# Supplementary Information for Multiple lines of evidence of early goose domestication in a 7,000-y-old rice cultivation village in the lower Yangtze River, China

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**Table S1.** Histological observations of age-known goose bones.

Appendix 1. The histological observation of age-known goose bones

| Species | *Anser caerulescens* | *Anser anser* | *Anser anser* | *Anser anser* | *Anser anser* |
|---|---|---|---|---|---|
| Age at death | 2 days | 4 weeks | 4-8 weeks | c.16 weeks | 16 weeks |
| Stored | UCZM | UCZM | BSCAP | UCZM | Southampton University |
| Specimen number | A759 | A 84 | 10 | A 79 | 968 |
| Sex | unknown | Male | Unknown | Male | Unknown |
| Sternum | - | Porous | Porous | Mature, keel porous | Mature, keel porous |
| Coracoid | Porous | Porous | Porous | Mature | Mature |
| Scapula | Porous | Porous | Porous | Mature | Mature |
| Humerus | Porous | Porous | Porous | Mature | Mature |
| Radius | Porous | Porous | Porous | - | Mature |
| Ulna | Porous | Porous | Porous | - | Mature |
| Carpometacarpus | Porous. Mc II and III not united | Porous. Mc II and III not united | Porous. Mc II and III not united | - | - |
| Synsacrum | Not united, neither ilium nor ischium unfused to pubis | Not united, ilium unfused to pubis. Ischium fused to pubis, fusion line visible | United, ilium and Ischium fused to pubis, only ilium and pubis fusion lines visible | Partly united, ilium and ischium fused to pubis, only ilium and pubis fusion lines visible | Partly united, ilium fused to pubis, fusion lines invisible |
| Femur | Porous | Porous | Porous | Mature | Mature |
| Tibiotarsus | Unfused prox, unfused dist, porous. | Fused prox and dist, prox and dist fusion line visible, porous. | Fused prox and dist, prox fusion line visible, dist fusion line invisible, porous. | Fused prox and dist, mature. | Fused prox and dist, mature. |
| Tarsometatarsus | Unfused prox, porous | Unfused prox, fusion line of metatarsi visible, porous | Fused, prox fusion line visible, porous. | Fused prox fusion line visible, slightly porous | – |
| Prox phalanx | Unfused prox, porous | Unfused prox, porous | Unfused, porous | Fused prox, slightly porous | – |

–: absent, UCZM: University of Copenhagen Zoological Museum, BSCAP: Bavarian State Collection for Anthropology and Palaeoanatomy

