Human Palaeontology and Prehistory

Preliminary dating of the Mansu-Ri and Wondang-Jangnamgyo Early Paleolithic sites

Datations préliminaires des sites du Paléolithique ancien de Mansu-Ri et Wondang-Jangnamgyo

Anne-Elisabeth Lebatard a,*, Didier L. Bourlès a, Samir Khatib b, Thibaud Saos c, Pierre Rochette a, Régis Braucher a, Kidong Bae d

a Aix-Marseille Université, CNRS-IRD UMR34 CEREGE, Technopôle de l'environnement Arbois-Méditerranée, BP 80, 13545 Aix-en-Provence cedex 4, France
b Laboratoire de préhistoire Nice Côte d'Azur, 15, boulevard Maurice-Maeterlinck, 06300 Nice, France
c Université de Perpignan Via Domitia, UMR-CNRS 7194, EPCC Centre européen de recherches préhistoriques, avenue Léon-Grégory, 66720 Tautavel, France
d Institute of Cultural Properties, Hanyang University, Sa 1-dong, Ansan-si, 425-791, Gyeonggi-do, South Korea

A R T I C L E  I N F O

Article history:
Received 14 September 2015
Accepted after revision 18 April 2016
Available online 11 June 2016
Handled by Amélie Vialet

Keywords:
Early Paleolithic
South Korea
Cosmogenic nuclides
Burial ages

A B S T R A C T

The lack of carbonates and fossils in Early Paleolithic open air river terrace sites in Korea makes chronological assessment difficult. Nevertheless, a paleomagnetic study of the thickest section (about 9 m) at Mansu-Ri (Locality IV) revealed only normal polarity, indicating an age younger than 0.78 Ma all along the section. In Mansu-Ri (Loc. IV), measurements of the in situ-produced 10Be and 26Al concentrations in two pebbles yield similar 26Al/10Be burial durations ranging from a minimum duration of 225 ka to a maximum duration of 621 ka. In Wondang-Jangnamgyo, two pebbles yield different 26Al/10Be burial durations with a minimum duration of 235 ka and a maximum duration of 495 ka for one and ranging from 975 ka to 3.2 Ma for the other. This last unrealistically old burial duration range most likely results from a complex history of successive burials and exposures. Interestingly, by analogy with the Chinese loess section, the obtained minimum burial durations are coherent with the paleomagnetism result interpretation associating to glacial cycles the 3 paleosols covering the samples dated at Mansu-Ri.

© 2016 Académie des sciences. Published by Elsevier Masson SAS. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

RÉ S U M É

La médiocre préservation des carbonates et des fossiles dans les terrasses alluviales aériennes des sites coréens du Paléolithique ancien complique leur cadrage chronologique. Une étude paléomagnétique de la section la plus épaisse (environ 9 m) du site de Mansu-Ri (localité IV) a néanmoins mis en évidence une polarité normale, suggérant pour l’ensemble de la section un âge inférieur à 0.78 Ma. Pour ce site, la mesure des concentrations en 10Be et 26Al produits in situ dans deux galets de quartz conduisent à des durées 26Al/10Be

Mots clés :
Paléolithique ancien
Corée du Sud
Nuclides cosmogéniques
Durées d’enfouissement

* Corresponding author.
E-mail addresses: lebatard@cerege.fr (A.-E. Lebatard), bourlies@cerege.fr (D.L. Bourlès), samirkhatib@aol.com (S. Khatib), saos@cerptautavel.com (T. Saos), rochette@cerege.fr (P. Rochette), braucher@cerege.fr (R. Braucher), bkdr537@gmail.com (K. Bae).

https://doi.org/10.1016/j.crpv.2016.04.008
1631-0683/© 2016 Académie des sciences. Published by Elsevier Masson SAS. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
1. Introduction

The advent of the Accelerator Mass Spectrometry (AMS) technique has offered opportunities to develop several dating methods linked to the detection and measurements of cosmogenic nuclide concentrations such as carbon 14, beryllium 10 and aluminum 26 ([14C, 10Be, 26Al; e.g., Bourlès, 1992; Granger, 2006]). One of these new dating methods, developed less than fifteen years ago, is based on the temporal exponential decrease of the 26Al/10Be ratio in substrates containing siliceous minerals that have been exposed to the cosmic ray before being buried under deposits that protect them from secondary cosmic ray radiation (e.g., Granger and Muzikar, 2001).

