |
| 180426-12-6  | 0.45     | 0.177                               | 0.006 | 0.0254                              | 0.0003 | 0.0513                               | 0.0018 | 166  | 5.2 | 161.8  | 1.7  | 250   | 39  | 1.7      |
| 180426-12-95 | 0.67     | 0.182                               | 0.011 | 0.0268                              | 0.0015 | 0.0504                               | 0.0011 | 169.8  | 9.1 | 170.2  | 9.3  | 213   | 27  | 11.0     |



Appendix 14. U-Pb ratio of Jandong Fm. (North area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/<br>U | <sup>207</sup> Pb/ <sup>235</sup> U | 2σ    | <sup>206</sup> Pb/ <sup>238</sup> U | 2σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | 2σ     | <sup>235</sup> U- <sup>207</sup> Pb<br>age(Ma) | 2σ  | <sup>238</sup> U- <sup>206</sup> Pb<br>age(Ma) | 2σ  | <sup>207/206</sup> Pb<br>age(Ma) | 2σ | disc.(%) |
|--------------|----------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|--------|--|-----|--|-----|----------------------------------|----|----------|
| 180426-12-92 | 0.38     | 0.187                               | 0.006 | 0.0270                              | 0.0008 | 0.0508                               | 0.0013 | 173.8  | 5.4 | 171.4  | 5.1 | 251                              | 32 | 4.7      |
| 180426-12-99 | 0.42     | 0.188                               | 0.007 | 0.0272                              | 0.0008 | 0.0495                               | 0.0010 | 174.8  | 6.1 | 172.9  | 5   | 202                              | 33 | 5.3      |
| 180426-12-66 | 0.38     | 0.191                               | 0.005 | 0.0278                              | 0.0006 | 0.0498                               | 0.0007 | 177.1  | 3.9 | 176.8  | 3.9 | 197                              | 19 | 4.2      |
| 180426-12-84 | 0.35     | 0.192                               | 0.005 | 0.0281                              | 0.0006 | 0.0501                               | 0.0005 | 178.1  | 4   | 178.8  | 3.7 | 190                              | 15 | 4.7      |
| 180426-12-89 | 0.36     | 0.193                               | 0.006 | 0.0281                              | 0.0006 | 0.0492                               | 0.0007 | 178.8  | 4.6 | 178.8  | 3.6 | 167                              | 18 | 4.6      |
| 180426-12-90 | 0.30     | 0.194                               | 0.008 | 0.0281                              | 0.0010 | 0.0500                               | 0.0008 | 180.4  | 6.9 | 178.8  | 6   | 187                              | 23 | 6.3      |
| 180426-12-91 | 0.32     | 0.195                               | 0.007 | 0.0282                              | 0.0009 | 0.0503                               | 0.0007 | 180.6  | 5.7 | 179  | 5.9 | 207                              | 19 | 5.6      |
| 180426-12-94 | 0.37     | 0.194                               | 0.005 | 0.0282                              | 0.0006 | 0.0498                               | 0.0006 | 180.2  | 4.3 | 179  | 3.9 | 195                              | 17 | 3.9      |
| 180426-12-8  | 0.43     | 0.196                               | 0.006 | 0.0282                              | 0.0002 | 0.0489                               | 0.0014 | 182.1  | 4.7 | 179.1  | 1.5 | 159                              | 33 | 1.8      |
| 180426-12-7  | 0.38     | 0.193                               | 0.006 | 0.0282                              | 0.0003 | 0.0511                               | 0.0013 | 179.4  | 5.1 | 179.2  | 1.7 | 220                              | 29 | 3.7      |
| 180426-12-31 | 0.31     | 0.194                               | 0.003 | 0.0283                              | 0.0003 | 0.0497                               | 0.0006 | 179.8  | 2.7 | 179.8  | 1.7 | 190                              | 17 | 2.4      |
| 180426-12-18 | 0.37     | 0.195                               | 0.005 | 0.0283                              | 0.0004 | 0.0493                               | 0.0006 | 180.5  | 4.1 | 179.9  | 2.5 | 169                              | 17 | 3.3      |
| 180426-12-52 | 0.47     | 0.197                               | 0.008 | 0.0283                              | 0.0005 | 0.0505                               | 0.0017 | 184.2  | 5.9 | 180.1  | 3.2 | 240                              | 57 | 2.8      |