**Table S2.** List of goose bones analyzed from the Tianluoshan site, and their characteristics.

| Sample No | Grid | Layer | Age | C/N | $\delta^{13}C_{Co}$ | $\delta^{15}N_{Co}$ | $\delta^{18}O_p$ | $\delta^{18}O_w$ | LDS | Lab. code # | $^{14}C$ age (BP) | | cal BP (σ) | No. in Fig. 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 517 | T106 | 3 | | 3.2 | −22.0 | 5.9 | 9.6 | −13.5 | | | | | | |
| 587 | T406 | 4 | | | Not determined | | 14.6 | −7.8 | 0.021 | | | | | |
| 501 | T206 | 4 | | 3.3 | −21.2 | 5.5 | 13.7 | −8.9 | -0.093 | | | | | |
| 586 | T406 | 4 | | | Not determined | | 13.5 | −9.1 | 0.021 | | | | | |
| 502 | T206 | 4 | | 3.2 | −20.9 | 6.3 | 12.9 | −9.8 | | | | | | |
| 514 | T305 | 4 | | | Not determined | | 12.7 | −10.0 | | | | | | |
| 527 | T406 | 5 | | 3.2 | −14.1 | 12.4 | 15 | −7.5 | | | | | | |
| 513 | T206 | 5 | | 3.2 | −18.6 | 9.8 | 14.6 | −7.8 | | | | | | |
| 526 | T406 | 5 | | | Not determined | | 14 | −8.5 | 0.020 | | | | | |
| 528 | T406 | 5 | | | Not determined | | 13.8 | −8.8 | 0.021 | | | | | |
| 511 | T206 | 5 | | 3.2 | −21.7 | 6.5 | 10.3 | −12.7 | -0.009 | | | | | |
| 504 | T106 | 6 | 4-16 weeks | 3.2 | −13.7 | 0.3 | 18.6 | −3.4 | | TKA−19343 | 6085 | ± 40 | 7146−6890 | 2 |
| 542 | T406 | 6 | | 3.3 | −21.1 | 9.2 | 16.3 | −5.9 | 0.053 | TKA−19341 | 6005 | ± 30 | 6887−6793 | 7 |
| 544 | T406 | 6 | 4-16 weeks | 3.3 | −24.3 | 9.8 | 16.1 | −6.2 | | TKA−19345 | 5900 | ± 35 | 6746−6797 | 1 |
| 509 | T305 | 6 | | 3.5 | −20.7 | 11.2 | 15.4 | −7.0 | 0.045 | | | | | 8 |
| 521 | T406 | 6 | | 3.8 | −16.4 | 8.2 | 13.4 | −9.2 | 0.052 | | | | | |
| 523 | T406 | 6 | | 3.2 | −22.2 | 6 | 11.6 | −11.3 | | | | | | |
| 585 | T406 | 6 | | 4.5 | −22.9 | 7.2 | 11.2 | −11.7 | 0.086 | | | | | |
| 539 | T303 | 7 | 4-8 weeks | 3.3 | −19.1 | 2.6 | 18.3 | −3.8 | | TKA−19344 | 6025 | ± 30 | 6937−6797 | 4 |
| 582 | T406 | 7 | | 3.2 | −15.3 | 11.7 | 14.2 | −8.3 | 0.013 | | | | | |
| 551 | T406 | 8 | | 3.2 | −21.0 | 7.3 | 15.9 | −6.4 | 0.046 | | | | | 6 |
| 549 | T406 | 8 | | 3.3 | −18.9 | 9.5 | 15.5 | −6.9 | 0.044 | TKA−19342 | 5885 | ± 35 | 6740−6668 | 5 |
| 577 | T406 | 8 | | 3.2 | −21.8 | 7 | 13.3 | −9.3 | 0.042 | | | | | |
| 550 | T406 | 8 | | 3.2 | −20.3 | 6.6 | 13.1 | −9.5 | 0.043 | | | | | |
| 575 | T406 | 8 | | | Not determined | | 10.8 | −12.2 | 0.056 | | | | | |
| 569 | T406 | 8 | 4-16 weeks | | | Not analyzed | | | | | | | | 3 |

**Table S3.** Results of isotope analysis of mammal bones collected at Tianluoshan.

| Sample Name | Species | Layer | Grid | C/N | $\delta^{13}C_{Co}$ | $\delta^{15}N_{Co}$ | $\delta^{18}O_p$ | $\delta^{18}O_w$ |
|---|---|---|---|---|---|---|---|---|
| Buffalo_1 | *Bubalus* sp. | 7 | T406 | 3.1 | −12.8 | 8.7 | 16.9 | −6.8 |
| Buffalo_2 | *Bubalus* sp. | 6 | T406 | | | | 16.8 | −6.9 |
| Buffalo_3 | *Bubalus* sp. | 7 | T301 | | | | 18.3 | −5.2 |
| Buffalo_4 | *Bubalus* sp. | 8 | T307 | | | | 18.4 | −5.1 |
| Buffalo_5 | *Bubalus* sp. | 8 | T305 | | | | 18.1 | −5.4 |
| Père David's deer_1 | *Elaphurus davidianus* | 7 | T303 | 3.1 | −19.6 | 8.3 | 16.7 | −7.0 |
| Père David's deer_2 | *Elaphurus davidianus* | 7 | T303 | 3.1 | −19.0 | 8.6 | 17.3 | −6.3 |
| Sambar_1 | *Rusa unicolor* | 8 | T207 | 3.1 | −22.8 | 5.7 | 16.7 | −7.0 |
| Sambar_2 | *Rusa unicolor* | 8 | T103 | 3.4 | −23.1 | 5.5 | 16.4 | −7.3 |
| Sambar_3 | *Rusa unicolor* | 8 | T206 | 3.1 | −22.5 | 5.3 | 17.5 | −6.1 |
| Sika deer_1 | *Cervus nippon* | 6 | T207 | 3.2 | −22.3 | 5.8 | 17.3 | −6.3 |