This burial duration dating method initially used to date quartz gravels in caves in order to establish river incision rates (Granger and Muzikar, 2001) was then applied successfully to several sites of paleontological and archaeological interest. Indeed, this method made it possible to date the Hominin sites from the cave of Sterkfontein in South Africa, recently re-evaluated at ~3.7 Ma (Granger et al., 2015), then that of Sima del Elefante in Atapuerca (Spain) at ~1.1 Ma (Carbonell et al., 2008). More recently, it was applied to an Early Acheulean site, near the town of Windsor in South Africa, to determine the age of the Rietputs Formation, estimated between 1.2 and 1.7 Ma (Gibbon et al., 2009), and to the site of Zhokhovidian in China. In this last case, it involved a question of the age of Homo erectus, named “man of Beijing”, which now is estimated at ~0.8 Ma (Guanjun Shen et al., 2009). Also in Asia, the 26Al/10Be dating method applied to 6 quartz artefacts collected in the Paleolithic site of Attiram-pakkam postponed the arrival of the first hominins on the Indian peninsula at 1.51 Ma ± 0.09 Ma (Pappu et al., 2011). Lastly, the age of the Homo erectus of Kocabas was re-evaluated as between 1.2 and 1.6 Ma (Lebatard et al., 2014a, 2014b).

Recent discoveries of more than a hundred ancient Paleolithic sites in South Korea with which a rich lithic industry is associated (de Lumley et al., 2011) updated hominin dispersion in the Asiatic East and the settlement history of the Korean peninsula. In these sites, mainly in open-air fluvial context, rich industries were unearthed in siliceous detrital sediments where no fauna was conserved. Only a few cave sites have yielded large mammal faunas in association with Early Paleolithic industries, reflecting the great antiquity of the hominin presence in the Korean peninsula. In the absence of faunas, their chronological frameworks are less certain. To obtain radiometric dates, several dating methods (OSL, ESR, IRSL...) were employed at some sites, but the first attempts were inconclusive or inconsistent (de Lumley et al., 2011 and references therein) and the ancient Paleolithic sites remain poorly dated in Korea.

Among these open-air Early Paleolithic sites, the Mansu-Ri (Figs. 1 and 2) and Wondang-Jangnamgyo (Figs. 1 and 3) areas appear suitable to attempt absolute dating. Here, we present the preliminary results obtained using the burial dating method to determine the burial duration of quartz pebbles from these two South Korean Early Paleolithic sites. At Mansu-Ri (Locality IV) site, the thickness of the section allows to perform a paleomagnetic study whose data are compared to the determined burial durations obtained from the same site.

2. General Context

The two selected Paleolithic sites are open-air sites close to rivers. On both sites, lithic industries were mainly unearthed from soil horizons interbedded with sandy-clayey silt levels corresponding to flood, Aeolian and colluvium deposits (de Lumley et al., 2011).

The Mansu-Ri (Loc. IV) site, located in Cheongwon, Chungcheongbuk-do province, 108 km SSE from Seoul (36°37′N, 127°19′E; altitude: 27–45 m; Fig. 1), was excavated in 2006. Along the ~9 m deep excavated clay-sand sequence (Fig. 2), 5 archaeological levels contained nearly 400 lithic artifacts. Within the first meter, 3 tephras were identified whose oldest age is 90–95 ka (de Lumley et al., 2011, and references therein). The 5-c cultural layer at 6 m depth, from which 46 lithic tools typical from the ancient Paleolithic were unearthed, is the second richest layer. Two quartz pebbles from it were selected for burial dating (Fig. 4). The amplitude of the Mansu-Ri (Loc. IV) sedimentary sequence (up to 9 m) allows us to study the paleomagnetism along the longest section.

The Wondang-Jangnamgyo site, located in the Yeoncheon commune in the Gyeonggi-do province, 50 km north from Seoul (37°97′N, 126°89′E; altitude: 19–25 m, Fig. 1), was discovered in 2008. The longest 5 m section is composed by a succession of brownish clay levels covering pebbled sand with basalt brecias and basalt. However, dated
between 130 and 500 ka, the basalt has not yet allowed accurate absolute dating (de Lumley et al., 2011). Three archaeological levels were recognized within the mainly brownish clayed 2 first meters (Fig. 3). One of the two quartz pebbles (Fig. 4) selected for burial dating was sampled in the second archaeological level V (WJ S-3) and the second one in the second VII' layer (WJ S-1). Due to their repartitions in the excavation area, both were collected at 2 m depth (Fig. 3).