| 180426-12-24 | 0.41     | 0.194                               | 0.008 | 0.0283                              | 0.0009 | 0.0503                               | 0.0014 | 179.9  | 6.6 | 180.2  | 5.7 | 212                              | 27 | 7.0      |
| 180426-12-57 | 0.28     | 0.194                               | 0.007 | 0.0284                              | 0.0009 | 0.0493                               | 0.0005 | 179.9  | 5.6 | 180.2  | 5.5 | 164                              | 15 | 6.3      |
| 180426-12-23 | 0.39     | 0.195                               | 0.006 | 0.0284                              | 0.0006 | 0.0497                               | 0.0008 | 181.1  | 5.2 | 180.8  | 3.6 | 199                              | 27 | 4.7      |
| 180426-12-47 | 0.44     | 0.194                               | 0.004 | 0.0284                              | 0.0004 | 0.0498                               | 0.0005 | 180.2  | 3.7 | 180.8  | 2.7 | 195                              | 11 | 3.9      |
| 180426-12-71 | 0.38     | 0.196                               | 0.004 | 0.0285                              | 0.0004 | 0.0499                               | 0.0006 | 181.4  | 3   | 180.8  | 2.7 | 185                              | 15 | 2.8      |
| 180426-12-32 | 0.20     | 0.197                               | 0.005 | 0.0285                              | 0.0003 | 0.0506                               | 0.0011 | 182.9  | 3.9 | 180.9  | 2   | 246                              | 26 | 2.2      |
| 180426-12-11 | 0.40     | 0.198                               | 0.004 | 0.0285                              | 0.0003 | 0.0498                               | 0.0009 | 183.1  | 3.1 | 181.2  | 1.8 | 177                              | 23 | 1.7      |

Appendix 14. U-Pb ratio of Jandong Fm. (North area) of the Neungju Basin, arranged by chronological order

| sample name   | Th/<br>U | <sup>207</sup> Pb/ <sup>235</sup> U | 2σ    | <sup>206</sup> Pb/ <sup>238</sup> U | 2σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | 2σ     | <sup>235</sup> U- <sup>207</sup> Pb<br>age(Ma) | 2σ  | <sup>238</sup> U- <sup>206</sup> Pb<br>age(Ma) | 2σ  | <sup>207/206</sup> Pb<br>age(Ma) | 2σ  | disc.(%) |
|---------------|----------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|--------|--|-----|--|-----|----------------------------------|-----|----------|
| 180426-12-49  | 0.51     | 0.191                               | 0.009 | 0.0285                              | 0.0005 | 0.0484                               | 0.0020 | 176.6  | 7.7 | 181.3  | 3.1 | 263                              | 50  | 8.5      |
| 180426-12-55  | 0.35     | 0.197                               | 0.006 | 0.0285                              | 0.0006 | 0.0500                               | 0.0010 | 182.3  | 4.8 | 181.4  | 3.7 | 193                              | 24  | 4.2      |
| 180426-12-40  | 0.35     | 0.196                               | 0.005 | 0.0286                              | 0.0004 | 0.0492                               | 0.0008 | 181.6  | 4   | 181.7  | 2.3 | 181                              | 22  | 3.5      |
| 180426-12-60  | 0.39     | 0.197                               | 0.005 | 0.0286                              | 0.0005 | 0.0499                               | 0.0007 | 182.1  | 4.2 | 181.7  | 2.9 | 205                              | 20  | 3.7      |
| 180426-12-82  | 0.22     | 0.197                               | 0.006 | 0.0286                              | 0.0007 | 0.0505                               | 0.0010 | 183.2  | 5.3 | 181.7  | 4.1 | 212                              | 24  | 4.3      |
| 180426-12-28  | 0.36     | 0.198                               | 0.006 | 0.0286                              | 0.0003 | 0.0503                               | 0.0013 | 184.1  | 5.1 | 182  | 2   | 227                              | 35  | 2.7      |
| 180426-12-64  | 0.76     | 0.198                               | 0.007 | 0.0286                              | 0.0007 | 0.0503                               | 0.0012 | 184.4  | 5.7 | 182.5  | 4.4 | 226                              | 26  | 4.5      |
| 180426-12-56  | 0.28     | 0.200                               | 0.004 | 0.0292                              | 0.0004 | 0.0494                               | 0.0007 | 184.7  | 3.5 | 185.8  | 2.7 | 168                              | 17  | 3.9      |
