High mobility rates during the period of the "Celtic migrations"?

$^{87}Sr/^{86}Sr$ and $\delta^{18}O$ evidence from Early La Tène Europe

Mirjam Scheeres

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Mirjam Scheeres

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(D77)

Ich erkläre hiermit, dass ich die vorliegende Arbeit

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Mainz, Januar 2014

Yesterday is history

Tomorrow is a mystery

Today is a gift

That is why we call it the present

-Eleanor Roosevelt-

PREFACE

This thesis encompasses the first results of the bioarchaeometric ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) research that started on the 1st of November 2008. The study, conducted under the supervision of Prof. Dr. Kurt W. Alt in Mainz, resulted in three manuscripts that will be presented in this thesis. The first paper (**Chapter 3**) is in press and will appear in “The Oxford Handbook of the Archaeology of the Continental Celts” (Scheeres et al., 2013a). In this contribution $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ data are used to investigate whether the biologically related individuals of Münsingen-Rain (Switzerland) originated from a local or non-local community and if non-local individuals occurred in both the early and the late phase of the cemetery. The second paper (**Chapter 4**), which is published in the Journal of Archaeological Science, examines if the $^{87}Sr/^{86}Sr$ data indicate different mobility rates among the deceased at the Early La Tène cemeteries of Nebringen (Germany) and Monte Bibele (Italy) (Scheeres et al., 2013b). Their location in respectively the Celtic core and expansion area and their grave goods suggest such a difference. The results of the oxygen isotope analysis performed on the human tooth enamel samples of these two cemeteries were not yet available at the time the manuscript was published and will be discussed at a later stage. The last paper (**Chapter 5**), which is submitted to the American Journal of Physical Anthropology, represents the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ data of the three Bohemian cemeteries of Radovesice I, Radovesice II and Kutná Hora (Czech Republic) (Scheeres et al., 2013c). It investigates whether the observed change in material culture from characteristic Early La Tène finds to a typical Bohemian La Tène style around 300 BC was caused by increased mobility. The last chapter (**Chapter 6**) presents the main conclusions obtained from the results of these studied cemeteries.

The presented isotope data derives from an interdisciplinary research between the Institute of Anthropology, Department of Bioarchaeometry and the Institute of Pre- and Protohistory at the Johannes Gutenberg-University, and the Römisch-Germanisches Zentralmuseum (RGZM) in Mainz. In the context of this project sixteen Early La Tène cemeteries were selected to examine the importance of residential changes during the period of the “Celtic migrations” (**Fig. 1.1**). Six of these cemeteries, respectively Bobigny (France), Nebringen (Germany), Münsingen-Rain (Switzerland), and Radovesice I, Radovesice II and Kutná Hora (Czech Republic), lie in Central Europe, the core area of the La Tène culture. The ten other cemeteries are located in the expansion area of the Celts. They include the Italian cemeteries of Monte Bibele and Monterenzio Vecchio, the Austrian cemeteries of Oberndorf, Ossarn and Pottenbrunn, the Hungarian cemeteries of Sajópetri and Tiszavasvári, and the Rumanian cemeteries of Aradul Nou, Fântânele “Dâmbu Popii” and Fântânele “La Gâta”. A prerequisite for their selection was that they formed key sites – cemeteries of major scientific importance within their region, used for several generations and containing significant grave inventories of LT B (380-250 BC). For isotope analysis it was important that the skeletal material, especially teeth, were well preserved. Skeletal material was obtained during the course of the project in Paris (France), Tübingen (Germany), Bern (Switzerland), Bologna (Italy), Prague (Czech Republic), Vienna (Austria), Budapest (Hungary), Nyíregyháza (Hungary), Cluj (Rumania) and Năsăud (Rumania). This collected material was analysed archaeologically (Maya Hauschild) and isotopically ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) (Mirjam Scheeres). Sample preparation for isotope analysis was performed in the laboratory of Prof. Dr. Bernd R. Schöne, Institute of Geosciences, Department of Paleontology, in Mainz, whereas the further processing of the strontium samples was completed in the clean laboratory at the Department of Geosciences under the supervision of Prof. Dr. Wolfgang Siebel in Tübingen. Oxygen isotope measurements were partly executed at the Department of Geosciences in Tübingen by Bernd Steinhilber and the Department of Paleontology in Mainz by Michael Maus. Ancient DNA analysis was performed on the cemetery of Sajópetri by Sarah Karimnia and on the cemeteries of Aradul Nou, Fântânele “La Gâta”, Tiszavasvári, Nyíregyháza, Bobigny, Oberndorf, Ossarn and Pottenbrunn by Ole Warnberg in the clean laboratory at the Department of Bioarchaeology in Mainz.

I would like to use this preface to thank all the people that contributed to this study.

Mainz, 27 January 2014

Mirjam Scheeres

Erratum to Dissertation:

High mobility rates during the period of the "Celtic migrations"? $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ evidence from Early La Tène Europe

Mirjam Scheeres

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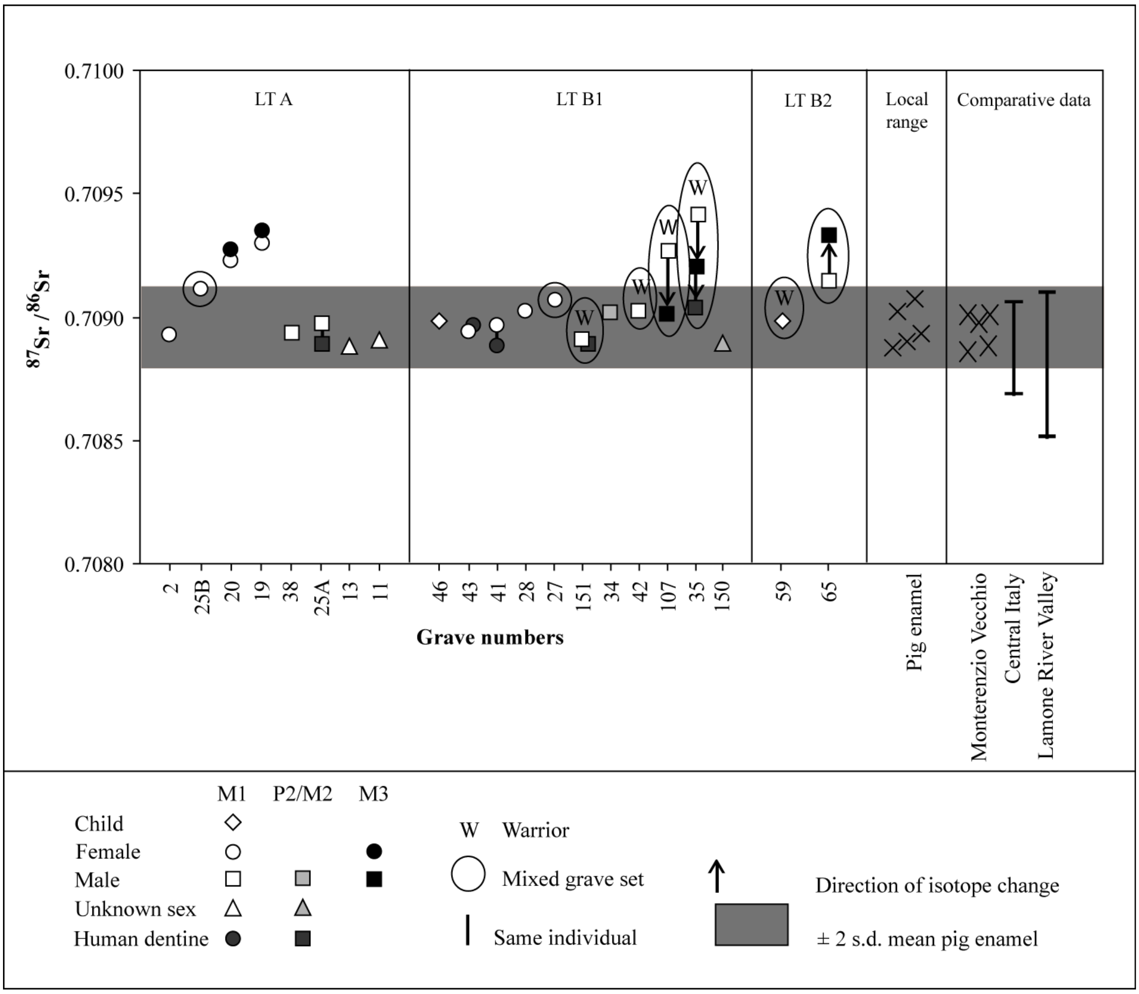