3. Materials and methods

3.1. Burial dating method

The burial dating method is based on the relative radioactive decay of two cosmogenic nuclides, $^{26}$Al and $^{10}$Be, which accumulate with a known $^{26}$Al/$^{10}$Be production ratio of 6.61 within the quartz ($\text{SiO}_2$) mineral fraction (in situ production) of rocks exposed at the earth’s crust surface due to nuclear reactions induced by the cosmic ray derived energetic particles on silicon (Si) and oxygen (O). Since the cosmic ray flux is efficiently attenuated by matter, the deposition of a few meters of sediments over a previously exposed surface (burial) leads to a sufficient reduction of the effective energetic particle flux to stop the $^{26}$Al and $^{10}$Be production. In the absence of production, the initial concentrations of each cosmogenic nuclide consequently start to radioactively decay according to their respective half-life, that is $0.717 \pm 0.017\text{ Ma}$ for $^{26}$Al (Granger, 2006; Samworth et al., 1972) and $1.387 \pm 0.012\text{ Ma}$ for $^{10}$Be (Chmeleff et al., 2010; Korschinek et al., 2010). The $^{26}$Al concentration thus decreases approximately twice as fast as that of $^{10}$Be, the $^{26}$Al/$^{10}$Be ratio decreases exponentially with an apparent half-life of $1.48 \pm 0.04\text{ Ma}$. This method thus allows determining quartz mineral burial duration from 100 ka (100,000 years) to approximately 5 Ma (Granger and Muzikar, 2001).

The physico-chemical treatments performed on the four studied quartz pebbles as well as the accelerator mass spectrometry measurements at ASTER of their $^{10}$Be and $^{26}$Al concentrations followed the protocols and parameters fully described in Lebatard et al. (2014a) and references therein.
The concentrations measured for these two cosmogenic nuclides in the same quartz sample insure that they both record the same history in term of exposition, denudation, and burial. They allow calculating the $^{26}\text{Al}^{10}\text{Be}$ ratio associated to each sample and, consequently, to determine their corresponding burial duration and denudation rate using the method fully described in the SOM of Pappu et al. (2011). This modeling method is based on the equation (1) describing the evolution of the in situ produced cosmogenic nuclide concentration $C(x, \varepsilon, t)$ as a function of the depth ($x$), the denudation rate ($\varepsilon$) and the time ($t$):

$$C(x, \varepsilon, t) = C(x, 0) \cdot e^{-\varepsilon t} + \frac{P_n \cdot \frac{\varepsilon}{\lambda} \cdot (1 - e^{-\frac{(x - \frac{\varepsilon}{\varepsilon} \cdot t)}{\lambda}})}{\frac{1}{\varepsilon} + \lambda} + \frac{P_{\mu sl} \cdot \frac{\varepsilon}{\lambda} \cdot (1 - e^{-\frac{(x - \frac{\varepsilon}{\varepsilon} \cdot t)}{\lambda}})}{\frac{1}{\varepsilon} + \lambda} + P_{\mu ft} \cdot \frac{\varepsilon}{\lambda} \cdot (1 - e^{-\frac{(x - \frac{\varepsilon}{\varepsilon} \cdot t)}{\lambda}})$$

where $\lambda$ is the radioactive decay constant, $P_n$ is the spallation production rate linked to the neutrons, $P_{\mu sl}$ and $P_{\mu ft}$ are production rates linked to slow and fast muons, respectively (Braucher et al., 2011 and associated references), $\Lambda_{\mu}$ is the neutrons attenuation length, and $\Lambda_{\mu sl}$ and $\Lambda_{\mu ft}$ are the slow and fast muons attenuation lengths, respectively. Modeling were computed using the parameters discussed in Braucher et al. (2011), including the $^{26}\text{Al}^{10}\text{Be}$ spallogenic production rate ratio of 6.61 ± 0.50. Neutronic production rates have been scaled using (Stone, 2000) and are based on a weighted mean $^{10}\text{Be}$ spallation
production rate at sea level and high latitude (SLHL) of 4.03 ± 0.18 at g⁻¹ a⁻¹ (Molliex et al., 2013).