| 180426-12-63  | 0.38     | 0.315                               | 0.028 | 0.0301                              | 0.0006 | 0.0759                               | 0.0057 | 277  | 21  | 191  | 4   | 1090                             | 120 | -31.9    |
| 180426-12-77  | 0.21     | 0.242                               | 0.042 | 0.0314                              | 0.0063 | 0.0558                               | 0.0080 | 220  | 35  | 199  | 40  | 500                              | 340 | 27.1     |
| 180426-12-34  | 0.29     | 5.063                               | 0.075 | 0.3021                              | 0.0040 | 0.1226                               | 0.0007 | 1829   | 12  | 1701   | 20  | 1997.8                           | 6.8 | -5.6     |
| 180426-12-16  | 0.21     | 5.741                               | 0.031 | 0.3275                              | 0.0016 | 0.1246                               | 0.0004 | 1937.4   | 4.7 | 1826.2   | 7.8 | 2024.2                           | 4.1 | -5.4     |
| 180426-12-100 | 0.25     | 5.350                               | 0.180 | 0.3380                              | 0.0110 | 0.1155                               | 0.0004 | 1878   | 28  | 1872   | 51  | 1886                             | 3.4 | 3.9      |
| 180426-12-12  | 0.11     | 5.460                               | 0.160 | 0.3394                              | 0.0097 | 0.1156                               | 0.0010 | 1893   | 25  | 1883   | 46  | 1899                             | 10  | 3.2      |
| 180426-12-3   | 0.12     | 5.610                               | 0.110 | 0.3453                              | 0.0061 | 0.1189                               | 0.0005 | 1916   | 17  | 1911   | 29  | 1940.5                           | 3.1 | 2.1      |
| 180426-12-54  | 0.11     | 5.760                               | 0.160 | 0.3494                              | 0.0094 | 0.1192                               | 0.0003 | 1937   | 23  | 1930   | 45  | 1945.8                           | 2.4 | 3.2      |
| 180426-12-19  | 0.34     | 5.960                               | 0.140 | 0.3555                              | 0.0076 | 0.1228                               | 0.0011 | 1969   | 20  | 1960   | 36  | 1999                             | 11  | 2.4      |
| 180426-12-65  | 0.34     | 5.970                               | 0.130 | 0.3556                              | 0.0080 | 0.1222                               | 0.0006 | 1974   | 19  | 1961   | 38  | 1987.1                           | 4.4 | 2.2      |
| 180426-12-85  | 0.62     | 6.080                               | 0.240 | 0.3570                              | 0.0140 | 0.1234                               | 0.0005 | 1987   | 32  | 1961   | 66  | 2004.5                           | 4.7 | 3.7      |
| 180426-12-74  | 0.39     | 6.000                               | 0.160 | 0.3568                              | 0.0090 | 0.1223                               | 0.0004 | 1977   | 23  | 1964   | 43  | 1991.2                           | 2.9 | 2.7      |

**Appendix 14.** U-Pb ratio of Jandong Fm. (North area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/<br>U | <sup>207</sup> Pb/ <sup>235</sup> U | 2σ    | <sup>206</sup> Pb/ <sup>238</sup> U | 2σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | 2σ     | <sup>235</sup> U- <sup>207</sup> Pb<br>age(Ma) | 2σ  | <sup>238</sup> U- <sup>206</sup> Pb<br>age(Ma) | 2σ | <sup>207</sup> / <sup>206</sup> Pb<br>age(Ma) | 2σ  | disc.(%) |
|--------------|----------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|--------|--|-----|--|----|---|-----|----------|
| 180426-12-75 | 0.33     | 6.000                               | 0.140 | 0.3574                              | 0.0083 | 0.1224                               | 0.0003 | 1980   | 20  | 1966   | 39 | 1989.1  | 2.6 | 2.3      |
| 180426-12-4  | 0.25     | 5.915                               | 0.033 | 0.3569                              | 0.0027 | 0.1226                               | 0.0005 | 1963.5   | 4.8 | 1968   | 13 | 1992  | 4   | 1.1      |
| 180426-12-67 | 0.21     | 6.070                               | 0.160 | 0.3581                              | 0.0099 | 0.1228                               | 0.0004 | 1992   | 23  | 1971   | 47 | 1996.7  | 3.3 | 2.5      |
| 180426-12-15 | 0.16     | 6.170                               | 0.120 | 0.3580                              | 0.0025 | 0.1219                               | 0.0023 | 2000   | 16  | 1973   | 12 | 1982  | 15  | 0.1      |