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1. INTRODUCTION

1.1. The period of the „Celtic migrations“

“The Gauls, imprisoned as they were by the Alps … first found a motive for overflowing into Italy from the circumstance of a Gallic citizen from Switzerland named Helico, who had lived in Rome because of his skill as a craftsman, [and] brought with him when he came back some dried figs and grapes and some samples of oil and wine: consequently we may excuse them for having sought to obtain these things even by means of war”

Pliny, *Natural History*, 12, 2, 5

Pliny (AD 23 to AD 79) and many other classical authors provide us with a variety of reasons for the movement of the “barbarians” living north of the Alps into the “civilised” world of the Romans and Greeks south of the Alps during the 4th and 3rd century BC. These “barbarians” are called Gauls (*Galli*) by Roman authors and Celts (*Keltoi*) by Greek writers, although inconsistently (Dietler, 1994; Wells, 2002). In this study they will be referred to as Celts; the prehistoric Iron Age peoples that are characterised by a uniform La Tène culture that originated from Central Europe (Stöckli, 1991; Wells, 1998). It is, thereby, noted that these people formed anything but a unified community (e.g. Dietler, 1994), but the debate whether it is correct to use this ambiguous and imprecise term is beyond the scope of this thesis. Although the purposes of these transmitted “Celtic migrations” appear to deviate, all written sources are consistent in the fact that it concerned large population groups that migrated from their main Central European homeland to eastern, western and southern Europe, even as far as Asia Minor (e.g. Collis, 2010; Tomaschitz, 2002). However, the exact character and scale of these migrations remains unclear and appears more complex than a simple one-way movement from the Celtic core to the expansion area (Collis, 2010; Wells, 2002).

The archaeological record also reveals an extensive expansion of the Early La Tène culture during the 4th and 3rd century BC throughout continental Europe (Collis, 2010; Dobesch, 1996; Tomaschitz, 2002). Profound traces of migration and mobility are observed in the Mediterranean area and the entire Central European region: graves with grave goods attest to personal contacts, but also the adoption of foreign cultural artefacts. Very different influences from the east, the west and the south are archaeologically detected in the Central European region (Ramsl, 2003; Charpy, 1996; Cižmář, 1995). These developments were accompanied by important changes. Deteriorating climatic conditions around 400 BC (cf. Kromer and Friedrich, 2007) led to the partial abandonment of farmland in marginal areas (e.g. Maise, 1998; Nortmann and Schönfelder, 2009; Tinner et al., 2003). The burial custom changed from wealthy equipped tumuli to flat inhumation graves in which males were buried with weaponry and females with sets of jewellery (Collis, 2010; Wells, 2002). Although these developments suggest population decline, it should be noted that flat inhumation graves affect the archaeological visibility of sites. Beside that, cultural continuity is observed for thousands of years in this area (Stöckli, 1991) and completely empty settlement areas are not observed during this time. The similarities and regional differences in material culture throughout continental Europe are therefore not necessarily associated with mass migration, but could also indicate increased mobility of individuals and small groups (Collis, 2010).

Hitherto, however, no satisfying answers on the extent of mobility during the period of the "Celtic migrations" can be provided. The approach, whereby archaeological data is supplemented with bioarchaeometric methods, appears promising. This relatively new method allows distinguishing local and non-local individuals not just by burial customs, but also isotopically. Its potential became apparent from strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotope analysis of 47 human tooth enamel samples from the La Tène cemetery of Dornach, southern Bavaria (Germany). This study revealed 16 non-local individuals, which could be confirmed archaeologically (Eggl, 2007, 2003; Vohberger, 2007). At the site of Westerhausen, Sachsen-Anhalt (Germany), where 14 (pre-Roman) Iron Age individuals were isotopically analysed, only two adults were non-local, as they had more radiogenic $^{87}Sr/^{86}Sr$ values (Nehlich et al., 2009). Still unpublished strontium isotope data come from the Austrian La Tène cemeteries of Pottenbrunn, Ossarn and Mannersdorf (Ramsl, in progress). A selection of individuals from the first two Austrian cemeteries were also isotopically analysed for this project. The previously mentioned research therefore forms an important supplement to our study. Information on husbandry strategies during the Early La Tène period (around 450-300 BC) comes from Sr isotope analysis of animal teeth from the settlement of Eberdingen-Hochdorf, south-west Germany. The highly varied $^{87}Sr/^{86}Sr$ ratios in the faunal remains suggest movements and non-permanent pastures (Stephan, 2009; Stephan et al., 2012). Beside that, additional information on diet and social status comes from carbon and nitrogen analyses of the Early La Tène Bohemian cemeteries of Radovesice and Kutná Hora, which were also isotopically analysed for this study. This research revealed that males buried with iron weaponry might have had higher levels of animal protein in the diet (Le Huray and Schutkowski, 2005). Altogether it appears that for this specific time period still few studies that combine archaeological and bioarchaeometric data exist. Therefore, still little is known about this important time period and a large-scale interdisciplinary Iron Age research project was launched in which the Institute of Anthropology and the Institute of Pre- and Protohistory at the Johannes Gutenberg-University, and the Römisch-Germanisches Zentralmuseum (RGZM) in Mainz work closely together. For this study Early La Tène (4^{th} and 3^{rd} century BC) cemeteries throughout Europe were selected and the obtained archaeological data, from the studied grave inventories, and the bioarchaeometric data, acquired from the deceased buried at these cemeteries, were combined.

In this thesis the first archaeological and bioarchaeometric ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) results from Münsingen-Rain (Switzerland), Nebringen (Germany), Monte Bibele (Italy) and the Czech cemeteries of Radovesice I, Radovesice II and Kutná Hora will be discussed (**Fig. 1.1**). How these selected cemeteries can shed light on the character and scale of mobility and migration during the period of the "Celtic migrations" will be discussed in the next paragraph (**1.2.**). Subsequently the application of strontium and oxygen isotopes in mobility studies will be discussed (**Chapter 2**). The next chapters (**Chapters 3, 4 and 5**) will cover the results of the six analysed cemeteries, followed by the main conclusions of this study (**Chapter 6**).

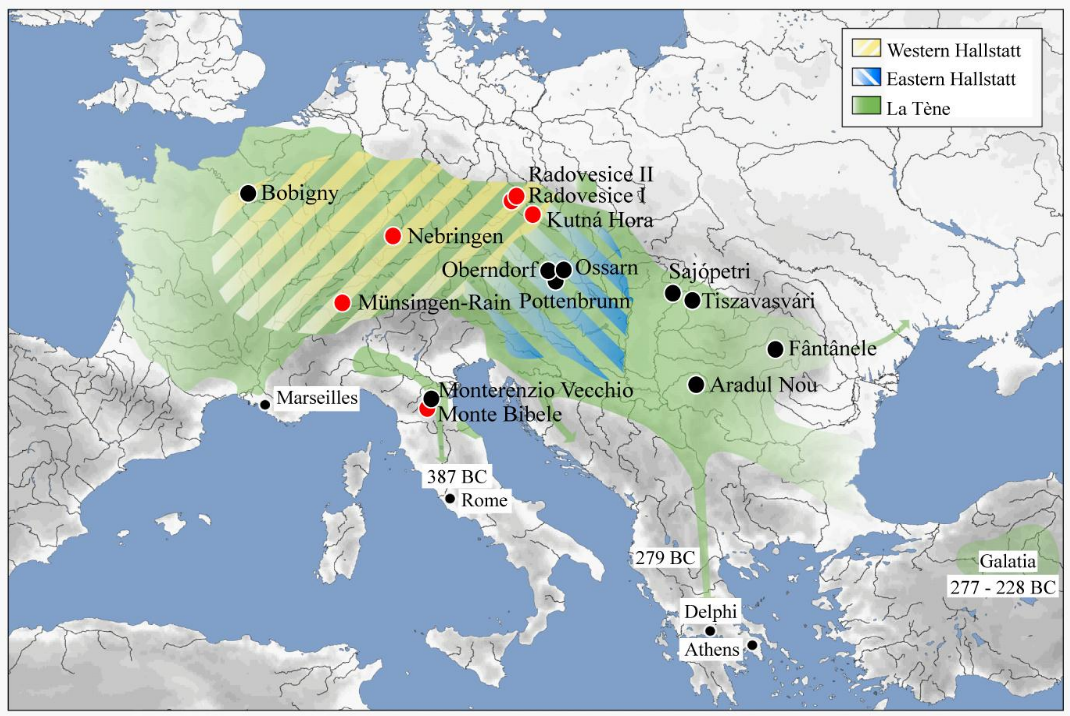

Figure 1.1 Map showing the expansion of the La Tène culture throughout continental Europe. The cemeteries represented with the large black and red circles were selected for this study. The red circles indicate the cemeteries that are discussed in this manuscript (Map modified from V. Kassühlke, RGZM).

