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Shifting weaning practices in Early Neolithic Cis-Baikal, Siberia: New insights from stable isotope analysis of molar micro-samples

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Abstract

Reconstructing individual dietary histories at Shamanka II, an Early Neolithic (7000–5700 cal. BP) Kitoi hunter-gatherer cemetery in Cis-Baikal, Siberia, revealed surprising intrapopulation variability in childhood diets. Stable isotope analytical data produced by micro-sampled first molars identified changes in both the timing and rate of weaning for different individuals. Further, examination within the framework of a high-resolution radiocarbon chronology identified shifting practices between two phases of cemetery use, and additional links with mortuary treatment that indicates differences relating to group and/or family structure. The differential treatment of infants, correlated with the complex hunter-gatherer social structure, and subsequent burial treatment evident at this cemetery are investigated in light of regional dietary trends.

KEYWORDS

dietary patterns, hunter-gatherer, incremental analysis, parental strategies

1 | INTRODUCTION

Bulk data for carbon (δ^{13}C), and nitrogen (δ^{15}N), indicate dietary variability and the need for refined temporal resolution prior to their use in support of behavioural inferences for hunter-gatherers at the Shamanka II cemetery in Cis-Baikal, Siberia (Katzenberg & Weber, 1999; Weber, Link, & Katzenberg, 2002). Recent studies at Shamanka II using short-turnover bones and long-bone subsampling have demonstrated that fish consumption was increasing within populations during the Early Neolithic (EN; Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016). Increased reliance on aquatic resources could not be clearly linked with any single technological means of harvesting, or other evidence of intensification (Scharlotta, Bazaliiskii, & Weber, 2016; Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016).

Efforts to demonstrate links between social hierarchies during life and differential burial treatment in death (e.g., Linderholm, Jonson Charlotte, Svensk, & Lidén, 2015; Privat, O'Connell, & Richards, 2002) using dietary isotopes and graves inferred as holding status or value (inclusion of such goods as nephrite rings and axes) have proved

inconclusive (Scharlotta et al., 2016). As a result, questions remain regarding how observable variability in the mortuary record (i.e., differential distribution of prestigious grave goods) came into being and was perpetuated through two phases of cemetery activity over a period of 1,300 years (Bazaliiskii, 2003; Bazaliiskii, 2010; Scharlotta et al., 2016; Weber, 1995; Weber et al., 2002). Uncertainty regarding the underlying forces driving the variability and inequality observed in Early Neolithic mortuary assemblage suggests that more individualised aspects of nutrition are likely involved.

Micro-sampling of human molar dentin provides refined temporal resolution and allows the direct examination of subsistence responses to conditions experienced by hunter-gatherers through individual life histories (Beaumont, Gledhill, Lee-Thorp, & Montgomery, 2013; Eerkens, Berget, & Bartelink, 2011; Zvelebil & Weber, 2013). These patterns of individual life history can then be used to extrapolate larger group-level reactions to environmental risks through time.

Variability in breastfeeding and weaning practices, or lack thereof, may be an indication of the existence of community norms. For example, differential weaning onset/duration, standardisation of weaning/

post-weaning diets that could indicate the preferential use of specific weaning foods, or differences in the care provided to male/female children (Hewlett & Lamb, 2005; Tsutaya, 2017; Tsutaya & Yoneda, 2015). Fluctuations in these dietary trends through time could indicate changing cultural norms, or reactions by the population to changing environmental conditions, demographic shifts, and subsistence decisions influenced by technology (e.g., storage facilities and mass harvesting tools; Bentley, 1985). Poor evidence for any type of standardisation in diet and weaning and diets would suggest either a lack of any clear expectations for child-rearing practices within the culture (Greenwald, Eerkens, & Bartelink, 2016) or the presence of child-foraging subsistence practices (Eerkens, Washburn, & Greenwald, 2017; Greenwald et al., 2016). The goal of this research is to investigate how, or the degree to which, aspects of breastfeeding and weaning relates to patterning in adult diets, subsistence behaviour, and mortuary treatment.

2 | RESEARCH FRAMEWORK

2.1 | Weaning inferences

There are consistent hierarchical relationships for nitrogen enrichment based on trophic level within food webs (Ambrose, 1991; DeNiro & Epstein, 1981; Hedges & Reynard, 2007; McCutchan Jr., Lewis Jr., Kendall, & McGrath, 2003; Perkins et al., 2014; Post, 2002). An infant's diet represents a trophic step (2–4‰) above their mother (Fogel, Tuross, & Owsley, 1989; Millard, 2000). The process of weaning is visible in the isotopic record as a decline from this elevated trophic position to one representing consumption of solid foods (Fuller, Fuller, Harris, & Hedges, 2006).

Archaeologists can use this pattern to reconstruct weaning patterns in archaeological bones and teeth in several ways, including analysis of entire cemeteries that contain nonadults of varied age-at-death; intra-long bone analysis of portions from the diaphysis and metaphysis of nonadults whose bones have not remodelled; as well as through incremental analysis of dentin (Beaumont, Montgomery, Buckberry, & Jay, 2015; Eerkens et al., 2011; Fogel et al., 1989; Fuller et al., 2006; Fuller, Richards, & Mays, 2003; Tsutaya & Yoneda, 2015; Waters-Rist, Bazaliiskii, Weber, & Katzenberg, 2011). One challenge of analysing the skeletons of children is that they died before reaching adulthood and therefore may represent a biassed picture of dietary and/or health patterns in a prehistoric population. The benefit of incremental dentin analysis is that they are collected from individuals who reached adulthood; their M1 contains records of the weaning process, post-weaning diets, and the transition to juvenile/adolescent diets without the uncertainty of potential health/starvation issues (Eerkens et al., 2011; Eerkens & Bartelink, 2013).

Similar patterns are observable in $\delta^{13}C$, though with a smaller and more variable trophic-level effects of 0.2–1.0‰ for each level (Bocherens & Drucker, 2003; McCutchan Jr. et al., 2003; Perkins et al., 2014; Post, 2002). Due to the smaller and more variable nature of this trophic shift, $\delta^{13}C$ is generally not used as the primary means of inferring patterns of weaning. Instead, $\delta^{13}C$ tracks changes in the carbon source of dietary protein and routing through different food webs which in Cis-Baikal helps to differentiate between terrestrial and aquatic foods, and parse out different fisheries (Weber et al., 2011), based on the length of the food webs in different types of watercourses (e.g., small mountain rivers, large mature rivers, lake-shore, and deep-water lake). In this regard, $\delta^{13}C$ will primarily help to inform on post-weaning foods and diet breadth during the first decade of life (Drucker & Bocherens, 2004; Tsutaya, 2017), and hopefully shed light on the presence, or absence, of specialised child diets or evidence of child foraging (Eerkens et al., 2017; Greenwald et al., 2016; Tsutaya, Sawada, Dodo, Mukai, & Yoneda, 2013).

Diets excessively high in protein can also cause enriched $\delta^{15}N$ through high deamination (breakdown of amino acids in the liver) but also leads to wasting and kidney failure (Focken, 2001). The process of starvation, both protein-starvation and lack of overall nutritional intake, can also mimic the nursing pattern of $\delta^{15}N$ elevation in bodily tissues, including hair, bone, and dentin (Beaumont & Montgomery, 2016; D'Ortenzio, Brickley, Schwarcz, & Prowse, 2015; Fuller et al., 2005). Under nutritional stress the body catabolises stored nitrogen sources (e.g., muscle protein and unmineralized collagen), resulting in body wasting and ultimately death (Fuller et al., 2005). It is possible that growing infants could outpace the protein content of their mother's breastmilk and thus appear to be nutritionally deficient for short periods of time. The addition of solid foods presents a vector for intestinal parasites and food-borne pathogens that can (Filteau, 2000; Jay, 2009). These can cause illness and precipitate catabolization of tissues, with concomitant $\delta^{15}N$ enrichment (Katzenberg & Lovell, 1999).

Catabolysis may not be a major factor impacting studies on individuals who survived to adulthood. Infants do not have the bodily reserves to survive for very long without breastmilk or other foods. If this level of nutritional stress was present, skeletal indicators such as enamel hypoplasia and Harris lines are to be expected for surviving individuals; however, the high rate of mortality (69%) for weaning infants suggests that death was the more common outcome if there were problems (Waters-Rist et al., 2011). As discussed below this process may help to explain some individual weaning patterns.

Parental behaviour related to breastfeeding is an important element in understanding cultural aspects of investment in children and population level fertility. Lactation is energetically expensive, as the mother is feeding a second individual out of her nutritional intake, and lowers female fertility, impacting short-term birth-spacing and long-term population growth (Bentley, 1985; Borgerhoff Mulder, 1992; Borgerhoff Mulder, 2000; Dettwyler, 2004; Eerkens et al., 2017; Hill, 1993; Kaplan, 1996; Tsutaya & Yoneda, 2015). The relative costs will be correlated to the prevalence of disease, risks of resource shortfalls, and other environmental hazards, thus, the length of weaning is hypothesised to fluctuate with changing circumstances throughout the EN.

2.2 | Subsistence inferences

Remaining puzzles from previous work at Shamanka II include the source of increased risk(s) that differentiated the EN individuals. For example, were the risks of bacterial pathogens from relying on badly preserved fish resources increased by the absence of structured

storage facilities, currently unknown archaeologically from EN Cis-Baikal, impacting population growth? Or more broadly, are there correlations between the weaning age, used as a proxy for parental investment considering the extrinsic risks as they perceived them, grave goods, or consumption of fish? In general, more fish was known to have been consumed through two separate phases of cemetery use at Shamanka II, indicating that some aspect of the population's interaction with their environment was changing. This could include resource depletion, population expansion, or more random ebb and flow in human and animal population numbers. The extent to which optimal foraging theoretical expectations hold true for shifting dietary breadth as a response to various stressors is unclear.

Patterns of weaning are likely to shift because of nutritional stress. Shifting weaning to later age could increase the survivability of individual children as a short-term response to systemic dietary shortfalls (e.g., late winter-early spring fat depletion; Bentley, 1985). However, there may follow a long-term shift in group diets if dietary stress is being experienced for many years or decades. Changing the dietary breadth of the group as a whole would be expected as a result of stresses from overexploitation of higher ranked prey items (Bettinger, 1991; Broughton, 1997).

In the subarctic conditions of Cis-Baikal high fat resources such as moose, red deer, and seal are anticipated as holding the highest dietary rank and taking precedence over resources such as fish and roe deer that can be harvested in larger quantities. However, aquatic and terrestrial resources are at their prime at different times of the year but may be retained during the winter, which may confound the dietary breadth shifts (Bettinger, 2009; Bird & O'Connell, 2006; Brink, 2004). Overlapping isotopic ranges of multiple fish species (δ^{13}C: −28.6 to −9.6; δ^{15}N: 6.2–20.6) reported by Weber et al. (2011) coupled with the averaging effects of the dietary records over many months will negate the possibility of being able to recognise specific species.

Annual timing and shifting seasonal conditions can substantially alter their value within foraging economies (e.g., fat content, stress impacting meat quality, and fur/hide quality) both altering where they may fall in terms of dietary ranking (i.e., optimal foraging theory) as well as what the isotopic composition of the useable portions of animal (Ambrose, 1991; Ambrose, 1993; Fitzhugh & Habu, 2002; Formozov, 1964; Hedges & Reynard, 2007; Tieszen & Boutton, 1989). Dental data for Neolithic Cis-Baikal populations (Lieverse, Link, Bazaliiskiy, Goriunova, & Weber, 2007; Waters-Rist, Bazaliiskii, Weber, Goriunova, & Katzenberg, 2006) have suggested annual periodicity in stress episodes that fit well with both the changing state of animal health throughout the year, and with ethnographic accounts of seasonal late-winter/early-spring famines (Black-Rogers, 1986; Kuoljok, 1969; Stefansson, 1946; Turner & Davis, 1993). Regular periods of dietary shortfall may have been an important factor impacting the length of weaning, though Waters-Rist et al. (2011) notes caution, as the age when breastfeeding may no longer substantially moderate morbidity and mortality is variable within and between populations, being associated with multiple factors including pathogens, and the quality and quantity of weaning foods available (McDade & Worthman, 1998; Sellen & Smay, 2001).