Uncertainties associated with the ratios, the durations and the denudation rates, reported as 1σ, result from the propagation of the uncertainties previously referred and described (Table 1).

The performed modeling method allows to determine minimum burial durations, based on the sole differential cosmogenic nuclides radioactive decay, and the estimated associated denudation rates (Table 1: “Model without post-burial production”), and maximized burial durations, based on the assumption that the environmental conditions remained relatively stable since the burial, and the associated denudation rates (Table 1: “Model with post-burial production”). Minimum burial durations are also obtained using the exposure–burial diagram (Fig. 5; e.g.,

Fig. 3. The Wondang-Jangnamgyo paleolithic site. Map and stratigraphical logs of the site. The sampling location of WJ1⁰BeS-1 (WJS-1) and WJ1⁰BeS-3 (WJS-3) are reported on both map (yellow squares) and logs (stars) (modified from de Lumley et al., 2011).

Fig. 3. Le site paléolithique de Wondang-Jangnamgyo. Plan et logs stratigraphiques. La localisation d’échantillonnage de WJ1⁰BeS-1 (WJS-1) et WJ1⁰BeS-3 (WJS-3) est reportée sur le plan (carrés jaunes) et sur les logs (étoiles) (modifié d’après de Lumley et al., 2011).
### Table 1

In situ produced $^{26}$Al and $^{10}$Be concentrations, burial durations and denudation rates. Uncertainties (± 1σ) include only analytical uncertainties. The burial durations are in ka (1000 a). The denudation rates are given in m Ma$^{-1}$ (meter per million years). The target neutral production for the studied sites is 6.93 x $10^{-4}$ a$^{-1}$ for $^{10}$Be and 45.83 x $10^{-4}$ a$^{-1}$ for $^{26}$Al, slow muons production is 0.02 x $10^{-4}$ a$^{-1}$ for $^{10}$Be and 1.12 at g$^{-1}$ a$^{-1}$ for $^{26}$Al, and fast muons production is 0.05 at g$^{-1}$ a$^{-1}$ for $^{10}$Be and 0.09 at g$^{-1}$ a$^{-1}$ for $^{26}$Al (Braucher et al., 2011; Stone, 2000). Density is considered to be 2.2 g cm$^{-3}$. The chemical blank ratio is 2.84 x 10$^{-15}$ and 1.84 x 10$^{-15}$ for $^{10}$Be/$^{9}$Be and $^{26}$Al/$^{27}$Al ratio, respectively. The measured ratios are corrected from these values. W. dis. Qz: Weight of dissolved quartz; Gr.: graphically deduced from the exposure–burial diagram (Fig. 5). The graphically determined minimum burial durations were obtained considering the radioactive decay duration necessary to straightforwardly reach from the lower “steady erosion” curve of the “steady-state erosion island” the minimum $^{26}$Al/$^{10}$Be ratio value considering the associated uncertainties. According to Pappu et al., 2011, the “Model without post-burial production” assuming that no cosmogenic nuclides were accumulated in the samples while buried (infinite burial depth) yields minimum burial duration. The “Model with post-burial production” assuming that the samples remained buried at their sampling depths and accumulated cosmogenic nuclides produced by muons yields maximized burial durations in a steady denudation over the burial period.