1.2. Aim and research questions

The aim of this project is the detection of local and non-local individuals by combining archaeological and bioarchaeometric data. Mobility and migration only exist as archaeological and historical hypotheses that were previously not verifiable. The question is if this archaeological methodology is correct? In this study bioarchaeometric research methods ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) are applied to verify these archaeological hypotheses for each individual. Misconceptions about the real processes and background of the period of the “Celtic migrations” originate from the written sources. Greek and Roman authors describe the Celts as wandering tribes and mercenaries who participated in nearly all military conflicts (Tomaschitz, 2002). Migration is, thereby, wrongly associated with the “invasion of population groups” (Burmeister, 1998; Prien, 2005). Beside that the expansion of the La Tène culture led to the assumption that graves with such finds were “Celtic”, even though it is questionable to which extent this archaeological culture can be identified as a single ethnic group (Burmeister and Müller-Scheeßel, 2006; Collis, 2010; Dobesch, 1996).

It appears that mobility and migration was not restricted to the expansion area, as in the Celtic core area also migrations, respectively settlement and resettlement, of upland areas are presumed. A large-scale examination of both the Celtic core and expansion area is, therefore, essential to understand whether the Celts or the La Tène culture spread over continental Europe. In order to address this issue the grave inventories and human tooth enamel samples from the flat inhumation cemeteries of Nebringen (Germany) and the Czech cemeteries of Radovesice I and Radovesice II, and a selection of individuals from Münsingen-Rain (Switzerland), Monte Bibele (Italy) and Kutná Hora (Czech Republic) were archaeologically and isotopically analysed. Most of these cemeteries are located in the Central European core area of the Celts, whereas Monte Bibele is situated south of the Alps in the so-called expansion area. These cemeteries contained significant grave inventories of LT B (380-250 BC) and were used for several generations. During this time migrations are presumed which must have had an impact on the social structure and settlement patterns (Dobesch, 1996; Stöllner, 1998). The trans-regional spread of grave goods point to mobility or even to the presence of non-local individuals. Bioarchaeometric analysis will shed light on the whereabouts of these individuals.

There are also no indications that the area north of the Alps becomes completely deserted and it is therefore unlikely that a complete exodus of people from the Celtic core to the expansion area occurred. Instead of a one-way mass migration, mobility of smaller groups or single individuals for various reasons, such as exogamy, trade, craftsmanship, warfare or nomadism, should also be considered. The study of burial customs, but also the isotopic analysis of human skeletal remains and the classification of individuals by sex and age will contribute to a better understanding of these prehistoric communities. Of particular interest are the Celtic warriors - males buried with weaponry - to whom Greek and Roman authors ascribe high mobility rates (e.g. Tomaschitz, 2002). Are males buried with weaponry local or non-local? Do males buried with weaponry show higher mobility rates than males buried without weaponry? As it is not uncommon in prehistoric periods for a woman to reside in the community of her spouse (e.g. Bentley, 2007), a high number of non-local females might indicate patrilocal residential patterns. Are females local or non-local? Do we observe patrilocal residential patterns? Additionally it is of interest if specific population groups or whole families changed their residency. Are only adults or also children non-local?

2. THE APPLICATION OF STRONTIUM AND OXYGEN ISOTOPES IN MOBILITY STUDIES

The utilisation of strontium isotope analysis ($^{87}Sr/^{86}Sr$) in an archaeological context to establish residential patterns was introduced by Ericson (1985). In his study Ericson analysed human tooth enamel of second molars and bones. By comparing these two materials, which represent different formation periods in life, differences in $^{87}Sr/^{86}Sr$ values indicate individuals, who spent time in another geological area. Since its introduction in the mid-1980s many studies yielded new perspectives on the utilisation of Sr isotopes in human mobility research (cf. Bentley et al., 2002; Ezzo et al., 1997; Price et al., 2000; Sealy, 1989; Sealy et al., 1991), which make it presently to a well-established method (cf. Bentley, 2006; Knipper, 2011; Price et al., 2002). The application of oxygen isotope analysis ($\delta^{18}O$) in archaeology came with the discovery of Longinelli (1984) that oxygen isotope ratios in mammal bone phosphate correlated with local meteoric water. Since that time $\delta^{18}O$ has been used to determine geographic origin (Müller et al., 2003), to establish non-local individuals (Dupras and Schwarcz, 2001; White et al., 2002), to detect migration (Tütken et al., 2008**)** and to determine the moment of weaning of infants (White et al., 2004; Wright and Schwarcz, 1998).

The strength in combining these two isotope systems lies in the fact that strontium informs about the geological (Bentley, 2006; Price et al., 2002) and oxygen about the geographical and climatic conditions (White et al., 1998) a person grew up in. From this study (cf. **Chapter 4**) it became also apparent that the utilisation of only strontium isotope analysis has the disadvantage that both in areas with homogeneous and heterogeneous geological conditions non-local individuals stay unnoticed unless they fall completely outside the range expected for the area. Although only little variation in $\delta^{18}O$ is observed in climatically similar regions on the European continent (Bowen and Revenaugh, 2003; IAEA/WMO, 2006), this (cf. **Chapters 3 and 5**) and many other studies (e.g. Chenery et al., 2010; Grupe et al., 2012; Müldner et al., 2011) revealed their supplementary importance.

A relatively new approach is the application of mixing models to distinguish two populations with overlapping $^{87}Sr/^{86}Sr$ ranges (Montgomery et al., 2007). By using simple graphical means, dietary end-members, based on Sr isotope concentrations, are identified. It is, thereby, assumed that a community that lives on and obtains their food from a single, homogeneous rock unit will exhibit a range of $^{87}Sr/^{86}Sr$ values that fall between these two end-members: the local rock and rainwater (e.g. Evans and Tatham, 2004; Montgomery et al., 2007). However, this model only functions in certain areas, as it highly depends on the obtained drinking water sources, food acquisition strategies, level of sedentism and cultural practices. In regions of complex, heterogeneous geological conditions or if multiple sources contribute to the dietary Sr this approach may not work. For this study it was not applicable, as Sr isotope concentrations were not measured.

In the next paragraphs (**2.1. – 2.1.2.**) the use of strontium isotopes in mobility studies will be elaborated, whereas in the subsequent paragraphs (**2.2. – 2.2.2.**) the utilisation of oxygen isotopes in mobility studies will be addressed in more detail.