**Table S4.** Results of isotope analysis of goose bones collected at Kuahuqiao.

| Sample No. | Layer | Grid | C/N | $\delta^{13}C_{Co}$ | $\delta^{15}N_{Co}$ | $\delta^{18}O_p$ | $\delta^{18}O_w$ |
|---|---|---|---|---|---|---|---|
| 191 | 8c, 10, 11 | 0411 | 3.2 | −21.4 | 7.9 | 7.2 | −16.1 |
| 193 | | 0512 | 3.2 | −21.8 | 8.5 | 9.5 | −13.6 |
| 194 | 3b | 0511 | 3.2 | −21.0 | 5.0 | 13.2 | −9.5 |
| 195 | 8c | 0511 | 3.2 | −20.8 | 4.5 | 14.0 | −8.6 |
| 196 | 4 | 0411 | 3.2 | −20.8 | 5.5 | 13.8 | −8.8 |

**Table S5.** Results of isotope analysis (the $\delta^{18}O_C$ contents of tooth enamel and the $\delta^{18}O_P$ contents of tooth enamel, dentin, and bone) of four water buffalo samples collected from Tianluoshan. $\Delta^{18}O_P$ Ena−Den and $\Delta^{18}O_P$ Ena−Bone indicate the differences in $\delta^{18}O_P$ between tooth enamel and dentin, and between tooth enamel and bone, respectively.

| Sample | $\delta^{18}O_C$ | $\delta^{18}O_P$ Enamel | $\delta^{18}O_P$ Dentine | $\delta^{18}O_P$ Bone | $\Delta^{18}O_P$ Ena−Den | $\Delta^{18}O_P$ Ena−Bon |
|---|---|---|---|---|---|---|
| Buffalo_2 | 24.9 | 18.0 | 17.9 | 16.8 | 0.0 | 1.2 |
| Buffalo_3 | 24.0 | 17.7 | 18.0 | 18.3 | −0.3 | −0.6 |
| Buffalo_4 | 23.1 | 17.5 | 17.4 | 18.4 | 0.0 | −0.9 |
| Buffalo_5 | 23.5 | 17.9 | 17.9 | 18.1 | 0.0 | −0.2 |
| Mean ± S.D. | 23.9 ± 0.8 | 17.8 ± 0.2 | 17.8 ± 0.3 | 17.9 ± 0.7 | −0.1 ± 0.2 | −0.1 ± 0.9 |