### Tableau 1

Concentrations en $^{26}$Al et $^{10}$Be produits en situ, durées d’enfouissement et taux de dénudation. Les incertitudes (± 1σ) incluent seulement les incertitudes analytiques. Les durées d’enfouissement sont exprimées en ka (1000 a). Les taux de dénudation sont donnés en m Ma$^{-1}$ (mètre par million d’années). La production neutronique établie pour les sites est 6.93 x $10^{-4}$ a$^{-1}$ pour $^{10}$Be et 45.83 x $10^{-4}$ a$^{-1}$ pour $^{26}$Al. La production par les muons lents est 0.02 x $10^{-4}$ a$^{-1}$ pour $^{10}$Be et 0.09 x $10^{-4}$ a$^{-1}$ pour $^{10}$Be, la production par les muons rapides est 0.05 x $10^{-4}$ a$^{-1}$ pour $^{10}$Be et 0.09 x $10^{-4}$ a$^{-1}$ pour $^{26}$Al (Braucher et al., 2011; Stone, 2000). La densité est 2.2 g cm$^{-3}$. Les rapports des blancs chimiques sont 2.84 x 10$^{-15}$ et 1.84 x 10$^{-15}$ pour les rapports $^{10}$Be/$^{9}$Be et $^{26}$Al/$^{27}$Al, respectivement. Les rapports mesurés sont corrigés de ces valeurs. W. dis. Qz: poids de quartz dissous; Gr.: graphiquement déduit du diagramme exposition–enfouissement (Fig. 5). Les durées d’enfouissement minimums déterminées graphiquement ont été obtenues en considérant la durée de décroissance radioactive nécessaire pour atteindre directement à partir de la courbe inférieure “érosion régulière” de l’îlot des états stationnaires la valeur du rapport $^{26}$Al/$^{10}$Be minimum, compte tenu des incertitudes associées. Selon Pappu et al., 2011, le “Modèle sans production post-enfouissement”, en supposant qu’aucun nucléide cosmogénique n’a été accumulé dans les échantillons au cours de l’enfouissement (profondeur d’enfouissement infinie) donne la durée d’enfouissement minimum. Le “Modèle de production post-enfouissement”, en supposant pour la modélisation que les échantillons soient restés enfoncés à leurs profondeurs d’échantillonnage et accumulent des nucléides cosmogéniques produits par les muons, conduit à maximiser les durées d’enfouissement de manière stable au cours de la période d’enfouissement.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Depth (g.cm$^{-2}$)</th>
<th>Wiss. Qz (g)</th>
<th>$^{26}$Al (10$^{-3}$ at.g$^{-1}$)</th>
<th>$^{10}$Be (10$^{-3}$ at.g$^{-1}$)</th>
<th>$^{26}$Al/$^{10}$Be</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS$^{10}$BeS-1</td>
<td>1320</td>
<td>29.0</td>
<td>19.42 ± 0.88</td>
<td>3.50 ± 0.14</td>
<td>5.54 ± 0.33</td>
</tr>
<tr>
<td>MS$^{10}$BeS-2</td>
<td>1320</td>
<td>28.7</td>
<td>24.59 ± 0.88</td>
<td>4.36 ± 0.15</td>
<td>5.64 ± 0.27</td>
</tr>
<tr>
<td>WJ$^{10}$BeS-1</td>
<td>1320</td>
<td>29.4</td>
<td>13.25 ± 1.87</td>
<td>3.75 ± 0.14</td>
<td>3.54 ± 0.52</td>
</tr>
<tr>
<td>WJ$^{10}$BeS-3</td>
<td>1320</td>
<td>28.7</td>
<td>9.23 ± 0.34</td>
<td>1.56 ± 0.05</td>
<td>5.91 ± 5.91</td>
</tr>
</tbody>
</table>

Model without post-burial production

<table>
<thead>
<tr>
<th>Burial duration (ka)</th>
<th>Denudation before burial (m.Ma$^{-1}$)</th>
<th>7.0 ± 0.4</th>
<th>3.9 ± 0.6</th>
<th>17.8 ± 0.9</th>
</tr>
</thead>
</table>

Model with post-burial production

<table>
<thead>
<tr>
<th>Burial duration (ka)</th>
<th>Denudation before and after burial (m.Ma$^{-1}$)</th>
<th>7.0 ± 0.4</th>
<th>3.9 ± 0.6</th>
<th>17.8 ± 0.9</th>
</tr>
</thead>
</table>

Post-burial $^{26}$Al produced (10$^{-3}$ at.g$^{-1}$)

<table>
<thead>
<tr>
<th>% post-burial prod /measured $^{26}$Al</th>
<th>7</th>
<th>5</th>
<th>67</th>
<th>26</th>
</tr>
</thead>
</table>

Post-burial $^{10}$Be produced (10$^{-3}$ at.g$^{-1}$)

<table>
<thead>
<tr>
<th>% post-burial prod /measured $^{10}$Be</th>
<th>4</th>
<th>31</th>
<th>16</th>
</tr>
</thead>
</table>