2.1. Strontium ($^{87}Sr/^{86}Sr$)

The method of strontium isotope analysis originally derives from the fields of geochemistry and geochronology, where it was applied to estimate the age of rocks and the source of rock formations (Faure, 1986; Faure and Powell, 1972; Fullagar et al., 1971). Strontium (Sr) is a trace element which is present in all rocks. Since Sr has a slightly larger ionic radius (1.13 Å) than calcium (Ca) (0.99 Å) Sr^{+2} substitutes for Ca^{+2} in Ca-bearing minerals (Bentley, 2006; Faure, 1986; Faure and Powell, 1972). Of the four naturally occurring Sr isotopes, ^{84}Sr (~ 0.56%), ^{86}Sr (~ 9.87%), ^{87}Sr (~ 7.04%) and ^{88}Sr (~ 82.53%), only ^{87}Sr is radiogenic (Bentley, 2006). ^{87}Sr is thereby formed by the radioactive decay of its mother isotope ^{87}Rb (rubidium) with a half-life of about 48.8 billion years (Faure, 1986). The Sr isotope composition in a rock or mineral depends, thereby, on its Rb/Sr ratio and its age (Capo et al., 1998; Faure, 1986). Older geological units (> 100 million years ago) with high original Rb/Sr content generally show $^{87}Sr/^{86}Sr$ ratios above 0.710 (e.g. granites), while younger geological units (< 1-10 million years ago) with low original Rb/Sr content generally exhibit $^{87}Sr/^{86}Sr$ ratios less than 0.704 (e.g. basalts) (Bentley, 2006; Price et al., 2002). To establish this variation in ^{87}Sr, ^{87}Sr is expressed in relation to the non-radiogenic ^{86}Sr, the so-called $^{87}Sr/^{86}Sr$ ratio (Bentley, 2006).

As rocks weather, Sr is released and ends up in the biosphere (Price et al., 2002) (**Fig. 2.1**). During the transport of Sr in ecosystems no mass-dependent fractionation occurs due to the high mass of Sr and its lack to participate in oxidation-reduction reactions. Variation in Sr isotopic composition, therefore, entirely depends on mixture of Sr from different geological terrains with deviating isotopic compositions (Graustein, 1989). An observation also made by Blum and colleagues (2000) who studied the $^{87}Sr/^{86}Sr$ ratios of two different forest ecosystems. Via the consumed food and drinking water Sr is incorporated into the carbonated hydroxyapatite ($Ca_9[(PO_4)_{4.5}(CO_3)_{1.5}](OH)_{1.5}$) of bones and teeth, where it substitutes for Ca (Driessens and Verbeeck, 1990; Hoppe et al., 2003). As plants have the highest Sr/Ca ratio, they have the highest impact on the Sr isotope composition of skeletal tissues (Burton et al., 1999; Burton and Wright, 1995; Sillen and Kavanagh, 1982). This is due to the averaging effect of biopurification (Elias et al., 1982), whereby Ca is absorbed by organisms in favour of Sr (Burton et al., 1999). This decreases the Sr/Ca ratio up the food chain (Bentley, 2006). The Sr isotope ratios recorded in the human skeleton thus reflect the origin of the diet of an individual, which represents the geology of the place of residence during tissue formation or remodelling (Bentley, 2006; Budd et al., 2000; Price et al., 2002).

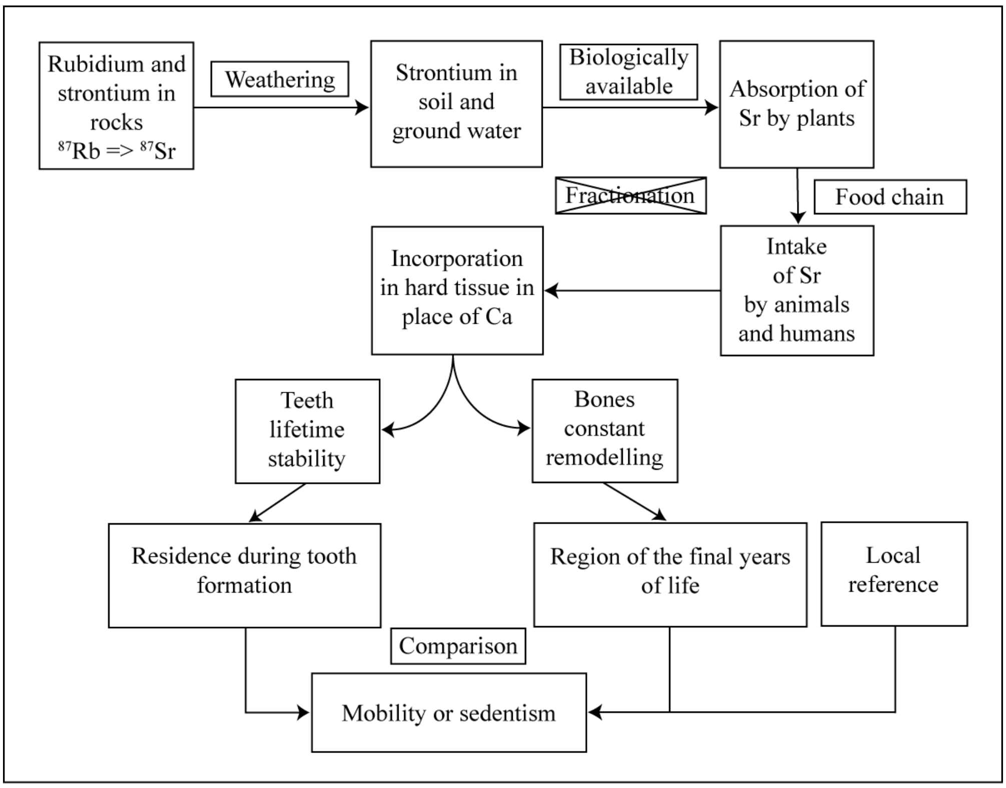

Figure 2.1 Diagram of how strontium, as a trace element in rocks, is incorporated in human skeletal tissues and informs about sedentism and mobility (Modified from Knipper, 2011, Fig. 8.34).

For Sr isotope analysis tooth enamel is preferred, as it is most resistant to diagenetic alteration (Budd et al., 2000) due to its compact and highly mineralised structure (Driessens and Verbeeck, 1990; Hillson, 1996, 1986; Kohn et al., 1999). Once tooth enamel is formed, no remodelling takes place, due to its characteristic of being a non-cellular tissue with no active metabolism (Buddecke, 1981). Depending on the tooth analysed $^{87}Sr/^{86}Sr$ values roughly record the geological area where the food was acquired between early childhood (M1) and the early teens (M3) (Schroeder, 1992). Dentine also possesses the characteristic of remaining unchanged after its formation. However, with increasing age secondary dentine is formed after tooth injury or in dentinal tubules (Buddecke, 1981; Hillson, 1986). Bone remodels throughout life, once it has developed (Jaworski, 1984; Parfitt, 1984; Tomes and De Morgan, 1853). The remodelling rate depends on the bone tissue, i.e. compact or spongy bone, and the part of the skeleton, i.e. vertebrae or femora (cf. Pate, 1994; Price et al., 2002, Fig. 7). The porous structure of both dentine and bone make them susceptible to diagenesis (Budd et al., 2000). In archaeological context, they are frequently overprinted by Sr from the burial environment (Budd et al, 2000; Montgomery et al., 2007; Trickett et al., 2003). Bone and dentine are, therefore, often used as reference material to provide useful baseline information on the local labile Sr.

2.1.1. Biologically available strontium

The challenge of Sr isotope analysis is to differentiate between possible local and non-local individuals. In order to make such a distinguishing, information on the biologically available Sr in the studied area is required. A crude overview of expected $^{87}Sr/^{86}Sr$ values in a certain area can be obtained from numerous geochemical studies on bedrock available in the literature. However, a rock is composed of different minerals, which have variable $^{87}Sr/^{86}Sr$ ratios and generally weather at different rates (Bentley, 2006; Price et al., 2002). These weathered minerals do not necessarily represent the local baseline values, as Sr ends up in the environment through inputs from mineral weathering and the atmosphere, and outputs from stream- and groundwater, and intermediate reservoirs that include the biosphere and soil (Bentley, 2006, Fig. 2; Probst et al., 2000, Fig. 6). The Sr isotope composition, therefore, highly depends on the prevailing geological conditions in an area. Nowadays various modern and archaeological samples are utilised to establish the biologically available Sr for a region. From several studies it appeared that especially archaeological faunal samples from domestic animals that are fed in the same area as humans provide a reliable estimate for local $^{87}Sr/^{86}Sr$ values (cf. Bentley, 2006; Price et al., 2002 and references therein). These samples have the advantage that they are less likely to be contaminated with modern anthropogenic Sr, such as fertilisers, and that they yield more homogeneous $^{87}Sr/^{86}Sr$ values than rocks, soils and plants (Price et al., 2002).