Fat (lipids), protein, and carbohydrate dietary components are not equally represented by different isotopic proxies. For example, δ^{15}N and $\delta^{13}C_{collagen}$ values reflect the protein component of the diet more strongly than the carbohydrate or fat component, whereas $\delta^{13}C_{apatite}$ values reflect the entire diet; also, fats are heavily depleted in δ^{13}C as compared with other tissues of the same animal (Ambrose & Norr, 1993; Hedges, 2003; Lee-Thorp, Sealy, & van der Merwe, 1989; Tieszen & Fagre, 1993). Consumption of fat-rich or fat-poor portions of an animal will have different δ^{13}C values, as will any foods that included substantial amounts of fat (e.g., pemmican, berries mixed with seal oil [akutaq], and blubber [muktuk]; Griffin, 2009), potentially impacting efforts at dietary reconstruction (Fernandes, Grootes, Nadeau, & Nehlich, 2015). Lower ranked foods should still be visible in dietary trends even if fat resources are being conserved and mixed with other foods as the primary protein signal will stem from the lower fat foods.

Greenwald et al. (2016; Eerkens et al., 2017) discuss how shifting weaning ages correlate to changing conditions combining risks from natural hazards (including violence and predation), risks of resource failure or shortfall, with the ambient pathogen loads of the environment. Under conditions that are extrinsically high or low risk, the added value of additional parental investment in the form of extended breastfeeding is minimal, unlikely to alter the survival of their children. Under conditions of only moderate extrinsic risk, extending breastfeeding can have a substantial impact on the survival of children. As a result, extended breastfeeding can, under specific conditions, radically impact the survival of children and so alter the overall growth rate of populations.

Waters-Rist et al. (2011) observed that a large percentage (69%) of infants analysed from EN Shamanka II had died while breastfeeding. This suggests that a considerable stressor was affecting the population, exceeding the capacity of breastfeeding to shield infants from malnutrition or disease. The risks of malnutrition and mortality may have been influenced by annual periods of food scarcity, leading to later age-at-weaning in early versus Late Neolithic populations, as the latter population do not appear to have experienced the same level of hardship(s). The data from intra-long bone analysis of nonadults yielded similar conclusions as enamel defect data, suggesting that EN populations experienced more frequent, and possibly severe, stressors. Both datasets reflect stresses acute enough to suspend normal enamel development and/or lead to death.

3 | MATERIALS

3.1 | Shamanka II cemetery

The Shamanka II cemetery is located on the coast of Lake Baikal at its south-western-most end (Figure 1; Data S1; 103°42′11″E, 51°41′54″N). The cemetery is situated on a slope of a narrow peninsula that juts out into the lake in the E–W direction, near the mouth of a small river (Talaia). The peninsula is formed by two hills connected with each other by a bottleneck of low-lying land. The site was first discovered in 1962 when three graves were found to be eroding away along the cliff of the slope and has seen multiple excavations, with the most recent excavations completed in 2008 (Bazaliiski & Weber, 2004; Bazaliiski & Weber, 2006; Bazaliiskii, 2010).
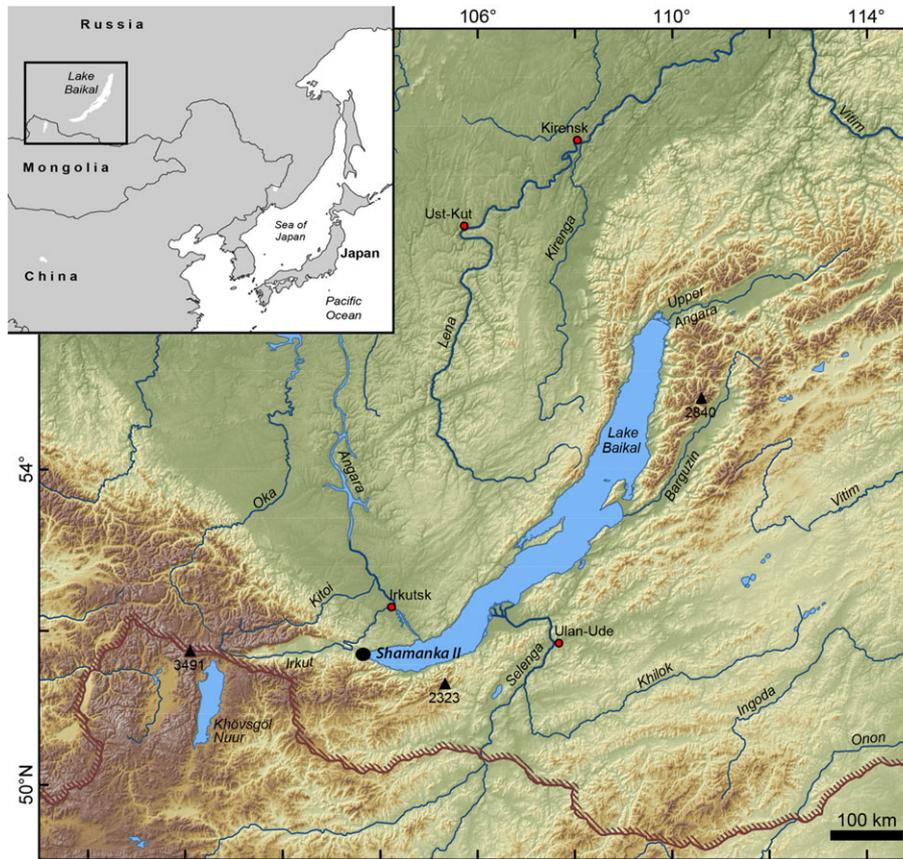
FIGURE 1 Location map of Cis-Baikal region, Siberia, within northern Asia. Topography is based on elevation Shuttle Radar Topography Mission (SRTM) v4.1 data (Jarvis, Reuter, Nelson, & Guevara, 2008) produced by Christian Leipe (FU Berlin) [Colour figure can be viewed at wileyonlinelibrary.com]

The EN component of this cemetery displays characteristics of the Kitoi mortuary tradition, including the extended supine body position, N–S or NE–SW orientation, graves with multiple interments, toe-to-head arrangements, and the use of red ochre (Bazaliiski & Weber, 2004; Bazaliiskii, 2003; Bazaliiskii, 2010). This tradition is also reflected in the assortment of grave goods, amongst that the most diagnostic are the shanks of Kitoi composite fishhooks and items of zoomorphic art, known from the other Kitoi cemeteries along the Angara valley (Bazaliiskii, 2010; Weber, 1995). The distribution of grave goods is quite variable, ranging from no objects, or very few, to interments with hundreds of items. The fact that many of the Kitoi graves at this site were extensively disturbed in the past is a rather unusual circumstance for this EN culture. A large number of the Kitoi burials have substantial parts of their skeletons missing.

A substantial freshwater reservoir offset in radiocarbon age between terrestrial herbivores and aquatic fauna of Lake Baikal from the same stratigraphic levels has been corrected using a combination of methods (Schulting, Ramsey, Bazaliiskii, Goriunova, & Weber, 2014; Weber et al., 2016). The results of corrections modelled with OxCal 4.2 indicate that there are two separate phases of cemetery use during the EN at Shamanka II: Phase 1 ($n = 94$) from approximately 7,532 to 7,461 corrected years BP (mean highest posterior distribution interval, 95.4% confidence level), and Phase 2 ($n = 16$) from 6,916 to 6,746 corrected years BP (mean highest posterior distribution interval, 95.4% confidence level).

First molars (M1) were sampled from 28 individuals at Shamanka II representing females ($n = 12$), males ($n = 16$), and include both Phases (Phase 1 [$n = 20$] and Phase 2 [$n = 8$]). These individuals were previously analysed for bone collagen carbon and nitrogen isotopes (Weber et al., 2011; Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016) as well as radiocarbon dates (Weber, Schulting, Bronk Ramsey, Bazaliiskii, Goriunova, & Berdnikova, 2016) calibrated for a regional reservoir correction (Table 1; Data S2).

4 | METHODS

4.1 | Sectioning and collagen extraction

Preparation protocols were modified from Eerkens et al. (2011). Molar crowns were scraped to remove any adhering calculus or exogenous material. Teeth were then carefully sectioned with a low-speed saw (Buehler Isomet), to first remove enamel, and then to remove a longitudinal (i.e., crown to root) section of dentin along the longest root. Enamel fragments were also collected for future analyses. Cut sections were sandblasted (Bego Duostar) in order to remove any remaining enamel, cementum, from the exterior and any secondary dentin from within the pulp chamber. Sandblasted sections were rinsed with deionised water and soaked in acetone for 24 hr. Rinsed samples were demineralised using 0.5 M hydrochloric acid (HCl) in a refrigerator set

TABLE 1 Age-at-death, sex, radiocarbon date, phase, beginning, end, duration, and rate of weaning, carbon (δ13C) and nitrogen (δ15N) results for bone, pre- and post-weaning M1, and standard deviation scores for δ13C and δ15N