| 180426-12-53 | 0.26     | 6.050                               | 0.230 | 0.3590                              | 0.0140 | 0.1234                               | 0.0007 | 1985   | 36  | 1973   | 67 | 2009.8  | 5.2 | 4.6      |
| 180426-12-37 | 0.34     | 6.003                               | 0.087 | 0.3587                              | 0.0046 | 0.1225                               | 0.0003 | 1975   | 12  | 1975   | 22 | 1994.1  | 2.8 | 1.7      |
| 180426-12-72 | 0.19     | 6.090                               | 0.160 | 0.3596                              | 0.0097 | 0.1223                               | 0.0002 | 1980   | 23  | 1975   | 46 | 1990.7  | 2.1 | 3.2      |
| 180426-12-88 | 0.21     | 6.100                               | 0.220 | 0.3600                              | 0.0130 | 0.1227                               | 0.0003 | 1985   | 33  | 1975   | 61 | 1996.1  | 2.9 | 4.3      |
| 180426-12-26 | 0.41     | 6.090                               | 0.110 | 0.3596                              | 0.0049 | 0.1230                               | 0.0004 | 1991   | 16  | 1980   | 23 | 2000.8  | 2.8 | 1.4      |
| 180426-12-27 | 0.31     | 6.060                               | 0.100 | 0.3597                              | 0.0045 | 0.1228                               | 0.0006 | 1983   | 14  | 1980   | 21 | 1998.7  | 4.3 | 1.6      |
| 180426-12-20 | 0.24     | 6.070                               | 0.130 | 0.3598                              | 0.0066 | 0.1226                               | 0.0005 | 1990   | 20  | 1981   | 31 | 1993.7  | 4.2 | 2.1      |
| 180426-12-68 | 0.18     | 6.072                               | 0.092 | 0.3601                              | 0.0055 | 0.1219                               | 0.0004 | 1987   | 13  | 1981   | 26 | 1985.4  | 3.3 | 1.7      |
| 180426-12-58 | 0.26     | 6.140                               | 0.160 | 0.3600                              | 0.0110 | 0.1233                               | 0.0004 | 2000   | 25  | 1982   | 50 | 2006.3  | 2.8 | 2.9      |
| 180426-12-96 | 0.62     | 6.110                               | 0.230 | 0.3610                              | 0.0130 | 0.1233                               | 0.0004 | 1993   | 30  | 1983   | 60 | 2004.4  | 2.7 | 4.0      |
| 180426-12-30 | 0.09     | 6.097                               | 0.083 | 0.3612                              | 0.0041 | 0.1228                               | 0.0003 | 1989   | 12  | 1987   | 19 | 1997.6  | 2.9 | 1.5      |
| 180426-12-73 | 0.31     | 6.090                               | 0.180 | 0.3610                              | 0.0110 | 0.1219                               | 0.0003 | 1991   | 26  | 1987   | 49 | 1985.5  | 3.1 | 3.6      |
| 180426-12-36 | 0.83     | 6.122                               | 0.086 | 0.3620                              | 0.0044 | 0.1233                               | 0.0003 | 1992   | 12  | 1991   | 21 | 2004.1  | 2.8 | 1.6      |
| 180426-12-44 | 0.32     | 6.130                               | 0.110 | 0.3625                              | 0.0046 | 0.1231                               | 0.0004 | 1993   | 15  | 1993   | 22 | 2003.6  | 3   | 1.9      |
| 180426-12-25 | 0.30     | 6.160                               | 0.150 | 0.3625                              | 0.0084 | 0.1233                               | 0.0008 | 1998   | 21  | 1994   | 40 | 2003.6  | 7.4 | 2.9      |
| 180426-12-59 | 0.35     | 6.130                               | 0.110 | 0.3630                              | 0.0064 | 0.1226                               | 0.0004 | 1995   | 15  | 1995   | 30 | 1995.5  | 3.6 | 2.3      |

**Appendix 14.** U-Pb ratio of Jandong Fm. (North area) of the Neungju Basin, arranged by chronological order

| sample name  | Th/<br>U | <sup>207</sup> Pb/ <sup>235</sup> U | 2σ    | <sup>206</sup> Pb/ <sup>238</sup> U | 2σ     | <sup>207</sup> Pb/ <sup>206</sup> Pb | 2σ     | <sup>235</sup> U- <sup>207</sup> Pb<br>age(Ma) | 2σ | <sup>238</sup> U- <sup>206</sup> Pb<br>age(Ma) | 2σ | <sup>207</sup> / <sup>206</sup> Pb<br>age(Ma) | 2σ  | disc.(%) |
|--------------|----------|-------------------------------------|-------|-------------------------------------|--------|--------------------------------------|--------|--|----|--|----|---|-----|----------|