In this study preferably tooth enamel of contemporaneous domestic pigs were sampled, as it is thought that these animals were kept and fed locally (Bentley, 2006). No animal teeth were available for the cemeteries of Nebringen, Radovesice I, Radovesice II and Kutná Hora, and human bone samples were, therefore, analysed. Comparing the $^{87}Sr/^{86}Sr$ values of our reference materials with the available Sr isotope values from the same or similar region showed that the pig samples fitted well to the analysed data (cf. **Chapters 3 and 4**). The human bone samples on the other hand showed a relatively narrow range and might, therefore overestimate the number of non-local individuals. Post-burial contamination from local sources is usually responsible for restricting the $^{87}Sr/^{86}Sr$ ratios in bones (Horn and Müller-Sohnius, 1999). The available comparative data from south-west Germany and the Czech Republic also suggest a broader local range and the biologically available Sr for these areas was accordingly adjusted (cf. **Chapters 4 and 5**).

2.1.2. Strontium isotope analysis

Strontium is extracted from the pre-cleaned powdered samples in a clean laboratory by means of cation exchange chromatography. This method utilises columns filled with extractive resin (Sr-Spec, 50-100 µm, ElChroM Industries) consisting of 4,4´(5´)-bis (tert-butylcyclohexano)-18-crown-6, impregnated on polymer support beads (Horwitz et al., 1992). Sr is thereby separated from major elements, such as Ca and Rb, by incrementally washing the columns with predetermined amounts of nitric acid (3M HNO_3). The isotope composition of the remaining Sr fraction is determined with a thermal ionisation mass spectrometer (TIMS) (Dickin, 2005). In this device the solid purified samples are heated under vacuum to thermally volatilise and ionise them. The applied high voltage accelerates the nuclides, which are focussed into a beam. This beam passes through a magnet field that separates the charged ions by mass, which are detected by the ion collector. The current that is thereby released is measured with a voltmeter. The final isotopic composition is determined with the mass spectrometer operating software (Brand, 2004; Dickin, 2005; Faure, 1986). $^{87}Sr/^{86}Sr$ ratios are thereby normalised to $^{86}Sr/^{88}Sr$ = 0.1194 after each measurement. As the lighter isotopes abandon the filament prior to the heavy isotopes, the activation of the sample during the process of volatilisation and ionisation leads to isotopic fractionation and, if not corrected, to measurement errors (Dickin, 2005).

2.2. Oxygen ($\delta^{18}O$)

Whereas Sr isotopes are related to geology and inform about the geographical origin of the obtained food sources (Sealy et al., 1991), O isotopes are associated with hydrology and climate, and advice about the geographical origin of the acquired drinking water, which is related to local precipitation (Kohn, 1996; Longinelli, 1984). The method of oxygen isotope analysis ($\delta^{18}O$) originally derives from the field of palaeoclimatology, amongst others to measure palaeotemperatures (e.g. Epstein et al., 1951). Oxygen consists of three stable isotopes, ^{16}O (99.757%), ^{17}O (0.038%) and ^{18}O (0.205%) (Rosman and Taylor, 1998). For oxygen isotope analysis the $^{18}O/^{16}O$ ratio ($\delta^{18}O$) is established, because of the higher abundance and greater mass differences of these two isotopes (Hoefs, 1997). Oxygen isotope compositions are expressed in the conventional δ-notation in parts per thousand (‰) relative to the standard Vienna Standard Mean Ocean Water (VSMOW) (Lécuyer, 2004), as ocean water is the largest and a relatively homogeneous water reservoir (Dansgaard, 1964; Gat, 1996).The $\delta^{18}O$ ratio displays the relative deviation of this heavy isotope (^{18}O) from its reference standard VSMOW. Positive $\delta^{18}O$ values represent an enrichment of the heavy isotopes relative to Vienna Standard Mean Ocean Water (VSMOW), whereas negative values signify a depletion of them (Schoeninger, 1995).

The isotopic composition of meteoric water depends on the fractionation of ^{18}O versus ^{16}O during evaporation, condensation and precipitation in the hydrological cycle (Gat, 1996) (**Fig. 2.2**). Noticeable isotope variations in precipitation are caused by the so-called Rayleigh processes (Dansgaard, 1964; Sonntag et al., 1978). In the hydrological cycle, the evaporated ocean water subsequently condenses during the atmospheric transport of the vapour (Rozanski et al., 1982). The distance from the coast, the amount of precipitation (the so-called amount effect), and the altitude and latitude effect cause the increasing depletion in $\delta^{18}O$ further inland, which is reflected in local ground water, rivers and streams (Dansgaard, 1964;

Longinelli, 1984). The water in evaporative systems, such as lakes, plants and soil water, are on the other hand more enriched, as the lighter isotope ^{16}O has a higher volatility than the heavier isotope ^{18}O (Dansgaard, 1964; Gat, 1996). In continental regions these parameters depend on temperature, as during cooling of the air mass moisture from the atmosphere is drawn out, leading to more depleted $\delta^{18}O$ ratios (Gat, 1996; Hoefs, 1997; Yurtsever, 1975). The amount effect is also related to temperature, it occurs, however, especially in wet tropical climates where temperatures rise above $20^{0}C$ (e.g. Higgins and MacFadden, 2004; Hoefs, 1997; Straight et al., 2004). Increasing humidity becomes thereby crucial for decreasing $\delta^{18}O$ in meteoric water.

Oxygen isotopes are absorbed into the body water (blood) through water, food and atmospheric O_2 and incorporated into the skeletal tissue (Bryant and Froelich, 1995; Kohn, 1996). Drinking water and to a smaller extent the food consumed appear to have the most influence on the O isotope composition of body water, as atmospheric O_2 has a constant $\delta^{18}O$ value. As the formation of biogenic apatite occurs at a constant body temperature of ca. 37 ^{0}C in mammals and is in isotopic equilibrium with the body water, $\delta^{18}O$ values of body water represent $\delta^{18}O$ values of the ingested local meteoric water. Absorption of oxygen from meteoric water into body water and the skeletal tissue is thereby subject to isotopic fractionation, whereby the isotopic composition of phosphate differs by a constant value from $\delta^{18}O$ of body water and both correlate linearly with the mean $\delta^{18}O$ of local meteoric water (Longinelli, 1984; Luz et al., 1984). This fractionation factor is species-specific, as it depends on physiology, body size and metabolism (Bryant and Froelich, 1995; Kohn, 1996; Luz et al., 1984). Therefore, various equations to convert $\delta^{18}O_p$ values to $\delta^{18}O_{dw}$ (drinking water, i.e. meteoric water) values have been empirically established from modern mammals (cf. Chenery et al., 2010). These equations yield varied results and the reliability of the required equation is best checked by comparing the outcomes with the mean $\delta^{18}O$ of modern precipitation (Bowen and Revenaugh, 2003; IAEA/WMO, 2006). In our dataset the equation of Levinson and colleagues (1987), taking a method bias correction of 1.4‰ into account (Chenery et al., 2010), appeared most suitable.