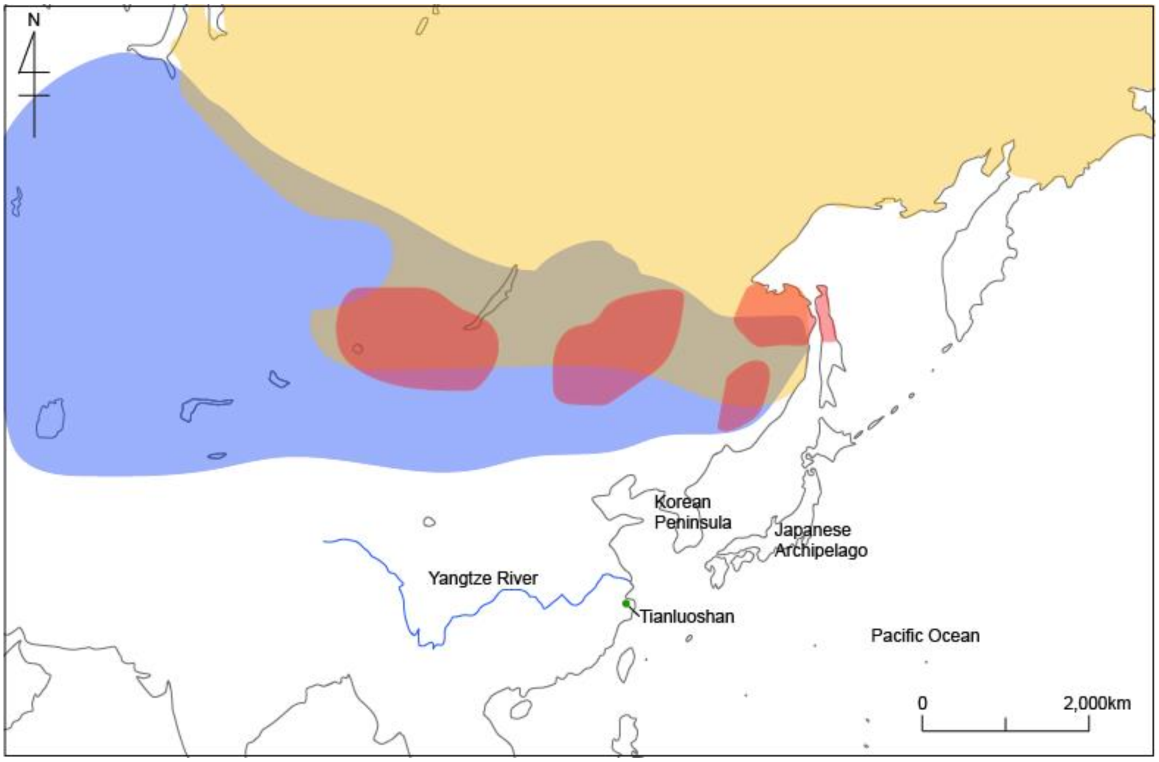


**Figure S1.** Modern breeding distribution range of greylag geese (*Anser anser*, blue color), bean geese (*A. fabalis*, orange color) and swan geese (*A. cygnoides*, red color) after del Hoyo and Collar (1). Note that all three species winter in the lower Yangtze River.