Burial #	Sample ID	Age	Sex	Date (14C)	+/-	Phase	Beginning of weaning (years)	Completion of weaning (years)	Length of weaning process (years)	Rate of weaning	Est. mother's diet 13C (‰)	Est. mother's diet 15N (‰)	Pre-weaning diet 13C (‰)	Pre-weaning diet 15N (‰)	Pre-weaning diet C:N	Post-weaning diet 13C (‰)	Post-weaning diet 15N (‰)	Post-weaning diet C:N	Bone values 13C (‰)	Bone values 15N (‰)	Bone values C:N	M1 variance 13C STDev	M1 variance 15N STDev
6	H 2012.033	16–18	M	5875	74	2	1.1	3.2	2.1	Abrupt	−16.3	14.1	−16.1	16.1	3.2	−15.9	13.8	3.2	−16.2	15.9	3.1	0.62	0.71
7	H 2002.260	20–30	F	6001	72	2	1.1	2.1(4.9)	1(3.8)	Abrupt	−16.1	12.8	−15.9	14.8	3.2	−16.2	13.1	3.2	−16.4	13.7	3.2	0.33	0.56
34	H 2003.681	35–45	M	6609	73	1	1.1	3.9	2.8	Gradual	−17.8	12.0	−17.6	14.0	3.2	−17.9	12.8	3.2	−16.6	14.0	3.2	0.42	0.76
42.1	H 2004.016	40–45	F	5921	73	2	0.5*	1.5*	1.0	Abrupt	?	?	?	?	?	−17.6	14.6	3.3	−16.7	14.8	3.2	0.37	0.50
42.2	H 2004.022	50+	F	6890	69	1	0.9	1.7	0.8	Abrupt	−17.4	15.0	−17.2	17.0	3.3	−17.1	15.7	3.3	−17.7	10.4	3.4	0.52	0.38
49.1	H 2004.053	17–20	M	6039	69	2	0.9	4.5	3.6	Gradual	−17.2	16.2	−17.0	18.2	3.3	−16.7	12.8	3.3	−16.2	13.5	3.3	0.15	1.35
50.1	H 2004.105	25–35	M	5981	69	2	0.9	1.9(6.5)	1.0(5.6)	Abrupt	−17.1	13.4	−16.9	15.4	3.3	−16.4	14.6	3.3	−16.5	14.5	3.3	0.26	0.48
51	H 2004.060	20–25	M	6356	76	1	1.1	4.3	3.2	Gradual	−16.4	14.9	−16.2	16.9	3.3	−16.5	14.8	3.3	−16.6	15.1	3.4	0.38	0.54
52	H 2004.134	20–24	M	6320	76	1	0.9	3.7	2.8	Gradual	−14.9	15.5	−14.7	17.5	3.2	−15.4	14.6	3.3	−14.7	15.3	3.2	0.42	1.00
53.1	H 2004.065	20–25	M	6347	74	1	1.1	4.3	3.2	Gradual	−16.6	17.4	−16.4	19.4	3.3	−16.2	15.5	3.3	−16.2	15.7	3.4	0.35	1.13
54.1	H 2004.074	17–21	F	6417	75	1	1.4	2.8	1.4	Abrupt	−15.4	14.3	−15.2	16.3	3.3	−16.2	14.6	3.2	−15.2	15.2	3.3	0.41	0.73
55.1	H 2004.096	35–39	M	6440	75	1	1.2	2.4	1.2	Abrupt	−16.4	15.0	−16.2	17.0	3.3	−16.3	14.5	3.3	−15.9	14.6	3.4	0.35	0.86
58.1	H 2004.086	35–45	M	6628	70	1	0.5*	1.5*	1.0	Abrupt	?	?	?	?	?	−17.0	14.1	?	−16.8	13.9	3.3	0.31	0.46
59.2	H 2005.082	15–19	F	6296	75	1	0.9	5.1	4.2	Gradual	−17.0	14.3	−16.8	16.3	3.3	−17.1	14.7	3.3	−17.7	14.2	3.2	0.25	0.41
60.2	H 2005.059	40–44	F	6456	75	1	0.9	2.7	1.8	Abrupt	−17.3	13.6	−17.1	15.6	3.3	−17.6	13.6	3.3	−15.9	15.1	3.2	0.99	0.89
61.1	H 2005.048	25–29	F	6399	76	1	1.0	5.3	4.3	Gradual	−15.8	15.7	−15.6	17.7	3.3	−15.2	15.4	3.3	−15.0	14.9	3.2	0.19	0.76
63.1	H 2005.051	25–29	M	6278	75	1	0.9	2.8	1.9	Abrupt	−16.8	14.6	−16.6	16.6	3.3	−17.3	14.3	3.3	−15.5	15.4	3.3	0.83	0.61
64.1	H 2005.067	30–39	M	5902	74	2	0.5*	2.5	2.0	Abrupt	?	?	?	?	?	−17.2	14.4	3.3	−16.5	14.9	3.2	0.78	0.92
65	H 2005.054	50+	M	6563	71	1	0.5*	2.0	1.5	Abrupt	?	?	?	?	?	−16.6	14.7	3.3	−16.6	14.4	3.2	0.83	0.86
66.1	H 2005.079	25–35	F	6653	70	1	0.8	2.5	1.7	Abrupt	−17.5	14.7	−17.3	16.7	3.3	−18.3	13.0	3.3	−17.1	13.6	3.2	0.55	1.00
71	H 2006.044	35–45	M	6384	70	1	0.5*	2.5	2.0	Abrupt	?	?	?	?	?	−17.4	14.0	3.2	−16.3	14.7	3.2	0.75	0.82
73	H 2006.049	16–18	F	6631	78	1	1.0	2.1(5.5)	1.1(4.5)	Abrupt	−17.0	13.6	−16.8	15.6	3.2	−16.8	14.8	3.2	−16.5	14.1	3.3	0.83	0.36
76	H 2006.035	40–50	M	6614	74	1	0.5*	1.5	1.0	Abrupt	?	?	?	?	?	−15.9	14.6	3.2	−16.4	15.1	3.1	0.91	0.59
85	H 2007.003	25–35	M	6607	75	1	0.7	2.8(5.3)	1.1(4.6)	Abrupt	−17.1	16.4	−16.9	18.4	3.3	−16.1	15.3	3.3	−15.6	13.7	3.3	0.38	1.09
93.2	H 2007.042	35–40	F	6581	74	1	0.5*	2.7	2.2	Abrupt	?	?	?	?	?	−14.8	14.9	3.2	−17.0	14.5	3.1	0.65	0.45
96.2	H 2007.011	30–35	F	6282	69	1	1.5	4.2	2.8	Gradual	−15.7	14.1	−15.5	16.1	3.2	−15.8	13.9	3.3	−16.1	14.3	3.2	0.48	0.74
104	H 2008.013	20–35	F	5981	67	2	1.2	4.8	3.6	Gradual	−16.3	13.8	−16.1	15.8	3.3	−16.8	12.0	3.3	−16.3	13.9	3.2	0.27	1.03
108.3	H 2008.044	25–35	M	5915	72	2	0.8	4.7	3.9	Gradual	−17.5	16.6	−17.3	18.6	3.3	−17.8	15.1	3.2	−16.7	14.7	3.1	0.37	1.00

aNote. a(b) = possible multiphase weaning including a gradual secondary weaning; * = estimated weaning; ? = pre-weaning values missing due to wear. Bone values from Weber et?al., 2011, Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016. Dates presented as calibrated 14C years BP, following Weber, Schulting, Bronk Ramsey, Bazaliiskii, Goriunova, & Berdnikova, 2016. Trophic-enrichment values of 0.2‰ δ13C and 2‰ δ15N were used to estimate Mother's Diet.

at 5°C. HCl was changed every other day until the sample was completely demineralised (generally 1–2 weeks). Following demineralisation, samples were immersed in 0.125 M NaOH (sodium hydroxide) for 18–20 hr to remove humic acids. The sample was rinsed with dH$_2$O to remove any residual NaOH.

Tooth sections were then sliced into parallel serial sections 1-mm thick, beginning at the dentine–enamel junction under the molar crown and working down to the apical root tip (Figure 2). Note that these cuts are generally parallel to growth layers within the crown, but cut across diagonal growth layers in the root (Beaumont et al., 2013; Eerkens et al., 2011). Because layers accumulate in a cone-like manner within the root and we are unable to manually cut cones out of the demineralised root, but must cut horizontally across growth planes. As a result, adjacent serial samples in the root include some material from the same layers of growth (i.e., adjacent sections do not represent mutually exclusive temporal windows).

Current research (e.g., Burt, 2015; Czermak, Schermelleh, & Lee-Thorp, Forthcoming; van der Sluis, Reimer, & Lynnerup, 2015) to refine the ability to either improve slicing methods or use smaller dental punches may be able to further refine micro-sampling methods soon but are not yet feasible for large comparative projects.

The number of serial sections varied (n = 9–18 for Shamanka II molars) depending on the degree of occlusal wear, and the size, length, and structure of the tooth. The 28 molars yielded a total of 372 sections to be analysed.

Sections were moved to individual vials and placed in slightly acidic (pH 3, 0.01 M HCl) water and solubilised at 75°C. Solubilised collagen was then freeze–dried to remove all remaining water, isolating the collagen fraction. Between 0.9 and 1.1 mg of collagen was weighed out from each serial section for stable isotope analysis. In cases, there was not enough collagen from a serial sample, and adjacent sections had to be combined to achieve a total of 1 mg.
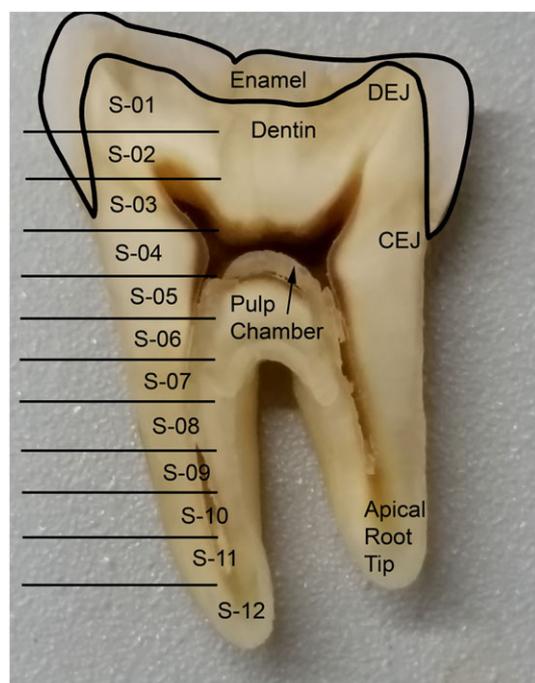
FIGURE 2 Model of molar dentine sectioning [Colour figure can be viewed at wileyonlinelibrary.com]

Carbon (^{13}C/^{12}C) and nitrogen (^{15}N/^{14}N) by isotope ratio analysis for each serial sample was measured at the Biogeochemical Analytical Laboratory of the Department of Biology, University of Alberta, using a EuroEA Elemental Analyzer (EuroVector) coupled with Isoprime Mass Spectrometer (GV Instruments). Mass spectrometer precision was ±0.1‰ for δ^{13}C and ± 0.2‰ for δ^{15}N.

Bone values for ^{14}C, δ^{13}C, and δ^{15}N have been previously published (Weber et al., 2011; Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016; Weber, Schulting, Bronk Ramsey, Bazaliiskii, Goriunova, & Berdnikova, 2016) and were conducted at the Oxford Radiocarbon Accelerator Unit.

4.2 | Reconstructing section-age

Ages were assigned to individual molar sections following Scharlotta, Goude, Herrscher, Bazaliiski, and Weber (2018) using a method derived from Beaumont (Beaumont et al., 2013; Beaumont & Montgomery, 2015). Beaumont's method approximates age based on the number of sections cut from a tooth and the population averaged growth rate for that tooth. For example, a mandibular first molar has a growth period of 9.7 years (age 0.3 through 10.0) based on age estimates from the London Atlas (AlQahtani, Hector, & Liversidge, 2010; AlQahtani, Hector, & Liversidge, 2014). If a molar is 13-mm long and cut into 13 sections, this would approximate a growth rate of 0.746 years (272 days) per 1-mm section.

Mildly worn (<½ mm wear) and unevenly worn teeth were sampled on the side of the tooth with the least wear and required no specific modification as minor offsets are likely within the errors produced by measuring and cutting when combined with overlaps resulting from conical formation. Teeth with dentin worn by more than ½ mm under the dentine–enamel junction, visual estimates of the extent of lost dentin were made based on remaining enamel. For example, if approximately 1½ mm of dentin was missing through wear, then the initiation age for the tooth was moved up by 408 days (272 days/mm * 1½ mm), and the total development time reduced accordingly. The growth rate derived from this estimation was then modified by a proportional multiplier to approximate the differing dentin growth rates along the molar root (Scharlotta et al., 2018). Ages are presented as the midpoint of the starting and stopping ages of the section.

The populations used by AlQahtani lived in London and thus are not purely indicative of genetically similar populations to those at Shamanka II. These records likely include a number of Asian populations but are not likely to solely reflect northern Asian or Siberian populations and may alter the precision of age-estimates for incremental sections. Analysis of the efficacy of different age-assessment and growth rate models (Scharlotta et al., 2018) showed superior results for aligning multimolar dietary sequences at Shamanka II using development ages from Haaviko (1970). The model was chosen to help refine the weaning age assessments.

4.3 | Weaning age

All individuals were assumed to have been breastfed by their biological mother, though a wet nurse or relative could have been recruited if the mother were unable to breastfeed. The weaning process was

inferred from changing $\delta^{15}N$ levels, expected to drop by 2–4‰ as the dietary protein source moves from breastmilk to another source, presumably transitioning to a diet of solid foods (Eerkens et al., 2011; Fuller et al., 2006). Cereal or other plant-based gruels are not anticipated for EN Cis-Baikal populations as there are limited plant resources; fish gruels seem probable given the dietary information available for adults (Katzenberg & Weber, 1999; Waters-Rist et al., 2011).