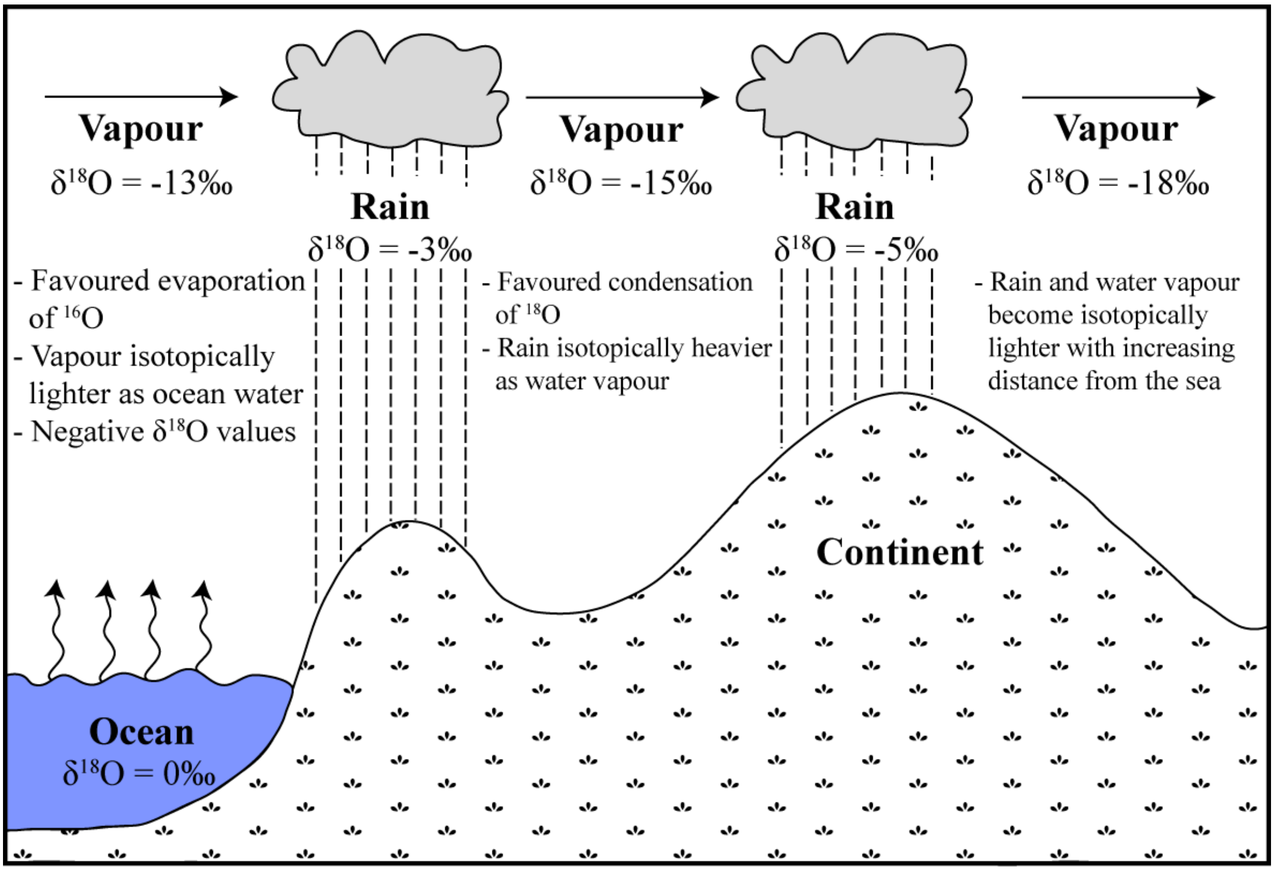

Figure 2.2 Fractionation of oxygen isotopes in the hydrological cycle (Modified from Hoefs, 1997, Fig. 42; Knipper, 2011, Fig. 8.10).

For oxygen isotope analysis tooth enamel is also preferred as sampling material. Teeth that are formed after weaning are usually selected, as the consumption of breast milk leads to more enriched $\delta^{18}O$ values (Wright and Schwarz, 1998). In this study only for Münsingen-Rain an earlier and later formed tooth was analysed to determine the effect of breastfeeding on the oxygen isotope composition. For the Czech cemeteries late forming teeth were chosen for analysis.

2.2.1. $\delta^{18}O$ in drinking water

The isotopic composition of drinking water, composed of environmental and meteoric water, predominately influences the $\delta^{18}O$ of biogenic apatite in humans (Levinson et al., 1987; Longinelli, 1984; Luz et al., 1984). In order to compare $\delta^{18}O_p$ with meteoric water the measured values have to be converted to $\delta^{18}O_{dw}$ by means of an equation (cf. **paragraph 2.2.**). The first approach is to compare these recalculated values with mean $\delta^{18}O$ values in modern precipitation to obtain a first impression on the expected $\delta^{18}O$ values in the studied area (IAEA/WMO, 2006). In order to be able to apply this modern oxygen isotope data to the studied time period similar climatic conditions should have prevailed. It was previously mentioned that several studies revealed that from 400 BC until ~280 BC, an unusual cold and humid climate appeared (cf. Grove, 1979; Gutiérrez-Elorza and Peña-Monné, 1998; Maise, 1998; Tinner et al., 2003) (cf. **Chapter 1**). This means that more depleted $\delta^{18}O$ ratios are expected for this specific time period. Such depletion was, however, not detected (cf. **Chapter 5**). It is, therefore, assumed that the modern data can be used as a reference for the Early La Tène period. The second approach is to compare the obtained data with available $\delta^{18}O$ values from the area. Especially archaeological data is of interest. Although for the studied Czech and Swiss cemeteries archaeological reference material was only scarcely available, comparison with the accessible data and observations made in other studies (e.g. Chenery et al., 2010; White et al., 2004, 2000) formed a reliable basis for interpretation.

2.2.2. Oxygen isotope analysis

For oxygen isotope analysis oxygen in the phosphate component (PO_4) of tooth enamel was analysed, as it appears more resistant to diagenetic alteration than $\delta^{18}O$ in the structural carbonate (CO_3) (cf. Koch et al., 1997; Kohn and Cerling, 2002). Another disadvantage of measuring $\delta^{18}O$ in the carbonate component is that $\delta^{18}O_{co3}$ (carbonate) has to be converted to $\delta^{18}O_p$ in order to be able to calculate $\delta^{18}O_{dw}$. It has already been noted by Pollard and colleagues (2011) that these conversions can lead to calculation errors making the data less reliable. In order to be able to analyse the oxygen isotopic composition from the phosphate component of tooth enamel precipitation of crystals of silver phosphate (Ag_3PO_4) is required (Dettman et al., 2001, modified by Tütken et al., 2006). Oxygen isotope compositions of this silver phosphate are measured on a Gas IR mass spectrometer according to the high-temperature reduction method. In this device the silver capsules, in which the samples are weighed in triplicate, are loaded into the autosampler of the TC-EA (high-temperature conversion-elemental analyser), which is connected to the reaction tube. From there the cups fall into the reactor in which the oxygen in Ag_3PO_4 is converted to CO with graphite at 1450 °C. The produced reaction gases are transferred into helium (He)-gas stream through a gas chromatograph, and transmitted to a Delta Plus XL mass spectrometer via a continuous flow

(ConFlow) interface. Here the oxygen isotope composition is measured against a reference gas of known isotopic composition (Vennemann et al., 2002, 322, 326-327). The samples were calibrated to the international standard VSMOW (Vienna Standard Mean Ocean Water) via the laboratory standards TU-1: 21.11‰; TU-2: 5.35‰; 130-0.5-1: -1.13‰ and YR-1a: -5.77‰ (Department of Geosciences, University of Tübingen).

3. BIOARCHAEOMETRIC INVESTIGATIONS ($^{87}Sr/^{86}Sr$ AND $\delta^{18}O$) OF THE LA TÈNE BURIAL COMMUNITY OF MÜNSINGEN-RAIN; SWITZERLAND

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B. Arnold (Ed.), *The Oxford Handbook of the Archaeology of the Continental Celts*, Oxford University Press, Oxford (*in press*).

3.1. Introduction

The La Tène cemetery of Münsingen-Rain (Bern/Switzerland) has already been subject of a wide range of investigations (summarised in Müller, 1998), as it is one of the most important reference sites for the chronology of the early and middle La Tène period (Müller et al., 2008). At first it was assumed that the cemetery was used by the inhabitants of a small settlement unit (e.g. Martin-Kilcher, 1973). Demographic analyses, however, point to a selection of representatives of a small social group (e.g. Hinton, 1986). The unusually long occupation time (~450-150 BC) and the richly equipped burials raised questions about the genetic relationship and the social position of the deceased (Alt et al., 2005). Biomolecular analysis was initiated, but the selected samples contained no traces of DNA. Therefore, a morphological kinship analysis, based on epigenetic characteristics of the teeth, skulls and the postcranial skeleton, was performed to shed light on possible biological relatedness. This research showed an above-average morphological homogeneity and revealed the frequent appearance of marked deformations of the skulls which, in sum, point to kinship relationships among the deceased (Kutterer and Alt, 2008). *Probable* cranial deformations already occurred among the earliest burials, while *definite* cases have been found in LT B1 and LT B2 and suggest inheritance of this and other rare epigenetic traits among different generations (Alt et al., 2005; Müller et al., 2008).