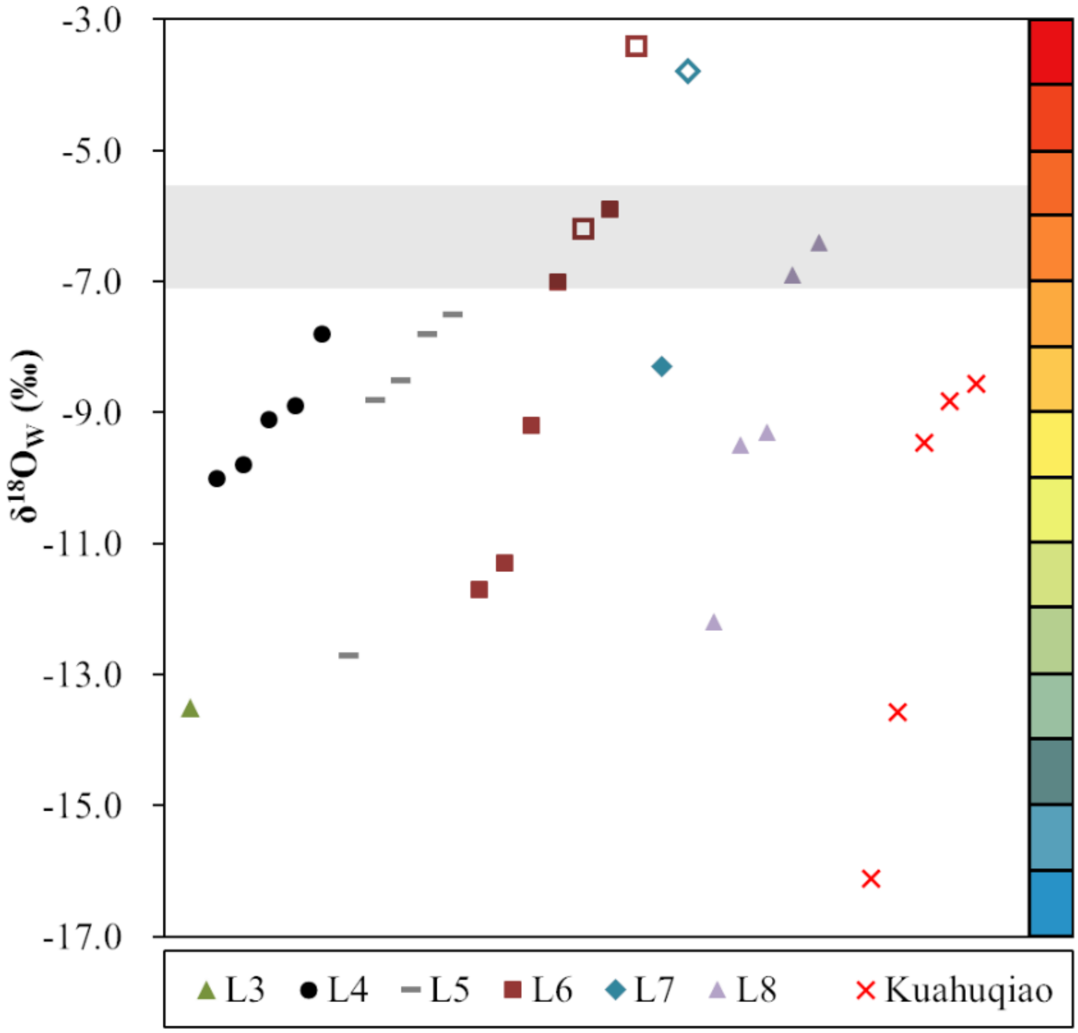


**Figure S2.** $\delta^{18}O_W$ values in goose bones (immature: open symbol) collected from several layers in Tianluoshan and the $\delta^{18}O_W$ values in goose bones (adult: red cross symbols) collected from Kuahuqiao. The gray shaded area delineates the range in $\delta^{18}O_W$ values (mean ± σ) observed in mammalian bones from Tianluoshan. Note that the samples represented by the five symbols in the gray shaded area are presumably from local individuals. The colored bars that represent $\delta^{18}O_W$ values correspond to the same colors used in Figure 1 for the oxygen isotope composition of annual precipitation.