This process is assumed to involve some type of weaning foods which could be softened foods (e.g., animal or cereal gruels), or simply foods prechewed by adults prior to consumption (Waters-Rist et al., 2011). Premastication of foods has dual benefits for the child, reducing the foods in size and toughness, making them physically easier to eat, as well as having the maternal saliva beginning the chemical process of enzymatic digestion for complex carbohydrates, a process that develops slowly in infants (Pelto, Zhang, & Habicht, 2009; Waters-Rist et al., 2011).

The speed of $\delta^{15}N$ shift will depend on the abruptness of the weaning and the isotopic composition of the weaning food (Eerkens et al., 2011; Eerkens & Bartelink, 2013). Cross-cultural surveys using ethnohistoric accounts show hunter-gatherers have an average weaning completion age of 32 months (Sellen & Smay, 2001). Sellen and Smay (2001) note that their data may be biassed by modern influences. This was described as more of influence by the presence of western ethnographers combined with biases in their accounts; however, the impacts of cultural influences by agrarian and pastoral neighbours remain unknown. Hunter-gatherers have been noted as being particularly resilient in maintaining cultural practices, though this does not necessarily suggest that modern hunter-gatherers should be taken as direct analogues for EN Siberians (Kelly, 2013; Smith, 2018).

This study uses two dichotomies related to the timing and rate of weaning: early/late and abrupt/gradual. Early denotes individuals who completed weaning by the age of 2.5 years, late those who completed the process later, following the distributions noted for historic and modern populations (Sellen & Smay, 2001). The rate of weaning aims to parse out aspects of the onset and duration of weaning, with abrupt referring to individuals who were weaned in less than 2.5 years (duration, not age), gradual those who took longer.

Weaning ages were determined based on the lowest $\delta^{15}N$ reached during the initial post-nursing dip. This drop in $\delta^{15}N$ can be thought of in two ways, as either the reduction and ultimate termination of breast milk to the infant and the dietary replacement of protein from other sources; or, as the reduction in protein sufficiency provided by breast milk to a growing infant, such that even if breast milk is being consumed, the total protein contribution is inadequate for the needs of the child and requires supplementation (Beaumont et al., 2015; Eerkens et al., 2011; Fuller et al., 2006; Jay, 2009; Oddy, 2002; Tsutaya & Yoneda, 2015).

Pre-weaning diets were inferred from point(s) preceding the $\delta^{15}N$ nursing decline. For many individuals, this reflects a single point as nitrogen values were declining by the second dentin section. Post-weaning diets are determined based on the weaning age, using the subsequent dentin section to infer foods eaten once breastmilk was no longer the primary protein source.

4.4 | Maternal diets

Indirect information can be inferred based on the infant's breastfeeding signals. The breastfeeding infant is a trophic level (~3‰ $\delta^{15}N$, ~1‰ $\delta^{13}C$) higher than their mother (or whomever was breastfeeding the infant; Fuller et al., 2006). A crude estimate of the adult's diet during this period can be made by removing this trophic step. There are many variables that will impact the accuracy of this estimate such as changing characteristics of maternal milk during the course of breastfeeding, or catabolism of maternal tissues to meet the nutritional needs of the child (Fuller et al., 2005; Herrscher, Goude, & Metz, 2017). These data can compare with adult diets reconstructed from bone isotopic values. The goal is not to reconstruct adult diets by proxy, as we can examine interred adults directly, but to investigate if any specialised diets were being given to mothers.

Another aspect of this information would be an estimate of dietary stability for the nursing mother. There is considerable variability in both adult diets (bone $\delta^{13}C$ and $\delta^{15}N$ values; Table 1) and within the subadult years represented by incremental sections of first molars (Data S2). If the mother experienced one or more of these drastic dietary shifts while breastfeeding, then the infant's $\delta^{15}N$ would be expected to change as well. The opposite can also be inferred to occur, so if infant dietary signals remain stable then their mothers are likely to have had consistent diets while breastfeeding.

4.5 | Diet breadth

Diet breadth models distinguish between long-term subsistence strategies based on food-prioritisation expectations. Focusing subsistence efforts on large-package game resources, as opposed to smaller animals and/or plant resources will produce different isotopic signatures (Drucker & Bocherens, 2004). The two highest ranked resource groups are anticipated to be large ungulates (moose and red deer) and seals, based on both their size and fat content (Bettinger, 1991; Broughton, 1997). Low-ranked resources would be small mammals (hare and ground squirrel) and small/low-fat fishes that are less likely to provide the total calories or fat content needed to survive in the subarctic.

There are various fish species that could hypothetically have been accessed in quantities to comparable to large-bodied mammals. Grayling, omul', sturgeon, and other fish that would rank highly in diet breadth model models share properties of large body size (individual package), form large schools (multicomponent package) routinely or during spawning runs, and/or contain higher fat content and desirable flesh qualities that also have modern commercial value (Broughton, 1997; Drucker & Bocherens, 2004).

Identifying isotopic signals of fishing strategies is challenging in Cis-Baikal as aquatic signals cover the broadest isotopic range (Katzenberg, McKenzie, Losey, Goriunova, & Weber, 2012; Weber et al., 2011). Seals and sturgeon have depleted $\delta^{13}C$ and elevated $\delta^{15}N$ values; omul' has depleted $\delta^{13}C$ and low-moderate $\delta^{15}N$ values. Grayling, lenok, and pike have enriched $\delta^{13}C$ and relatively low $\delta^{15}N$ values. Fishing efforts targeting smaller rivers would have yielded lower returns based on the limited productivity of the watercourse and would have exhibited depleted $\delta^{13}C$ and $\delta^{15}N$ values. Other fish

species (e.g., roach, dace, and perch) are variable depending on their habitat, being more common in smaller rivers, and span the gap between these two isotopic clusters, making it difficult to form clear fishing strategies as reference groups, though few of these can be targeted or mass-harvested and are likely to be opportunistic contributors. Terrestrial foods have more constrained ranges with depleted $\delta^{13}C$ and $\delta^{15}N$ values, though there is potential overlap between small mammals (e.g., hare and ground squirrel) and riverine aquatic groups (Weber et al., 2011).

Studies looking at changing diet breadth, generally focus on shifting population averages (Broughton, 1997; Drucker & Bocherens, 2004; Hildebrandt & McGuire, 2002; Lindstrom, 1996; Madsen & Schmitt, 1998); however, here, we can look at individual dietary decisions early to see if they are making different choices through time. Diet breadth was gauged using standard deviation of $\delta^{13}C$ and $\delta^{15}N$ values throughout the duration of M1 formation (Table 1). These values are calculated on the basis of individual variation, not on the basis of deviation from a population average, or other group metric.

Individual dentin sections represent subannual spans, so potentially reflect aspects of seasonal rounds, or portions of multi-annual cycles of subsistence efforts. In this scenario, increasing diet breadth is interpreted as more opportunistic exploitation of any fish species that can be accessed as this will be the single greatest contributor to isotopic variability. Reliance or focus on one or two of the major dietary resource groups (e.g., seals or deer) will reduce variability and homogenise long-term patterns, reducing standard deviation from the individual decadal dietary average. Conversely, increased variance would denote the use of all available subsistence options in comparable proportions, consistent with broad spectrum dietary patterns. Greater variability measured in this first decade of life is thus inferred as representing greater diet breadth.

5 | RESULTS

All samples have carbon-to-nitrogen (C:N) ratios between 2.9 and 3.6 (Table 1; Data S2), in line with guidelines for well-preserved collagen (Ambrose, 1990; DeNiro, 1985). Only two samples falling below 3.2 (2.9 and 3.0) and one sample above 3.5 (3.6), suggesting close adherence to the even higher quality standards of 3.1–3.5 suggested by van Klinken (1999). Collagen yield was not used as a data quality measure for this study, as teeth were demineralised prior to cutting, and no original weights were available for calculation. Collagen weight percentages were calculated from measured combusted collagen (Data S2). Bocherens, Mashkour, Drucker, Moussa, and Billiou (2006) suggested that weight per cent of 40% C and 14% N indicate good quality collagen. The Shamanka II samples fell above these marks with the exception of two samples. One sample had 13.1% N, and a second one had 38.1% C; however, both samples yielded acceptable C:N ratios.

Average weaning length for "abruptly" weaned individuals was only 1.3 years in spite of defining weaning rate division as 2.5 years. The shortest "gradual" rate was 2.8 years, with a mean of 3.4 years. Six individuals with an abrupt process still had gradual late weaning completion ages. Figure 3 shows examples of early/abrupt weaning, late/gradual, and several versions of a third mixed-gradual pattern.
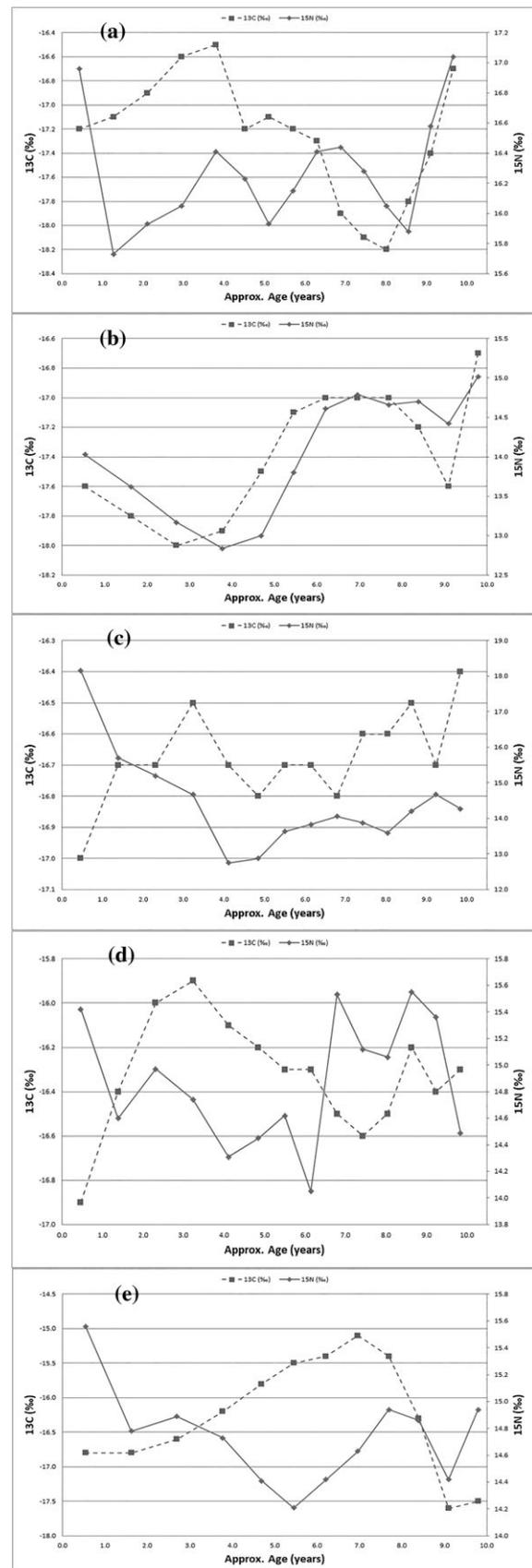
FIGURE 3 Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) molar data from (a) Burial 42.2 exhibiting an abrupt pattern of weaning; (b) Burial 34 exhibiting a gradual pattern of weaning; (c) Burial 49, (d) Burial 50.1, and (e) Burial 73, demonstrating variations of the mixed-gradual pattern of weaning. Note the initial sharp drop in $\delta^{15}N$ followed by gradual declines and/or temporary $\delta^{15}N$ elevations

There were 18 individuals identified as having an abrupt weaning process, lasting less than 2.5 years. Four of these "abrupt" individuals exhibited a secondary pattern where following an initial drop in $\delta^{15}N$ values; there was a second more gradual period of $\delta^{15}N$ decline. A total of 10 individuals were identified as having a gradual weaning pattern lasting longer than 2.5 years and lacking any initial steep decline in $\delta^{15}N$ values.