These results of the anthropological investigation as well as of the outstanding grave goods raised research questions that concern the local or non-local origin of the founder generation and the identification of possible migrants in the early and later phases of the cemetery (cf. Alt et al., 2005, 194). Therefore, Münsingen-Rain has been included in an extensive study of mobility in the 4th and 3rd century BC that aims on a re-appraisal of long-standing assessments concerning the "Celtic migrations" using archaeological and bioarchaeometric investigations (Hauschild, 2010).

This contribution presents the results of strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotope analyses on a selection of the burials from Münsingen-Rain and evaluates their significance for the identification of non-local individuals in the light of the anthropologically detected evidence for kinship relations. The isotope ratios of both elements are preserved in tooth enamel and relate to the particular geographical region in which a person was born and/or grew up (Budd et al., 2004; Mitchell and Millard, 2009).

Strontium (Sr) isotope ratios provide information about the prevailing geological conditions, while the oxygen (O) isotope composition depends on the climatic characteristics of an area. Sr is released from bedrock through weathering and is taken up by humans through the food chain (Comar et al., 1957; Elias et al., 1982; Toots and Voorhies, 1965). As Sr isotope ratios vary between geological units of different ages and lithology (Faure, 1986), differences are reflected in soils and in plants growing on them. The diet of humans and animals that depend on food sources from a certain area will, therefore, relate to the Sr isotope ratios of the underlying geology and hydrology (Price et al., 2006). Because the relative mass difference between ^{87}Sr and ^{86}Sr is very small, no considerable fractionation occurs during uptake and incorporation in the skeletal tissue (Schweissing and Grupe, 2000; Graustein, 1989). Oxygen isotope ratios in teeth reflect isotope differences of the drinking water and to a lesser extent of food, which are primarily related to local precipitation (Bryant and Froelich, 1995; Kohn, 1996). The O isotope composition depends on fractionation of ^{18}O versus ^{16}O during evaporation, condensation and precipitation in the hydrological cycle. This leads to a variation in O isotope ratios in precipitation depending on temperature, elevation and distance from the sea (Bowen and Revenaugh, 2003).

3.2. Archaeological setting

The cemetery of Münsingen-Rain is located south-east of the small town of Münsingen, which is situated in the Aar valley between Thun and Bern. It was discovered in 1906 on a small plateau of a river terrace during gravel quarrying (Hodson, 1968; Wiedmer-Stern, 1908). With approximately 220 graves Münsingen-Rain is one of the largest Iron Age cemeteries in Switzerland and was continuously used from the early to the middle La Tène period (LT A-C2; ~450-150 BC) (Müller et al., 2008) (**Fig. 3.1**).

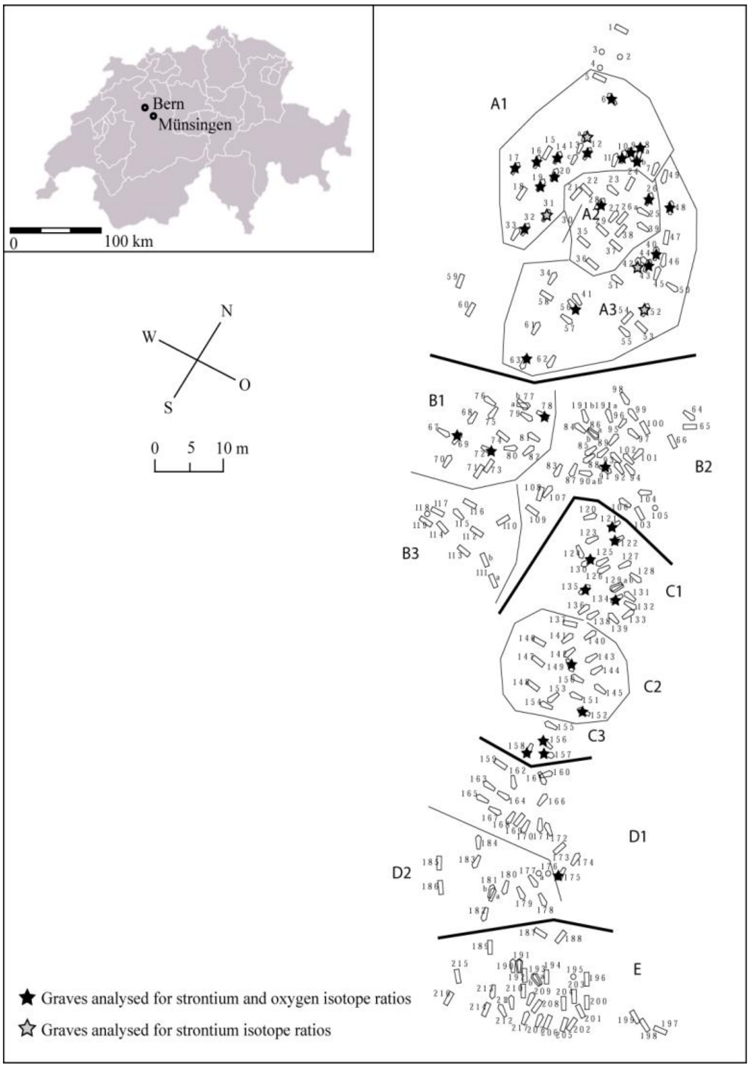

Figure 3.1 The cemetery of Münsingen-Rain, Switzerland, with the location of the analysed graves marked with a black star if both strontium and oxygen were analysed and with a grey star if only strontium was analysed (Modified from Jud, 1998).

Münsingen-Rain is located in the core area of the Celts, which in the 4th and 3rd century BC extended from Central Europe across the Alps to northern Italy, down the Danube area to the Carpathian Basin and reached as far as Asia Minor. The grave inventory primarily includes forms that are typical for this time period in Switzerland such as fibulae of the Münsingen and Dux type and bracelets of the Deisswill type (**Fig. 3.2**; Kaenel, 1990). However, some archaeological finds point to certain mobility within the burial community (Hauschild et al., 2013). Weapons are selectively allocated; typical warriors with full weapon equipment (sword, shield and lance) are rare. Notable is the high age of the males buried with weaponry. Half of them were between 40 to 60 years old, while one of them was over 60.