Exposure–Burial Diagram

<table>
<thead>
<tr>
<th>Gr. min. burial duration (ka)</th>
<th>390 ± 125</th>
<th>330 ± 95</th>
<th>1275 ± 300</th>
<th>325 ± 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr. denudation before burial (m.Ma$^{-1}$)</td>
<td>7.1 ± 0.3</td>
<td>5.7 ± 0.2</td>
<td>4.0 ± 0.2</td>
<td>17.7 ± 0.5</td>
</tr>
</tbody>
</table>

### 3.2. Paleomagnetism

Paleomagnetic sampling was performed all along the thickest sedimentary deposit section at Mansu-Ri (Locality IV; Fig. 2). All the sampling was handmade, oriented with a compass and consolidated with plaster tape. In these thus obtained 20–25 cm long and 7 cm large and wide oriented cores, cubes (7–8/core) were cut for natural remanent magnetization (NRM) measurements. The measurements were made using a 2D DC-Squid Superconducting Rock Magnetometer (SRM) at CEREGE. The direction of the characteristic remnant magnetization (ChRM) was retrieved by means of stepwise demagnetization using alternating field (AF) up to 60 or 80 mT.

### 4. Preliminary results

#### 4.1. Burial dating

The results obtained for the two quartz pebbles from Mansu-Ri (Loc. IV; a and b, Fig. 4) sampled 6 m beneath the surface and for the two quartz pebbles from Wondang-
Jangnamgyo (c and d, Fig. 4) sampled ~2 m beneath the surface are presented in Table 1. In Fig. 5, they are plotted on a graph (exposure–burial diagram; e.g., Granger, 2006) presenting the evolution of the $^{26}$Al/$^{10}$Be ratio as a function of the $^{10}$Be concentration.

Regarding the four studied quartz pebbles, the minimum burial durations obtained with the model without post-burial production range from 331.9 ± 18.0 ka to 1.28 ± 0.19 Ma associated with denudation rates between 3.9 ± 0.6 m Ma$^{-1}$ to 17.8 ± 0.9 m Ma$^{-1}$. In the exposure–burial diagram (Fig. 5), the pebbles located in the “burial area” lead to minimum burial durations ranging from 325 ± 100 ka for the youngest (WJ$^{10}$BeS-3) and to 1.28 ± 0.30 Ma for the oldest (WJ$^{10}$BeS-1) and denudation rates affecting the overlying surfaces ranging from 4.0 to 17.7 m Ma$^{-1}$, similar to the data obtained performing the model without post-burial production. However, it is worth mentioning that in both sites the samples were not deeply buried, especially those from Wondang-Jangnamgyo and that therefore, due to the thin soil cover, post production may have occurred leading to burial durations that should be longer. Performing the model with post-burial production to thus consider possible cosmogenic nuclide production during burial yields maximized burial durations and denudation rates ranging from 382.4 ± 20.8 ka to 2.77 ± 0.41 Ma and from 2.5 ± 0.4 m Ma$^{-1}$ to 18.8 ± 0.9 m Ma$^{-1}$, respectively. The denudation rate ranges obtained by the three methods are similar and the rates at the Mansu-Ri (Loc. IV) site are consistent.

Due to the sampling depths, the post-burial cosmogenic nuclide production is significant at both sites, between 3 and 7% at the Mansu-ri (Loc. IV) site and 16 to 67% at the Wondang-Jangnamgyo site.

Due to the data dispersion, no weighted mean burial duration can be calculated. Considering the individual durations and their associated uncertainties at the Mansu-Ri (Loc. IV) site, the burial duration of the two quartz pebbles from the archaeological level 5-c is longer than 235 ka (obtained by subtracting it uncertainty to the youngest age [MS$^{10}$Be S-2] derived from the diagram, that is 330–95 = 235 ka), but shorter than 494.6 ka (obtained by adding it uncertainty to the oldest age [MS$^{10}$Be S-1] derived from the model with post-burial production,
that is 464.2 ± 30.4 = 494.6 ka). Similarly, at the Wondang-Jangnamgyo site, the burial duration of the WJ\textsuperscript{10}Be 5-3 quartz pebble coming from the archaeological level V is longer than 225 ka, but shorter than 621.2 ka.