Onset of weaning begins at 0.7 year through to an age of 1.5 years. The weaning process varied from 0.8 to 5.6 years in length. There were seven individuals whose weaning process began before the first section analysed, nominally estimated as an onset age of 0.5 year (6 months). The completion of weaning ranged from 1.5 to 6.5 years, though showed two different patterns when divided by phase (Figure 5). Weaning completion ages increased through Phase 1 but decreased during Phase 2. Dividing these data by sex did not produce different patterns (Figure 6). Comparing weaning completion age with the number of associated grave goods (Figure 8), there was a correlation between the weaning age and the number of grave goods. Individuals with more than 30 grave goods all had gradual weaning patterns, yet not all individuals with gradual or late weaning patterns had abundant grave goods.

Pre-weaning $\delta^{13}C$ varied across 2.9‰ from −17.6‰ to −14.7‰ and $\delta^{15}N$ values covered an even wider range of 5.4‰, from 14.0‰ to 19.4‰. Post-weaning diets variability covered 3.5‰ (−18.3‰ to −14.8‰) for $\delta^{13}C$ and 2.7‰ (12.0–15.7‰) for $\delta^{15}N$ values. Investigating if sex-biassing was occurring (cf. Eerkens & Bartelink, 2013), and whether such a pattern was consistent through the two cemetery phases was inconclusive (Figure 7). Separating out Shamanka II individuals by sex and/or chronological phase produced observable but insignificantly (<1‰) different patterns.

Pre-weaning diets were used to approximate the diets of breastfeeding mothers. Taking away the trophic step resulting from nursing (pre-weaning) yields $\delta^{13}C$ and $\delta^{15}N$ values for the inferred diets of the mothers. If we use trophic-enrichment of 1‰ $\delta^{13}C$ and 3‰ $\delta^{15}N$, then the mother's diets averaged −17.4‰ (−18.6‰ to −15.7‰) $\delta^{13}C$ and 13.7‰ (11.0–16.4‰) $\delta^{15}N$, with the same variance as pre-weaning diet. This is different than the bone averages, −16.3‰ $\delta^{13}C$ and 14.5‰ $\delta^{15}N$ for these same individuals. Adult bone isotopic values show increasing trends on both carbon and nitrogen through each of the two phases (Figure 4). If the lower range of trophic-enrichment values 0.2‰ $\delta^{13}C$ and 2‰ $\delta^{15}N$ are employed, then mother's values are virtually identical to the adult averages at Shamanka II.

Diet breadth was gauged using standard deviation of $\delta^{13}C$ and $\delta^{15}N$ values throughout the duration of M1 formation and show opposing patterns during the two cemetery phases (Figure 9). Variance values for $\delta^{13}C$ ranged from 0.15 to 0.99, and $\delta^{15}N$ from 0.36 to 1.35. During Phase 1, the variance decreased for carbon and increased for nitrogen. During Phase 2, the opposite occurred, with carbon increasing variance and nitrogen decreasing.

6 | DISCUSSION

6.1 | Dietary variability inferred for breastfeeding mothers

The nursing and weaning periods are highly variable in terms of health and development. Factors including inputs from different protein sources (e.g., digestibility of different foods and metabolic conversion of food to breastmilk), inaccurate diet-to-collagen assumptions, metabolic prioritisation and routing factors in collagen formation, environmental stressors including extreme weather and pathogens, and individual growth rates amongst compounding factors (Ambrose, 1991, 1993; Ambrose & Katzenberg, 2001; Ambrose & Norr, 1993; Fogel et al., 1989; Fuller et al., 2006; Jay, 2009; Link, 1996; Millard,
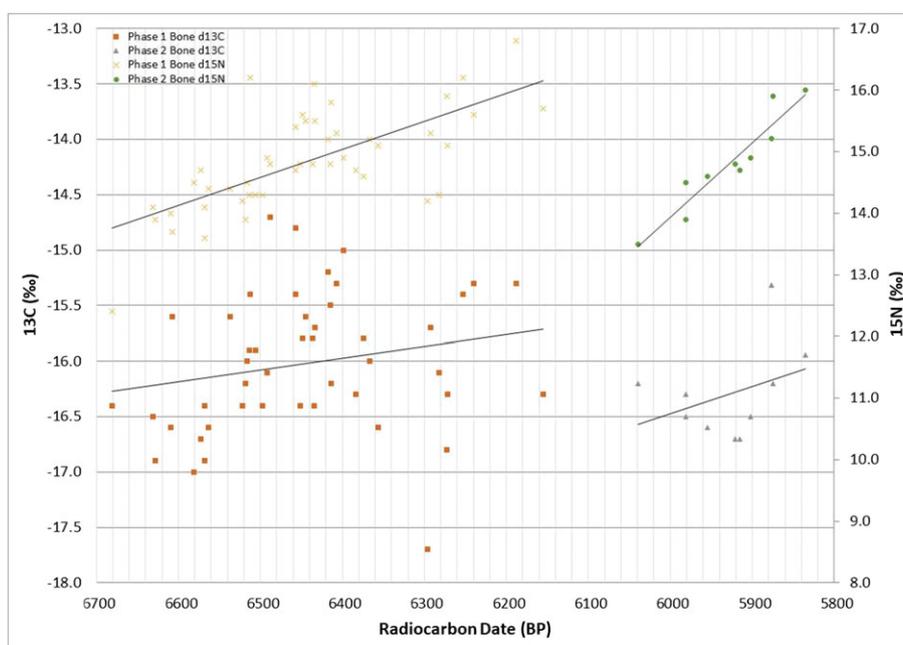
FIGURE 4 Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) data from bone samples at Shamanka II separated by chronological phases (1 and 2) [Colour figure can be viewed at wileyonlinelibrary.com]

2000; Reynard & Tuross, 2015; Tieszen & Fagre, 1993; Tsutaya & Yoneda, 2015; Waters-Rist et al., 2006, 2011). For example, protein-poor diets can errantly indicate high protein consumption, as even small amounts of milk protein make the largest contribution to collagen proxies (Reynard & Tuross, 2015; Waters-Rist et al., 2011). However, this type of masking effect is unlikely in high-protein diets characterising Cis-Baikal hunter-gatherers (Weber et al., 2011; Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016).

Assuming culturally and/or spatially related populations would experience the same sets of challenges may not be valid, as shown in California contemporaries (Eerkens et al., 2017). The long-term survival of the EN Kitoi culture suggests a population able to accommodate these potential challenges. Though as discussed below, the extrinsic risks may have reached a tipping point and required modification of weaning practices.

Waters-Rist et al. (2011) inferred that most adult females buried at Shamanka II are the mothers of the subadults also buried there, thus, could reasonably be expected to show similar isotopic variation between breastfeeding infants and adult females (see also Reynard & Tuross, 2015). Though they urged caution as intrasite variability can confound efforts to determine the feeding status of an infant; infants nursing from a breastfeeding female with particularly low $\delta^{15}N$ values would also have low values and could erroneously be interpreted as having completed weaning. Teeth do not share this uncertainty, with pre-weaning and adult (rib) values observable in the same individuals. Impacts of confounding factors appear limited as nonadult skeletons and adult dentin records yielded similar patterns.

The range of pre-weaning diets spans 5‰ $\delta^{15}N$, suggesting substantial variability in the diets of breastfeeding mothers. This was in line with variability in adult bone isotopic values for these same individuals was equally variable; with 3.0‰ (−17.7‰ to −14.7‰) for $\delta^{13}C$ and 5.5‰ (10.4–15.9‰) $\delta^{15}N$ values (Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016). The range of values does not support the idea that mothers were being given any type of specialised diet while breastfeeding, though one caveat is that if supplementary fats (e.g., akutaq) or fat-rich foods were being consumed, this would be difficult to observe in homogenised bone values. Future studies examining incremental dentin on M3s could potentially demonstrate such a pattern if a young adult were nursing and showed unusual shifts in $\delta^{13}C$ and $\delta^{15}N$ values.

6.2 | Post-weaning diet

Post-weaning children's diets are very similar to the adult bone values for these same individuals from Shamanka II. Weanlings average −16.7‰ $\delta^{13}C$ and 14.1‰ $\delta^{15}N$, whereas as adults their values are −16.3‰ $\delta^{13}C$ and 14.5‰ $\delta^{15}N$. With less than 1‰ difference between weanling and adult diets, it seems probable that children were given full access to whatever resources were available to the group, with no age-graded differences. However, if the offset visible with the mother's inferred diet is true and the trophic steps are comparative smaller with this group, then the carbon source may be somewhat different. Given the current understanding of $\delta^{13}C$ in Cis-Baikal (Katzenberg, Goriunova, & Weber, 2009; Katzenberg & Weber, 1999; Weber et al., 2011; Weber, Schulting, Bronk Ramsey, & Bazaliiskii,

2016), this difference is likely explicable by variability in which fish species individuals are consuming as children, versus their longer term adult averages.

6.3 | Weaning patterns

Within the Shamanka II samples analysed, there were multiple patterns of weaning observable. Eighteen of the individuals exhibited a pattern of early weaning (Figure 3a), in which the weaning process was begun essentially within the first year of life and was completed by the second or third sections representing approximately 18–32 months of life. This pattern suggests a complete replacement of breast milk as a protein source for the majority of children by the age of 2½ years. The second pattern (Figure 3b) was a gradual weaning process where the $\delta^{15}N$ decline was more gradual and the age of weaning appears to have been extended until ages 4–5 years.

Similar patterns have been observed in California hunter-gatherer populations, where the preferred method, seems to have been a gradual weaning process with the supplementation of infant/toddler diets with gruels (likely acorn, seeds, and/or tubers) and fish, shellfish (Eerkens et al., 2011; Greenwald et al., 2016). Individuals with very early or rapid weaning were inferred as having lost their mothers early and led different lives from the majority of the population. In Cis-Baikal, there are very limited vegetal resources, making a similar pattern implausible. Based on known resources, things such as prechewed meats or combinations of meat, fat, and possibly berries, mushrooms, and eggs seem more likely for EN populations that were extending their weaning (Waters-Rist et al., 2011). Fishes were being routinely harvested and can be prepared into a textural form that would suit infants (Weber, Schulting, Bronk Ramsey, & Bazaliiskii, 2016).

A third pattern is also present in a subset ($n = 4$) of the gradually weaned individuals (Figure 3c–e). They exhibit a mixed weaning pattern with a sharp initial drop in $\delta^{15}N$ but then show a pause before a second, elongated portion of the $\delta^{15}N$ decline-curve before finally reaching a minimum. These individuals would suggest several options: (a) that their protein needs were outstripping the capability of breast milk (i.e., mother may have been protein deficient) and was supplemented by solid food; (b) that the mother was experiencing a dietary shift, constituting a shift to foods with lower $\delta^{15}N$ values (e.g., terrestrial foods); (c) that weaning began but they were unable to retain healthy weight after an early weaning and required additional breast milk supplemented with additional foods for additional time; or (d) that some aspect of the weaning process resulted in disease, leaving the child with low $\delta^{15}N$ values (i.e., malnourished or minimally protein deficient).