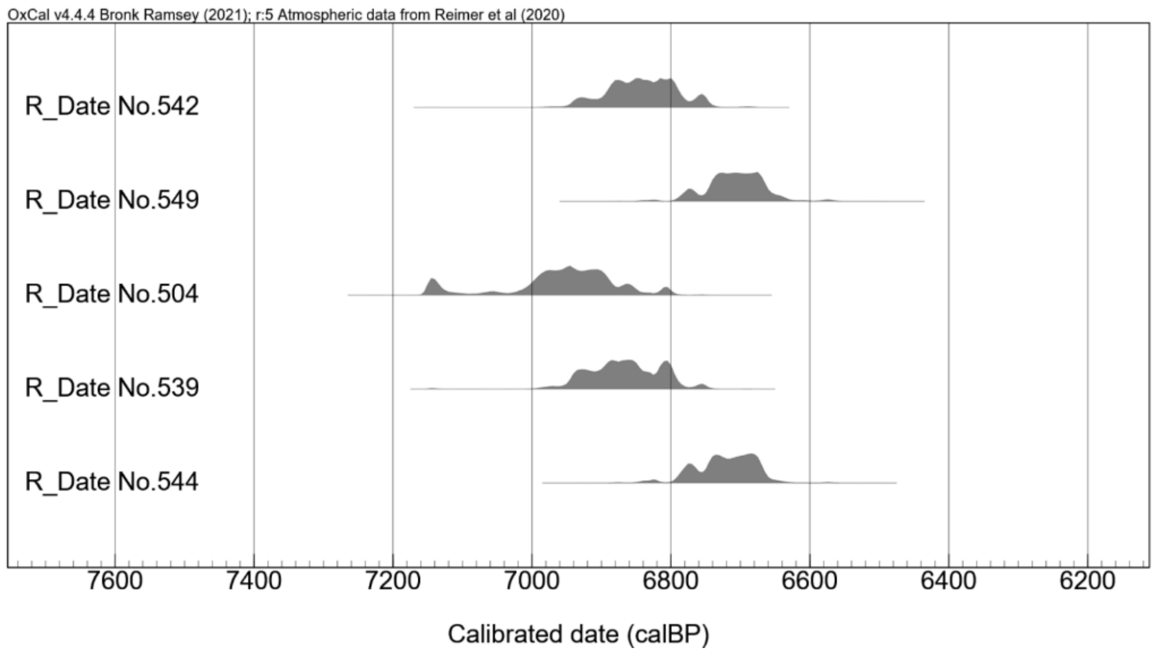


**Figure S3.** Calibrated $^{14}C$ dates of collagen from five goose bones collected at Tianluoshan.

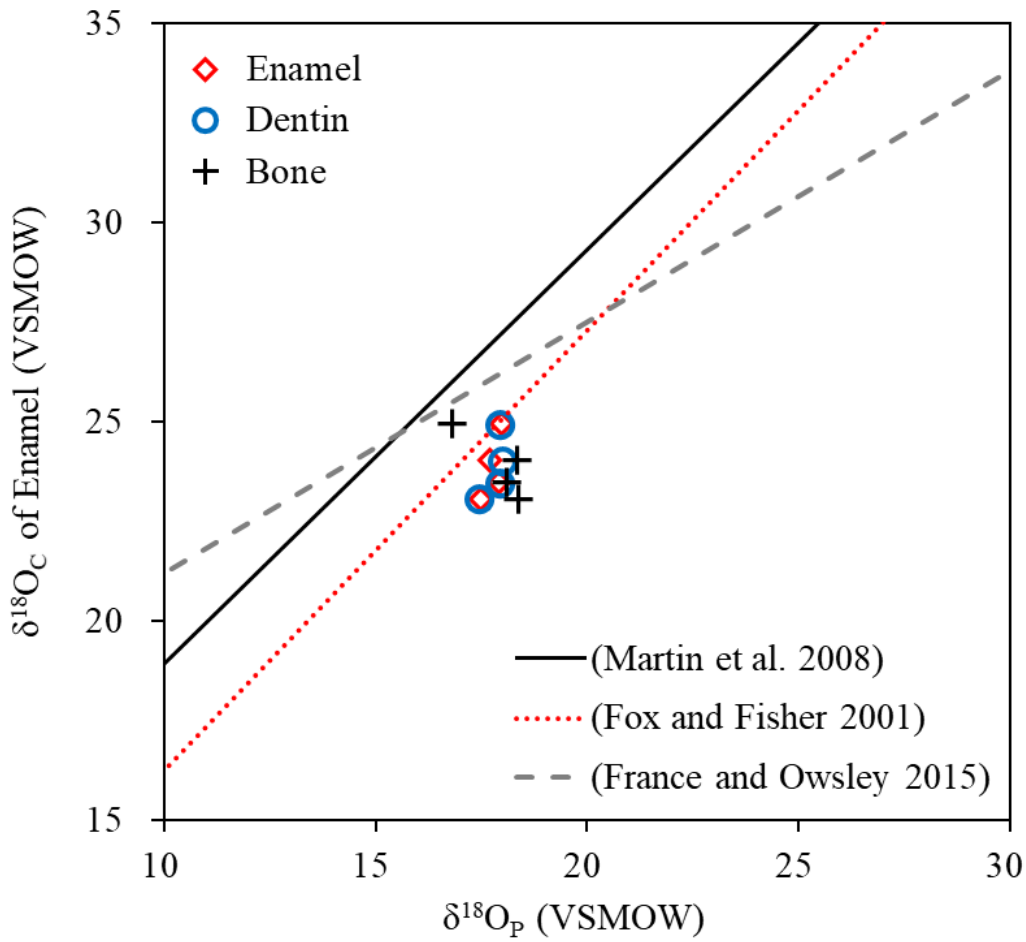


**Figure S4.** The $\delta^{18}O_C$ values for tooth enamel versus $\delta^{18}O_P$ values for tooth enamel, dentin, and bone from water buffaloes calculated in our study. Each line represents a regression line, derived from the results of previous studies (2-4), and depicts the $\delta^{18}O_C$ versus $\delta^{18}O_P$ values calculated for tooth enamel from well-preserved samples. The oxygen isotope compositions are shown as standardized by Vienna Standard Mean Ocean Water (VSMOW), an isotopic standard of water.