4.2. Preliminary Magnetic results on the Mansu-Ri site

The raw NRM intensity values of the sediment range between 30 and 80 × 10\textsuperscript{-3} A/m (Fig. 6). The maximum values occur in the sandy silt and in the plastic silty clay, at the base of the paleosols (50 ± 80 × 10\textsuperscript{-3} A/m). The minimum values occur in paleosols and sandy levels (< 10 × 10\textsuperscript{-3} A/m). The high magnetic intensity values below the paleosols may result from an intense weathering of the sediments followed by a downward migration of the iron oxides which then accumulated in the underlying sedimentary layers. These accumulations of iron oxide suggest that the deposits underwent, at least, four hot and wet climatic periods.

When confronted with the Chinese loess record, the high NRM intensity values measured along the sedimentary deposit section at Mansu-Ri (Locality IV) correspond to the high magnetic susceptibility values measured along the S1 to S5 Chinese soils (Fig. 6).

The inclination of the magnetic components varies between 34° and 66°. Nevertheless, the base of core 29 presents a significantly lower value of 14°. The declination of cores 1 to 29 exhibits values close to 0°.

Generally, all the cores analyzed in this locality present a normal magnetic polarity, similar to the current polarity. The average inclination is of the order of 50°, similar to the current inclination measured at Chengwon (South Korea) equals to 52°.

This normal polarity sequence can be thus undoubtedly awarded to the period of Brunhes younger than 780,000 years, with no hints of an excursionary record.

5. Discussion-conclusion

Three of the samples from the two Early Paleolithic studied sites located more than 150 km away show similar burial durations. The similarity of the 26Al/10Be ratio of the
two Mansu-Ri artifacts sampled at the same depth strongly suggests that they likely have the same exposure-burial history. However, sample MS10Be-2 presents higher 10Be and 26Al concentrations than sample MS10Be-1, suggesting that they may initially have been within the same deposit but with sample MS10Be-2 being above MS10Be-1. The simplest explanation of the burial duration difference between the two pebbles from Wondang-Jangnamgyo is that the oldest sample (Wi10Be-1) has a complex history of successive burials and exposures during which the pebble may have spent some time buried in another sedimentary section before to be reworked and rapidly re-sedimented in the Wondang-Jangnamgyo section. In such a scenario, the last burial event starts with an initial 26Al/10Be ratio significantly lower than 6.61.

This study represents the first burial duration estimations of the archeological layers at the Mansu-Ri (Loc. IV) and Wondang-Jangnamgyo areas and provides the first chronological framework for Early Paleolithic sites in South Korea. At Wondang-Jangnamgyo and Mansu-Ri (Loc. IV), the determined burial durations ranging from ∼225 ka to ∼621 ka and ∼235 ka to ∼495 ka connect the lithic industries found in the V and 5-c archaeological units, respectively, to the end of the time period covering the early Paleolithic.

Interestingly, by analogy with the Chinese loess section, the obtained minimum burial durations are coherent with the interpretation associating to glacial cycles the 3 paleosols covering the samples dated at Mansu-Ri. Using the presented preliminary results, a correlation based on magnetic susceptibility curves is thus proposed between the Chinese loess and the Mansu-Ri section (Fig. 6). These two studied sites are, according to the results, at least 200 ka younger than the Chinese Bose and Zoukoudian Acheulean site (Guanjun Shen et al., 2009; Wang et al., 2006).

Constraining burial durations of the selected archaeological layers will necessitate undergoing determination of the deposition rates of the shallow sedimentary layers overlaying the layers of interest.

Acknowledgments

This research was supported by the French Ministry for Foreign Affairs through the French–Korean programs (PHC STAR) on the ancient Paleolithic of Korea (n° 21469YC). The authors thank L. Leanni, M. Arnold, G. Aumaitre and K. Keddouche for their respective valuable assistance during chemical treatments, ICP-OES measurements and 10Be and 26Al measurements at the ASTER AMS national facility (CEREGE, Aix-en-Provence) which is supported by the INSU/CNRS, the ANR through the “Projets thématiques d’excellence” program for the “Equipements d’excellence” ASTER-CEREGE action, IRD and CEA. Thanks also to Ph. Dussouillez for artwork support. Professor Henry de Lumley is gratefully acknowledged for the opportunity given to work on such archaeological sites.

References