This third pattern is most intriguing. Previous research has noted higher frequencies of linear enamel hypoplasia (LEN) during the EN (7.5%—Lokomotiv, 6.1%—Shamanka II) as compared with Late Neolithic and Early Bronze Age cemeteries (0%—Ust'-Ida, 2.9%—Khuzhir-Nuge XIV) in Cis-Baikal (Lieverse et al., 2007). Of the teeth analysed, 75% of LEN was identified on incisors and canines, with less than 5% of LEN noted on molars. This is surprising given that I_1, I_2, and C overlap in part, or entirely with the growth period of M1 (AlQahtani et al., 2010; Hillson, 2002). There is however a difference in terms of the volume/surface area of enamel formed, potentially making

incisors and canines more likely to show LEN as compared with molars. As noted, none of the molars sampled in this study showed signs of LEN, but this does not discount the possibility that these individuals were not experiencing nutritional stress.

Famine signatures from Ireland (Beaumont & Montgomery, 2016) were identified using dentin micro-sampling through a combination of $\delta^{15}N$ enrichment and $\delta^{13}C$ depletion, indicating a combination of catabolysis and consumption of imported corn meal. Of the four individuals showing the third weaning pattern, only Burial 50.1 shows a similar $\delta^{13}C/\delta^{15}N$ reversal (Figure 3e) and not until the estimated age of seven, falling after the weaning period had ended. The difficulty in translating this signature to Cis-Baikal hunter-gatherers is that there were no plant food supplements being imported and no known C_4 plant resources were available in Siberia (Katzenberg et al., 2009; Katzenberg et al., 2012; Katzenberg & Weber, 1999; Weber et al., 2011), so the only evidence of nutritional stress would be the catabolysis itself. Based on trophic effects, this should manifest as elevated $\delta^{13}C$ (~1‰) and $\delta^{15}N$ (~3‰), or some fraction of this trophic step depending on what foods were being consumed during periods of hardship. None of these four individuals demonstrate such a pattern, showing uncorrelated fluctuations in $\delta^{13}C$ and $\delta^{15}N$ during this extended weaning period. The possibility of receiving only supplemental breast milk along with a mixed solid food diet during this second phase, or being ill and manifesting as malnourished even with regular food intake are possible.

6.4 | Weaning age by phase

The individual dietary histories of first molars from Shamanka II suggest that diets were highly variable, and that populations were predominantly opportunistic hunter-gatherers, incorporating a wide variety of foods rather than relying heavily on a single resource (e.g., migratory deer herds or specific fish species).

This picture is tempered however, when examined through a broader chronological lens.

Individuals attributed as having experienced an abrupt or gradual weaning indicate variable levels of parental effort and attention, or a shift in extrinsic risk conditions, but the variance within these categories suggest that there was no singular practice that could be viewed as cultural norm(s) for how to raise infants. The largely bimodal nature of the weaning duration may suggest several options were maintained by these hunter-gatherers. There is an apparent gap of more than a year between the abrupt and gradual weaning approaches, with the latter benefitting from 18+ months of additional breast milk at nutritionally significant quantities.

The patterns observable with bulk bone isotopic data (Figure 4) are replicated with micro-sampled dentine (Figure 5), showing increased reliance on aquatic resources through the progression of the primary phase of cemetery use at Shamanka II. Phase 1 dietary changes were also correlated with increased weaning age and the frequency of gradual weaning. The pattern is starker during the second phase of cemetery use at Shamanka II, with individuals either benefiting from extended nursing opportunities, or simply not, being weaning abruptly and slightly earlier than during the initial phase.

The general pattern during Phase 2 at Shamanka II was decreasing weaning age; however, the average age at weaning is older (Phase 1: 3.3 years, Phase 2: 4.1 years), and the duration of weaning is also longer (Phase 1: 2.4 years, Phase 2: 3.2 years). The sample size for Phase 2 is small, potentially influencing these results, but the stark contrast between abruptly and gradually weaned individuals is much clearer. In Phase 1, the duration of weaning increases through time, though the difference between abrupt and gradual weaning is only 0.6 years there is still a bimodal aspect to the distribution. Phase 2 is notable
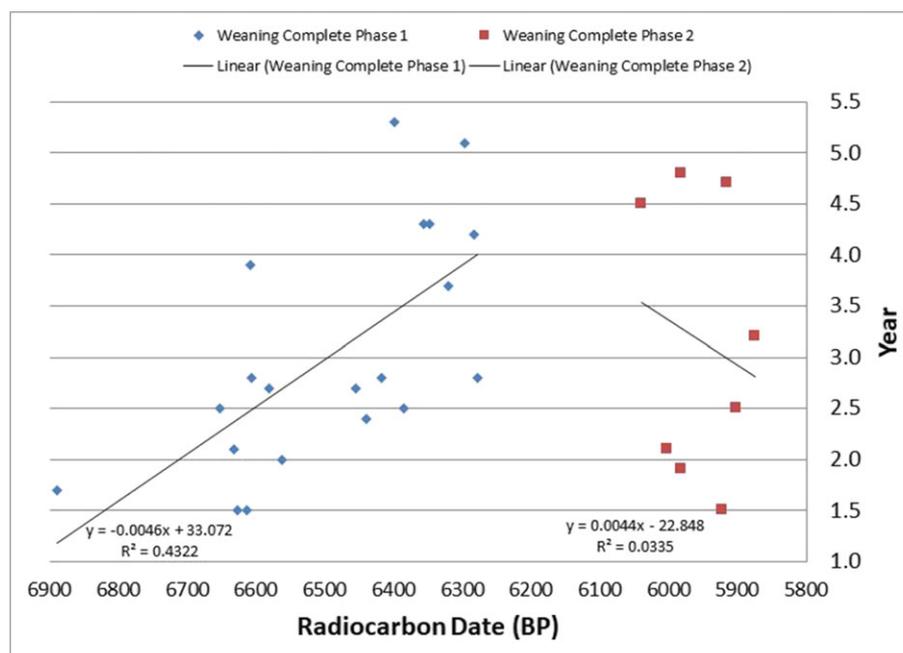
FIGURE 5   Weaning completion age for Phases 1 and 2 at Shamanka II [Colour figure can be viewed at wileyonlinelibrary.com]

for all individuals being clearly abrupt or gradual, with a separation between the two of 1.5 years. Extended breastfeeding was either practised or it was not, with little middle ground during this phase of cemetery use.

6.5 | Sex differences—Weaning age

In order to expand on the chronological differences in general weaning practices observed, the follow-up query is determining the extent that these data are being influenced or driven by sex-specific factors. Namely, are male or female children being breastfed differently? At Shamanka II (Figure 6a,b), no sex was necessarily valued more than the other, thus warranting special dietary attention as infants.

California hunter-gatherers have been identified as practicing sex-biassing in terms of diets within a largely monotonous general diet (Deniro & Schoeniger, 1983) as well as the weaning and post-weaning treatment of nonadults (Eerkens & Bartelink, 2013). Making inferences that males or females should be of higher value based on their relative contributions to either the subsistence economy or broader cultural patterns is less clear and depends on the values and structure of specific groups (Smith & Smith, 1994).

Gender-roles reflecting different societal value may not be surprising in a society heavily focused around hunting and fishing. Pursuit/capture of prey and production and maintenance of toolkits are often gendered tasks in ethnographic records of northern hunter-gatherers (Brumbach & Jarvenpa, 2017; Hodgetts, 2013; Smith & Smith, 1994). Further, assertions that gender-valued individuals will be doted upon in terms of infant nutrition is difficult to prove. Gendered or other social differences within a cultural group that would

lead to expectations of greater parental effort d towards one group over another are not supported for EN Cis-Baikal populations.

6.6 | Sex differences—Weaning/post-weaning diets

At the broader level, male and female children were not being breastfed differently, showing markedly similar age-at-completion and duration of weaning. There may yet be differences in how children are being treated at different points in life (e.g., age-specific taboos). Looking at sex differences between phases in terms of pre-, post-weaning, and adult bone dietary isotopic data, there is an interesting chronological trend (Figure 7a,b). Rather than identifying sex-based differences in parental investment akin to observations in California hunter-gatherers (Eerkens & Bartelink, 2013), we see a possible chronological gap in dietary patterns. On both δ^{13}C and δ^{15}N, we see a depression during Phase 2, but at less than 1‰, this difference is not statistically significant and may be limited by the sample size of the dataset.