| 180426-12-35 | 0.06     | 6.160                               | 0.250 | 0.3635                              | 0.0094 | 0.1172                               | 0.0003 | 1995   | 36 | 1998   | 45 | 1913.1  | 3.3 | 4.2      |
| 180426-12-38 | 0.25     | 6.140                               | 0.110 | 0.3634                              | 0.0044 | 0.1227                               | 0.0004 | 1994   | 15 | 1998   | 21 | 1993  | 3.1 | 2.0      |
| 180426-12-46 | 0.47     | 6.210                               | 0.260 | 0.3640                              | 0.0110 | 0.1219                               | 0.0011 | 2005   | 35 | 2001   | 52 | 1986  | 11  | 4.1      |
| 180426-12-10 | 0.20     | 6.810                               | 0.140 | 0.3645                              | 0.0047 | 0.1227                               | 0.0012 | 2087   | 18 | 2003   | 22 | 1993.3  | 4.5 | -2.2     |
| 180426-12-69 | 0.42     | 6.160                               | 0.100 | 0.3641                              | 0.0058 | 0.1220                               | 0.0004 | 1998   | 14 | 2003   | 27 | 1987  | 3.4 | 2.3      |
| 180426-12-62 | 0.36     | 6.200                               | 0.094 | 0.3649                              | 0.0060 | 0.1228                               | 0.0006 | 2004   | 13 | 2005   | 28 | 1998.6  | 5   | 2.1      |
| 180426-12-76 | 0.30     | 6.170                               | 0.150 | 0.3657                              | 0.0089 | 0.1225                               | 0.0004 | 1999   | 22 | 2005   | 42 | 1995.1  | 3.1 | 3.5      |
| 180426-12-5  | 0.22     | 6.210                               | 0.120 | 0.3651                              | 0.0050 | 0.1225                               | 0.0007 | 2004   | 16 | 2006   | 23 | 1989.8  | 5.4 | 2.0      |
| 180426-12-43 | 0.20     | 6.249                               | 0.078 | 0.3654                              | 0.0035 | 0.1242                               | 0.0003 | 2010   | 11 | 2007   | 16 | 2017.5  | 2.7 | 1.2      |
| 180426-12-97 | 0.90     | 6.250                               | 0.260 | 0.3660                              | 0.0150 | 0.1237                               | 0.0009 | 2011   | 38 | 2008   | 69 | 2006.3  | 5.8 | 5.2      |
| 180426-12-2  | 0.18     | 6.270                               | 0.130 | 0.3660                              | 0.0071 | 0.1235                               | 0.0007 | 2014   | 19 | 2010   | 33 | 2004.3  | 6.7 | 2.4      |
| 180426-12-61 | 0.03     | 6.610                               | 0.130 | 0.3667                              | 0.0081 | 0.1293                               | 0.0004 | 2063   | 18 | 2013   | 38 | 2089.7  | 3.1 | 0.3      |
| 180426-12-9  | 0.15     | 6.300                               | 0.100 | 0.3671                              | 0.0038 | 0.1234                               | 0.0003 | 2017   | 14 | 2015   | 18 | 2005.9  | 3   | 1.5      |
| 180426-12-17 | 0.17     | 6.330                               | 0.190 | 0.3675                              | 0.0091 | 0.1232                               | 0.0008 | 2021   | 26 | 2017   | 43 | 1999.7  | 6.9 | 3.2      |
| 180426-12-21 | 0.25     | 6.380                               | 0.230 | 0.3700                              | 0.0100 | 0.1237                               | 0.0009 | 2027   | 32 | 2027   | 47 | 2007.3  | 7.4 | 3.9      |
| 180426-12-39 | 0.23     | 6.630                               | 0.120 | 0.3770                              | 0.0052 | 0.1280                               | 0.0005 | 2061   | 15 | 2061   | 24 | 2072.7  | 4   | 1.9      |
| 180426-12-41 | 0.30     | 7.450                               | 0.300 | 0.3980                              | 0.0140 | 0.1236                               | 0.0007 | 2165   | 36 | 2159   | 63 | 2016.5  | 8.6 | 4.3      |
| 180426-12-22 | 0.26     | 7.730                               | 0.260 | 0.4021                              | 0.0060 | 0.1235                               | 0.0015 | 2199   | 31 | 2178   | 27 | 2007  | 13  | 1.7      |
| 180426-12-13 | 0.30     | 7.600                               | 0.260 | 0.4024                              | 0.0086 | 0.1230                               | 0.0020 | 2185   | 30 | 2180   | 39 | 2001  | 19  | 2.9      |
| 180426-12-50 | 0.75     | 12.740                              | 0.190 | 0.5109                              | 0.0058 | 0.1812                               | 0.0007 | 2659   | 14 | 2660   | 25 | 2662.6  | 3.7 | 1.5      |