**S1.** Preservation status and diagenetic alternation for bioapatite

The bioapatite of archaeological animal remains is exposed to the risk of post-mortem diagenetic alteration during burial, and the oxygen may be exchanged in the soil or contain secondary deposited oxygen (5). As tooth enamel has a more densely packed crystalline structure than tooth dentine or bone, tooth enamel is usually considered to be a more reliable material for oxygen isotope analyses of archaeological samples (2, 6). However, geese, our study species, do not have tooth enamel; therefore, we measured the oxygen isotope compositions of phosphate in bone. To evaluate the diagenetic effects of phosphate in bird bones, we used water buffalo teeth and bone samples from the same individual from Tianluoshan for reference.

In well-preserved samples, the $\delta^{18}O$ component of structural carbonate ($\delta^{18}O_C$) and $\delta^{18}O_P$ are known to correlate, and this correlation is considered to be a diagenetic indicator for ancient materials (4, 5). In contrast, it has been reported that there are inter-species differences in the intercept of the regression line between $\delta^{18}O_P$ and $\delta^{18}O_C$ (4), and it has been proposed that diagenetic alterations in apatite should be evaluated in combination with another indicator such as collagen C/N (2).

Tooth enamel and dentin were collected from four water buffalo individuals whose bones were measured. $\delta^{18}O_P$ was measured using the same pretreatment as for bone. After treatment with acetic acid, a part of each tooth enamel was split and the $\delta^{18}O_C$ values were measured. The stable oxygen isotope compositions for the structural carbonate of tooth enamel were determined using an IRMS system (GasBench II coupled to a Delta V Plus IRMS, Thermo Fisher Scientific, Bremen, Germany) with a PAL autosampler (GC PAL, CTC Analytics, Zwingen, Switzerland) at the Research Institute for Humanity and Nature. As a result, the $\delta^{18}O_P$ and $\delta^{18}O_C$ contents in the enamel from the water buffalo samples from Tianluoshan generally follow the same regression line shown in previous studies (Fig. S4). Therefore, it is likely that the $\delta^{18}O$ in the enamel samples from the Tianluoshan water buffaloes did not undergo significant post-mortem diagenetic shifts.

The $\delta^{18}O_P$ values in the enamel and dentin from the water buffaloes were measured at 17.8 ± 0.2 ‰ and 17.8 ± 0.3 ‰, respectively, and did not differ from that of bone (17.9 ± 0.7 ‰) (Table S5). The mean difference in $\delta^{18}O_P$ values between the enamel and dentin in each individual was −0.1 ± 0.2 ‰. Between enamel and bone the mean difference in $\delta^{18}O_P$ values was −0.2 ± 1.0 ‰. The difference between enamel and bone was slightly higher than that found between enamel and dentin, but this variation is probably due to the difference in time needed for teeth and bone to undergo crystallization. Therefore, it was assumed that less post-mortem diagenetic alterations have occurred in the phosphate of the water buffalo bones that would affect the $\delta^{18}O_P$. Therefore, using the water buffalo as a reference, it was expected that diagenetic $\delta^{18}O_P$ shifts would also not have occurred in goose bones that were exposed to the same depositional environment in Tianluoshan, nor would it have affected the habitat estimates in this study.

In addition, it is also said that the preservation of collagen, such as C/N ratios, can be a diagenetic indicator of bioapatite (2). The atomic C/N ratio of well-preserved collagen was expected to be in the range of 2.9–3.6 (7). As all the immature and adult individuals with high $\delta^{18}O_P$ values, identified as local geese, had well-preserved collagen (Table S2), there was no danger of mistakenly identifying poor-preserved samples as being locally derived. In addition, the samples with C/N ratios outside this range (2.9–3.6), or which contained less preserved collagen, also showed no indication that their $\delta^{18}O_P$ values were different from the others.

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