6.7 | Weaning and artefacts

During Phase 1(Figure 8), there is a spike in gradual weaning age towards the end of the phase which is also correlated with increasing mortuary wealth, making individuals interred with greater wealth or prestige also more likely to have experienced greater parental investment in breastfeeding to delay the weaning process. Phase 2 is the culmination of the process begun during Phase 1, with differentiation between social groups; one showing relatively few grave goods and
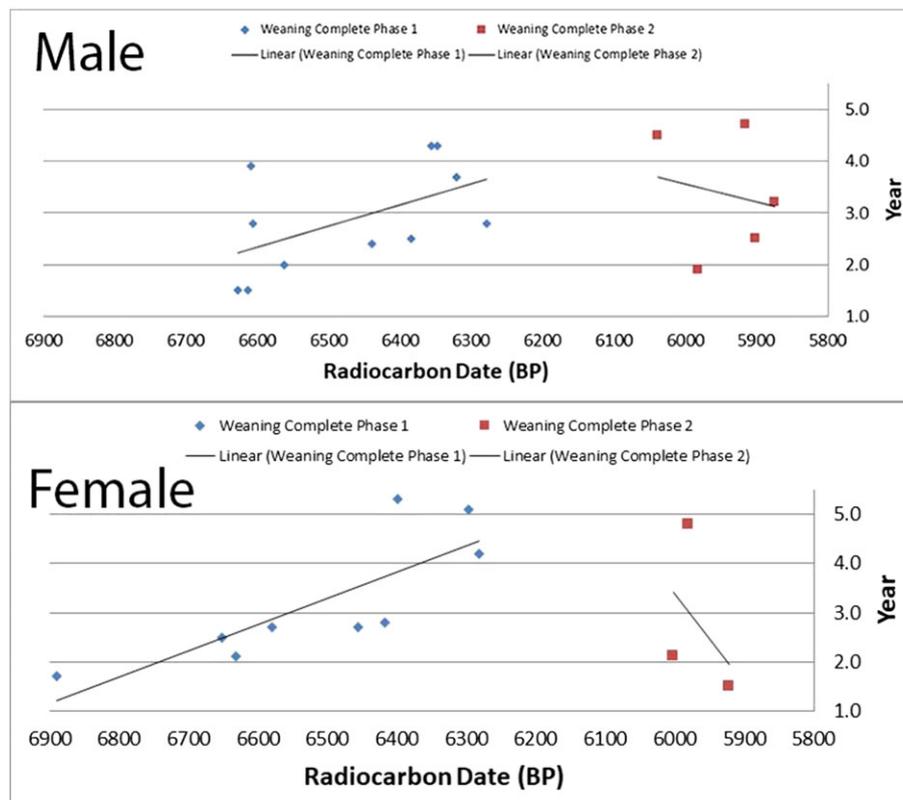
FIGURE 6 Weaning completion age for Phases 1 and 2 (a) Male and (b) Female [Colour figure can be viewed at wileyonlinelibrary.com]
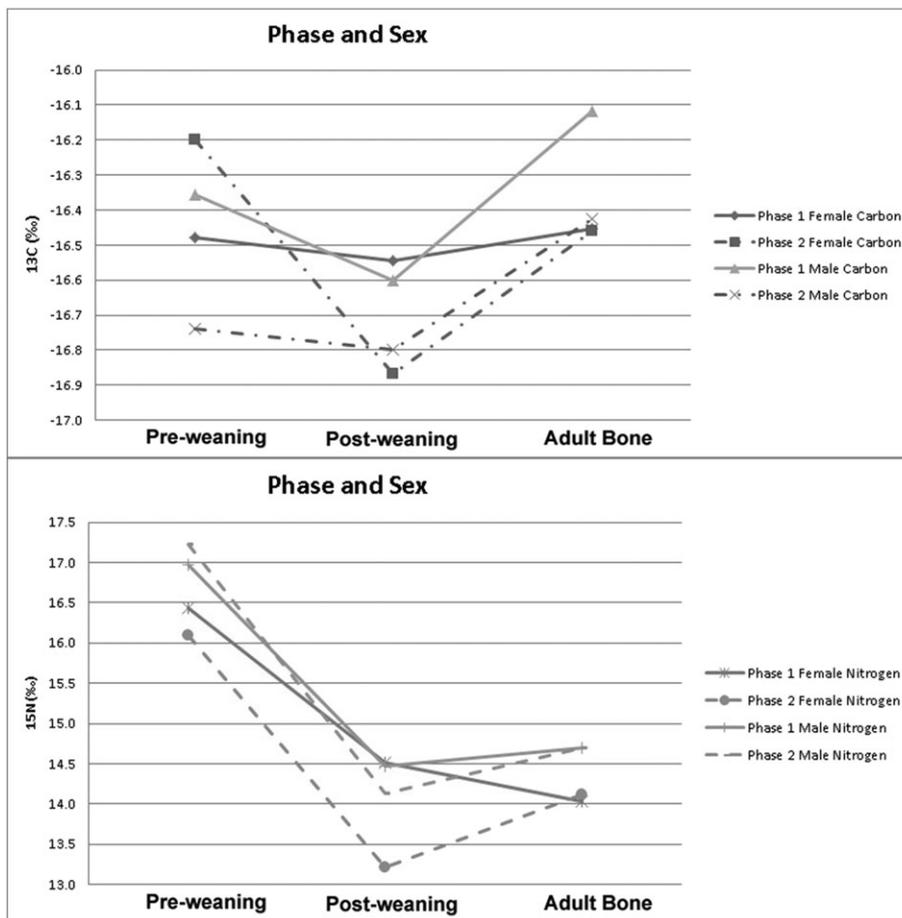
FIGURE 7 Averaged pre-weaning, post-weaning, and adult (bone) dietary information for males and females divided by phases at Shamanka II (a) carbon (δ^{13}C) and (b) nitrogen (δ^{15}N)
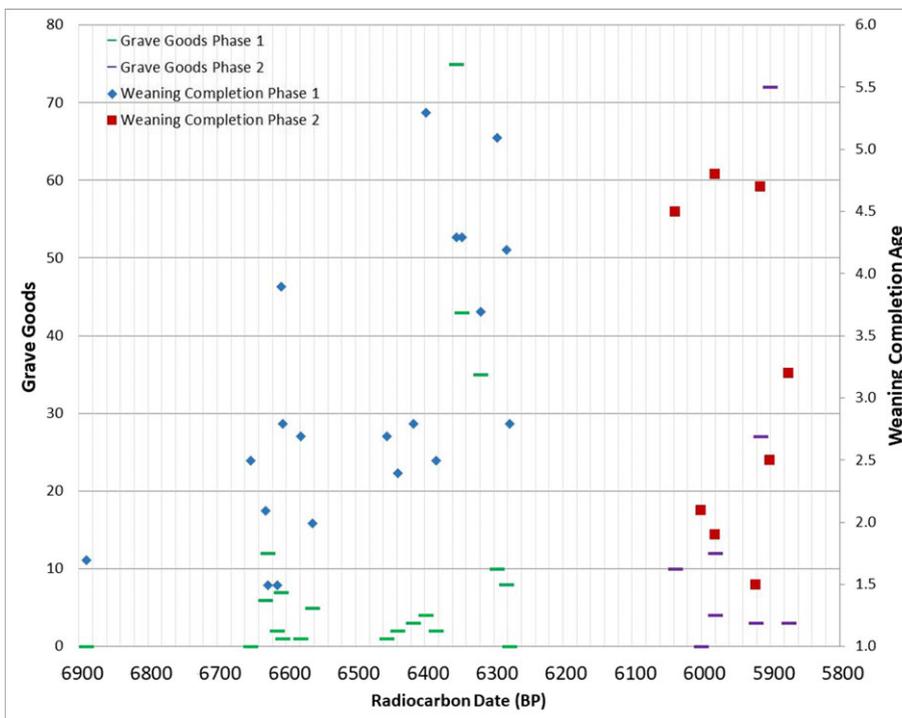
FIGURE 8 Weaning completion age for Phases 1 and 2 plotted against grave goods denoting wealth, prestige, and/or fishing technologies (scaled down) [Colour figure can be viewed at wileyonlinelibrary.com]

abrupt weaning patterns, the other showing greater burial wealth and extended nursing investment.

Correlating weaning age with mortuary wealth demonstrates an interesting contrast to previous research (Scharlotta et al., 2016). Correlation does not denote causation. It is possible that the increased grave good variance/inequality and the increasing weaning age represent either unrelated events (e.g., one cultural and one environmental) or are manifesting differently changing cultural dynamics within the regions.

Mortuary assemblages in Cis-Baikal have long been identified as having tremendous variance in grave good quality, quantity, and unequal distribution (Okladnikov, 1950; Okladnikov, 1955). Later work expanded upon regional culture histories and developed models for social inequality and cultural complexity amongst these hunter-gatherer populations (Bazaliiskii, 2003; Weber, 1995; Weber et al., 2002). Similar types of complexity have been observed in Palaeolithic and Mesolithic hunter-gatherer populations (O'Shea & Zvelebil, 1984; Price & Brown, 1985; Vanhaeren & d'Errico, 2005).

Working with cemeteries from later time periods and artefact classes that are historically linked with different social status, other researchers have identified status-specific diets (Linderholm et al., 2015; Privat et al., 2002). Previous research on EN Shamanka II individuals investigating similar correlations between diet and inferred status (Scharlotta et al., 2016) has failed to associate fishing or aquatic resources in general with prestigious or wealth items. Correlations between specific diets, total grave goods, or the presence of particularly wealthy/prestigious items could be used to support an explanation for intensification in the subsistence economy.

The individuals with correlated diet and mortuary wealth would be inferred as having social standing, and thus different mortuary treatment. This could manifest as individual prowess, as in successful hunters may have been interred with abundant hunting gear and had a more terrestrial diet, or seal hunters have more harpoons and elevated δ^{15}N values denoting increased seal consumption (Scharlotta et al., 2016). Conversely, if social standing did not result from individual prowess, but rather from trading acumen or the ability to mobilise labour for larger ventures such as building a fish weir, or leading mass harvest/storage efforts (Hayden, 2001; Kelly, 1991; Price & Feinman, 1995; Weber & Bettinger, 2010), then there may be dietary differences related to valuable or prestigious items that are not clearly functional, such as nephrite axes and rings made from imported raw materials.

6.8 | Dietary breadth

Efforts to identify specialised diets for breastfeeding mothers do not support that these women were eating anything different from the other EN adults at Shamanka II. Weaning patterns all follow the basic trophic-step expectations, although the timing and duration do vary.

There is a clear difference between the two phases of cemetery use in terms of shifting diet breadth (Figure 9). During Phase 1, carbon dietary breadth (δ^{13}C variance) is decreasing whereas nitrogen dietary breadth (δ^{15}N variance) is increasing. Decreasing δ^{13}C variance suggests more use of terrestrial resources and opportunistic consumption of small riverine fish that can be caught as opposed to concerted targeting of mass-harvestable omul' (depleted δ^{13}C and moderate δ^{15}N) or grayling (enriched δ^{13}C and depleted δ^{15}N). Increased use of riverine or lake species would expand carbon variance, unless all small riverine and terrestrial resources are removed from the diet and only mass-harvesting or species-targeting subsistence methods were used, which would contradict previous dietary reconstructions (Weber et al., 2011). This meets well with the expectations of expanding diet breadth in the context of EN Cis-Baikal.

During the second phase of cemetery use at Shamanka II, we have the inverse pattern. Sample sizes much are smaller, but there is much more strongly increasing δ^{13}C and decreasing δ^{15}N variance. Increasing carbon variance indicates use of a combination of riverine and lake resources. Decreasing nitrogen variance suggests greater focus on either high-trophic fish or seals, to the exclusion of small riverine fishes. These trends support the inference that there is greater focus
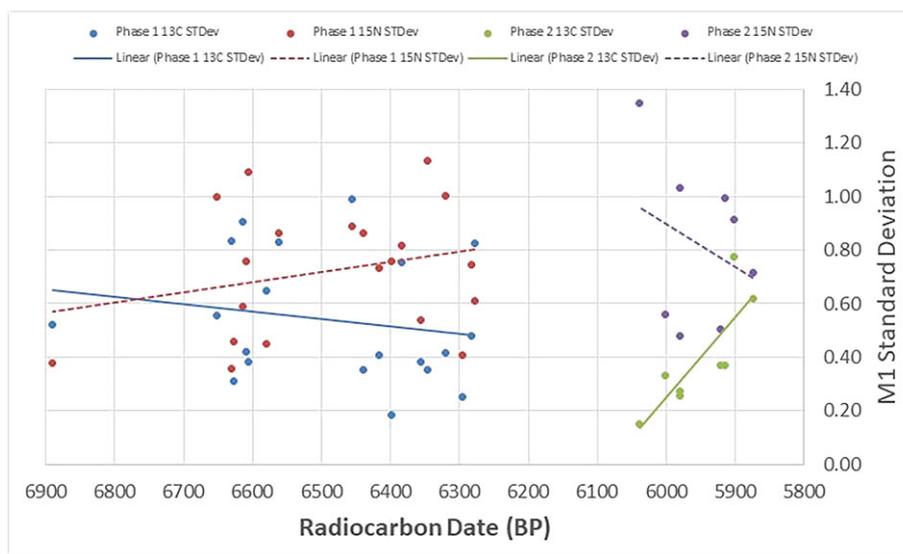
FIGURE 9 Standard deviation scores calculated for the variance throughout M1 for carbon (δ^{13}C) and nitrogen (δ^{15}N), through two phases of cemetery use at Shamanka II [Colour figure can be viewed at wileyonlinelibrary.com]

on a specific subset of subsistence options, for example, greater targeting of fish species or effort in pursuing seal. This is the hallmark of intensification and correlates well with other evidence for differential treatment of individuals and their eventual interment with variable grave wealth (Bettinger, 2009; Bettinger, Winterhalder, & McElreath, 2006; Hayden, 2001; Price & Brown, 1985; Price & Feinman, 1995; Weber & Bettinger, 2010). Not all individuals benefited from this trend as there was clear differentiation as to whom would have access to specific dietary options. It remains unclear whether this was a cultural barrier in terms of limiting access to food through restricted sharing, or if individuals with greater health and familial support had an easier time organising and participating in the targeted pursuit of any given terrestrial or aquatic game.

6.9 | Level of parental investment

A corollary question to the patterning of weaning age is how this reflects on parental investment (Greenwald et al., 2016; Kaplan, 1996). The weaning age itself is not a direct proxy for a Neolithic mother's interpretation of extrinsic risks in their environment (Eerkens et al., 2017), as individual agency is equally likely to influence weaning decisions. Rather, we are looking at changes in the breastfeeding decisions at the group level (e.g., Clayton, Sealy, & Pfeiffer, 2006; Fogel, Tuross, Johnson, & Miller, 1997; Schurr & Powell, 2005; Sellen & Smay, 2001). Based on bone data (Waters-Rist et al., 2011), the weaning process seems to have been quite dangerous. It is likely that EN mothers were aware of these risks. Their response, however, seems to be divided, as there is a predominantly bimodal pattern of weaning (18 abrupt, 10 gradual) during both phases at Shamanka II.

During Phase I, the weaning duration was increasing through time, though likely drawn in this direction by the gradually weaned individuals towards the end. This would suggest that extrinsic risk conditions were in the process of changing or had already changed, and the population was still in the process of adapting to new risks when the phase ended. The conditions during Phase 2 are more challenging to address. Although the data present as a simple early/late weaning age, the sample size has limited our ability to drawn broad conclusions based on this sample.

The question remains though, why some mothers were breastfeeding for longer than others. Perceptions of the extrinsic risks, or the potential value in extending breastfeeding may not have been universal. Or, were the extrinsic risks not the same throughout the group, suggesting that some portions of the population were at less risk of either pathogens, or resource shortfall?

Based on the increasing weaning age, it appears that extrinsic risks were increasing during the EN. The assumption that they were low to begin with and increasing through time, rather than the opposite, is based on the predominantly early weaning age at the beginning of Phase I combined with the increase in fish consumption, bringing increased parasite and bacterial pathogens, through time. The challenge is that this bimodal pattern persists for many generations.

Mothers having watched their peers or kin lose infants while trying to wean them may have come to opposing conclusions about the proper course of action, either to continue breastfeeding as long as possible or to simply attempt weaning early and accept the risks of

mortality. This assumes that mothers were cognizant of the links between breastfeeding, weaning foods, and their child's health. Things were likely not so clear-cut as these data suggest, as there was undoubtedly parental response to whether or not an infant was making a healthy transition to solid foods or had succumbed to pathogens and needed help.

6.10 | Population growth and demography

Age-at-death estimates from comparable hunter-gatherer demographic data, including the Lokomotiv and Ust'-Ida cemeteries in Cis-Baikal (Link, 1999; Weber et al., 2002), have been used to create a hunter-gatherer reference profile (Guraieb, Goni, & Tessone, 2015). The individuals used in this study are only a subset of Shamanka II and present a limited dataset, yet their age-at-death profiles (15–19.9 years [n = 5], 20–34.9 years [n = 12], 35–49.9 years [n = 8], 50+ years [n = 3]) largely match the patterns of the hunter-gatherer reference profile, forming a parallel distribution and supporting demographic expectations (Fogel et al., 1989; Guraieb et al., 2015; Schurr & Powell, 2005). The population represented do not appear skewed by unusually high disease or violence, or to evidence biassed mortuary practices (Jackes, 1992). As the Shamanka II data presented here lack nonadult data, and adults with partial dentition, this will need to be revisited in future studies and linked to fertility indices (Jackes & Meiklejohn, 2008).

Compared with other hunter-gatherer studies that include weaning age, stable isotopic, and demographic data (Clayton et al., 2006; Fogel et al., 1989; Guraieb et al., 2015; Schurr & Powell, 2005; Tessone, García Guraieb, Goñi, & Panarello, 2015), the Shamanka II samples show no correlation between adult diets and age-at-death, or differential survivorship based on the variable weaning ages; yet marked variability in weaning patterns.

Differences in demographic patterns between Early Neolithic and Late Neolithic/Bronze Age in Cis-Baikal have been suggested as relating to weaning age and interbirth intervals (Link, 1996, 1999; Waters-Rist et al., 2011). The early onset and extended weaning period largely fits with other hunter-gatherer studies (e.g., Clayton et al., 2006; Eerkens & Bartelink, 2013; Eerkens et al., 2017; Fogel et al., 1989; Weber et al., 2002; Schurr & Powell, 2005; Tessone et al., 2015; Waters-Rist et al., 2011), including areas where plant resources frequently used as supplemental foods are scarce and seasonal. The uneven distribution of weaning duration at Shamanka II has also been noted in Mississippian and Californian hunter-gatherer populations (Eerkens et al., 2011; Schurr & Powell, 2005) and relates to population growth (Eerkens et al., 2017).

The increasing weaning duration has ramifications for the overall group size and rate of regional population growth during the EN. Increasing breastfeeding duration improves survival rates under conditions of moderate extrinsic risks, reduces the overall fertility of the female population, and so slows long-term population growth (Borgerhoff Mulder, 1992, 2000; Eerkens et al., 2017; Hill, 1993; Hrdy, 1999; Quinlan, 2006, 2007; Waters-Rist et al., 2011). The caveat being the extent to which the assumption that extrinsic risk conditions were low to begin with and increased as fish consumption increased. If risks were low at the beginning of Phase I, then the

growth rate should have been comparatively high, slowing as time went on and weaning age was increased to stave off increasing risks to infant/toddler survival. This still seems the likely progression of events, with the gap between Phases I and II representing a shift into societal instability and/or high risks for survival such that population growth was curtailed and Shamanka II fell into disuse, or a less geographically confined pattern of land use supplanted the focus on the southern portion of Lake Baikal.

Explaining the second phase is somewhat more challenging. If the EN population had become unstable through increased pathogen risk, resource pressures from either environmental changes or population density, then how did it recover and why are weaning patterns different when they did? The most plausible answer to this seems to be that although the dominant patterns of subsistence and social structure remained intact, Phase 2 represents the transition from conditions of high risk, back down to moderate risks. If the limited sample size accurately reflects the social conditions during Phase 2, then the risks may have truly been unequal for groups' members. Individuals who were weaned for longer periods of time have more grave goods. The inference being that mothers who spent more time and energy breastfeeding their infants raised children to become adults who were ultimately interred with greater personal wealth (assuming grave goods are personal possessions), or greater prestige within the group (assuming grave goods are gifts from other group members).

This does not necessarily mean that there were aspects of material culture that were being traded to offset food shortfalls or within-group disparities. Environmental conditions could have been fluctuating greatly between decades or generations during Phase 2. Abruptly, weaned individuals may represent shifts towards milder or more seriously dangerous times where breastfeeding was not a major factor in survival rates. Then, the grave goods may simply be a reflection of the resources available during that generation. A speculative example, if it were a more difficult decade then perhaps they produced fewer and less fanciful artefacts that were interred, or more pragmatically, could not inter as many functional objects as they were needed by the living.

6.11 | Child foraging

Children generally supplement their diet with slightly different foods than the adults of their group, focusing more on resources that are easy to access and require minimal processing (e.g., berries, nuts, and small animals; Greenwald et al., 2016). As compared with adult foraging activities, these foods will generally represent low(er)-ranked foods in terms of diet breadth (Bettinger, 2009; Kelly, 2013). Independent child-foraging group behaviour observed ethnographically employ a large degree of peer-group learning over skillsets that require training or adult supervision (e.g., seal hunting). Ethnographers report children forming small, mixed-age (e.g., aged 5–9 years) foraging groups that pursue resources in proximity to adult foraging/processing or settlement areas (Bird & Bliege Bird, 2002; Bliege Bird & Bird, 2002; Bliege Bird, Bird, & Beaton, 1995; Blurton Jones, Hawkes, & Draper, 1994; Blurton Jones, Hawkes, & O'Connell, 1989; Blurton Jones & Marlowe, 2002; Crittenden, Conlin-Brittain, Zes, & Schoeniger, 2013). Archaeological investigations of child foraging have focused on warmer climates than Cis-Baikal (Bird & Bliege Bird, 2000; Crittenden et al.,

2013; Greenwald et al., 2016), potentially limiting the applicability of these analogues to sub-Arctic conditions.

Isotopic data from Cis-Baikal nonadults support the idea that childhood was a period distinct from infancy and toddlerhood (Waters-Rist et al., 2011). There was not clear evidence of different diets past early childhood during the EN, suggesting that there was not a culturally based system of differential access to and/or allocation of foods by age. Many hunter-gatherers are noted for having childhood beginning at the age of 3–4 years with important parameters including weaning, walking, being carried around less often, and the child's engagement with other persons independently of their parents in a responsive and culturally appropriate manner. Once "toddlerhood" has passed children eat what everyone else eats (Hewlett & Lamb, 2005).

Under normal circumstances it is difficult to envision children being given limited access to foods, especially in a population where many infants die during weaning; however, the treatment of children varies widely (Hewlett & Lamb, 2005). If starvation were prevalent amongst weaned children, then childhood foraging may have had a substantial impact to their lives. The inference being that children were not being adequately provisioned, minimally in terms of protein resources, by the adults of their group, and were expected to secure some small or large portion of their regular diet. The subset of individuals with a two-stage weaning pattern may have foraging for some, or all of their solid foods during the second stage. Or they may have been expected to forage and were failing to provision themselves and so were experiencing catabolism to a greater or lesser degree.

Many resources in Cis-Baikal, either demonstrated archaeologically or observable in the modern environment, would be difficult to routinely harvest in nutritionally significant quantities by children.

During the warmer-months there are low-ranked resources (e.g., snakes, frogs, ground squirrels, mushrooms, and berries) that could augment the diet and likely would have been accessible in proximity to adult foraging efforts. All of these resources are known or anticipated to have depleted $\delta^{13}C$ and $\delta^{15}N$ values, representing lower tiers of the terrestrial ecosystem (Katzenberg et al., 2012; Weber et al., 2011). Therefore, we would expect to see greater reliance on these types of foods, or of starvation if sufficient nutrition were not being foraged.

The results do not support catabolysis under the dietary parameters of EN Cis-Baikal. Uncorrelated variance in $\delta^{13}C$ and $\delta^{15}N$ values do not suggest that these individuals were wasting away, producing the appearance of either dietary stability or trophic enrichment. We also do not see a dip in dietary breadth relative to adult values that would suggest age-related reliance on low-ranked or terrestrial foods. Children from EN Cis-Baikal appear to have been fully provisioned by the adults in their group.

7 | CONCLUSION

Using weaning patterns as direct insight into parental investment into children through time and as a broader proxy for hunter-gatherer behaviours during the EN, the outcome was that there was not clear evidence for sex-biassing in parental investment. Parental investment

increasing along with greater consumption of fish is clearer using dentin micro-sampling than it was using previous methods.

Social, gendered, or some other cultural categorisation underlying social differentiation should have been observable in the material record. Although differences in weaning patterns are present, they are not clearly attributable to any category of parental investment, or specific artefact classes, yet more of the individuals with large grave good assemblages received extended breast milk from their mothers. The apparent cause for social inequality in EN Cis-Baikal was tied with parental investment in their children through extended breastfeeding above all other apparent divisions in society as specialist hunters, fishers, tool producers, trader, etc. Individuals with abundant grave goods were breastfed for extended periods of time, though not all individuals benefiting from extended breastmilk were interred with mortuary wealth. Some subsets of society were more successful in caring for their children, and these children went on to be buried with greater mortuary evidence of wealth or prestige.

There are subtle differences observable in the data between the two phases of cemetery use in terms of pre- and post-weaning dietary patterns, between abrupt and gradual weaning patterns; however, given the limited dataset, these observations must be taken with caution. The replication of temporal trends over gendered or status related differences is interesting, suggesting a different cultural structure between the difference phase of EN cemetery use at Shamanka II, at least in terms of social organisation and subsistence economy that is also evidenced in the mortuary record.

Incorporating hypotheses regarding how individual shifts in dietary breadth will operate as proxies for short and long-term culture, it becomes clear that there were ingrained social differences within these populations. Increased birth-spacing as a response to either periodic or intra-annual nutritional instability could not be identified at Shamanka II. As a whole, there was greater fish consumption, but individual diets varied considerably. Long-term hypotheses of shifting dietary breadth do appear to have been borne out at Shamanka II. Changing subsistence emphasis has not been clearly related to technological intensification. Individuals interred with greater wealth benefited from improved nutrition as infants. This pattern was not shared by all group members, so it is unlikely to have been readily recognised by all members of EN society.

It is possible that family groups within EN society were successful in maintaining mutual nutritional and material support to such an extent that complex social hierarchies were being demonstrated in the mortuary treatment of individuals. It remains intriguing that bulk dietary data reconstructions failed to demonstrate this point, whereas a focus on weaning efforts show the development of cultural complexity observable in the material assemblage.

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