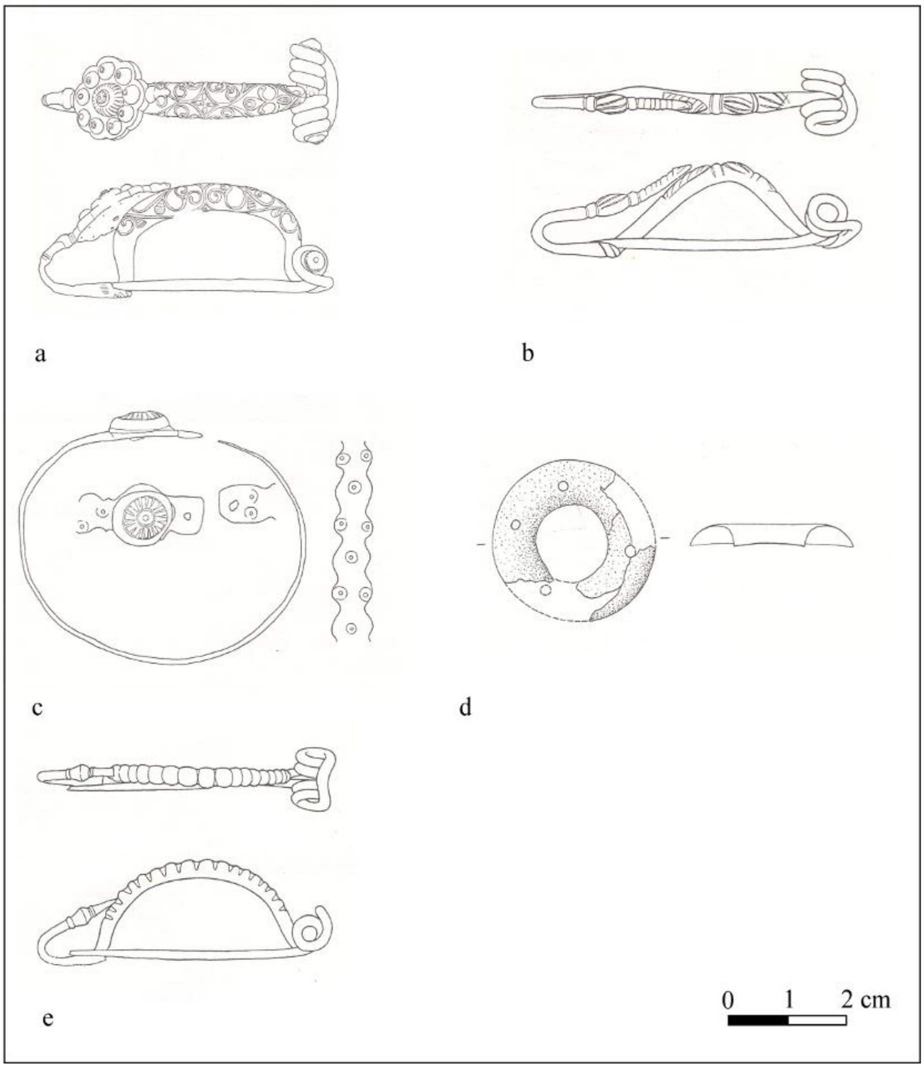

Figure 3.2a. The fibula of the Münsingen type from grave 48 (Hodson, 1968)**.– b.** The fibula of the pre-Dux type from grave 6 (Hodson, 1968)**. – c.** The bracelet of the Deisswill type from grave 121 (Hodson, 1968)**. – d.** The hollow bronze ring from grave 6 (Hodson, 1968)**. – e.** The fibula of the Dux type from grave 48 (Hodson, 1968).

3.3. Geological setting and isotope ratios of the biologically available strontium

Münsingen is located in the Swiss Plateau (*Mittelland*), the area between the Jura and the Alps, in the valley of the Aar river. The Central Alps form the hinterland for the sediments of the Swiss Molasse basin. The northern flank comprises the north-vergent stack of low- to medium-grade metamorphic to non-metamorphic Helvetic, Penninic and Austroalpine basement and cover nappes. The Helvetic nappes, south of Münsingen, are the main source rocks of the molasse clastics in this region. This nappe stack was thrusted over the molasse and comprises Mesozoic marine limestone, marls and shales. The surface of the Swiss Plateau is covered by molasse sequences which consist primarily of carbonate rocks with limestone and dolomite, alternated with moraine gravel (Von Eynatten, 2003). The cemetery of Münsingen-Rain itself lies on a sand mixed gravel terrace, which is overlain by a humus layer. The terrace presumably resulted from valley-fill deposits of sand and gravel laid down in glacial river plains of the Swiss Plateau (**Fig. 3.3**).

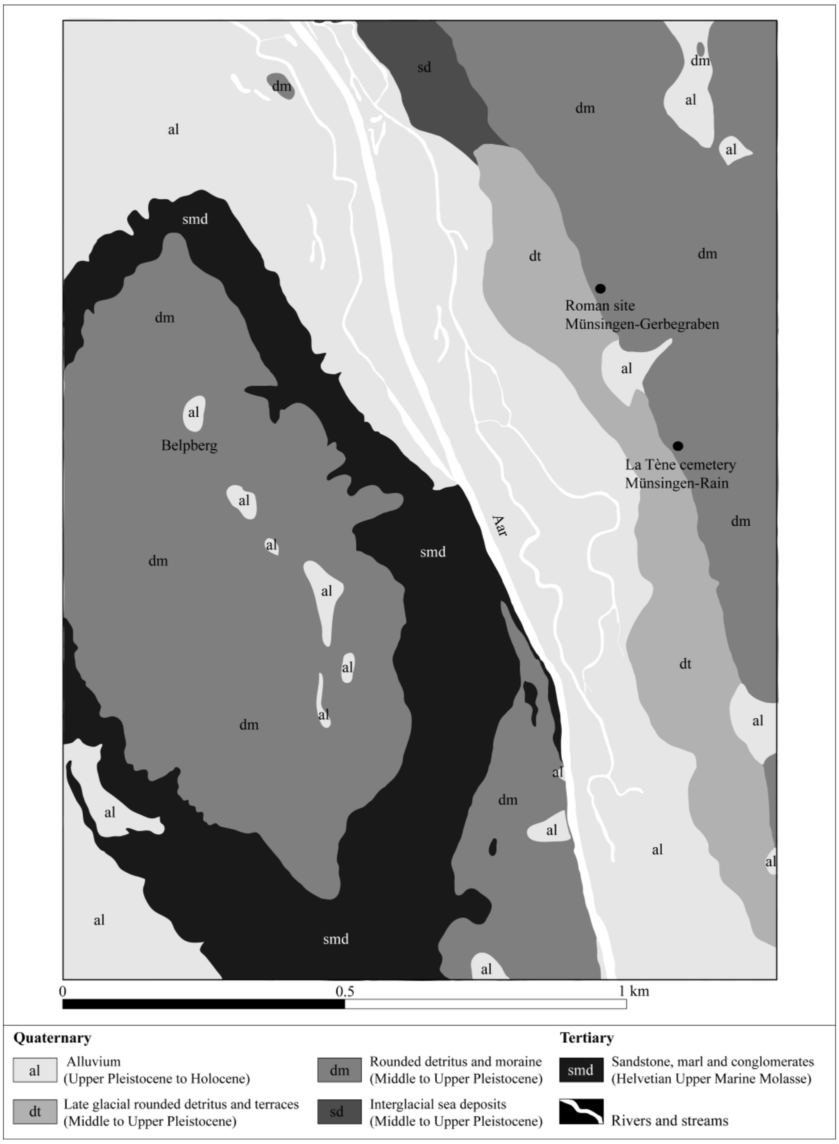

Figure 3.3 Simplified geological map of Münsingen and its surrounding (Redrawn after Beck and Rutsch, 1949). The La Tène cemetery Münsingen-Rain and the Roman site Münsingen-Gerbegraben are indicated with a black circle.

Although strontium isotope data from the closer environs of Münsingen are scarce, published $^{87}Sr/^{86}Sr$ ratios of samples from other sites where molasse sediments alternate with moraines, provide the framework for data interpretation. A very narrow range with the majority of $^{87}Sr/^{86}Sr$ ratios between 0.7083 and 0.7086 has been recorded in human and animal teeth, and bone samples from medieval Elsau (CH) (Tütken et al., 2008), pig enamel from the Roman site of Dietikon (CH) (Knipper et al., 2012), and ostracodes and calcite samples from a sediment core from the bottom of Lake Constance (Kober et al., 2007). More radiogenic Sr isotope ratios that concentrate between 0.7089 and 0.7095 were observed in human tooth enamel from the Neolithic collective burial of Spreitenbach (Aargau, CH) (Knipper et al., 2012) and two Roman mule bones from Upper Bavaria (D) (Berger et al., 2010). Finally, human, faunal and environmental samples from Singen and Hilzingen in the Hegau area west of Lake Constance revealed more variable data, including less radiogenic $^{87}Sr/^{86}Sr$ ratios that are influenced by the locally occurring Tertiary volcanic rocks (Knipper, 2011; Oelze et al., 2012a). A conservative assessment of these comparative data suggests that $^{87}Sr/^{86}Sr$ ratios between 0.7080 and 0.7095 are overall typical for the pre-Alpine molasse and moraine territories (**Fig. 3.4**).

3.4. Meteorological context

The Swiss climate is characterised by precipitation coming from the Atlantic Ocean and by cool, dry winds coming from the European continent (Pfister, 1999; Wanner et al, 1998). The progressive ^{18}O-depletion in precipitation with increasing distance from the ocean (Rozanski et al., 1982; Sonntag et al., 1983), known as the “continental effect”, is small within Switzerland (Schürch et al., 2003). In this area the altitude effect due to the Alpine barrier plays an important role. The Alps interact with moisture moving in from the Atlantic (Darling, 2004) and influence the transport of the air masses (Schotterer et al., 1993) leading to an increase of precipitation with altitude at the northern and southern side of the Alps, while inner-Alpine regions often experience dryness (Frei and Schär, 1998; Kirchhofer and Sevruk, 1992; Schürch et al., 2003).

The overall range of annual mean $\delta^{18}O$ values of modern precipitation on the Swiss Plateau is -10.0‰ to -8.0‰ (Bowen and Revenaugh, 2003; IAEA/WMO, 2006). The precipitation from

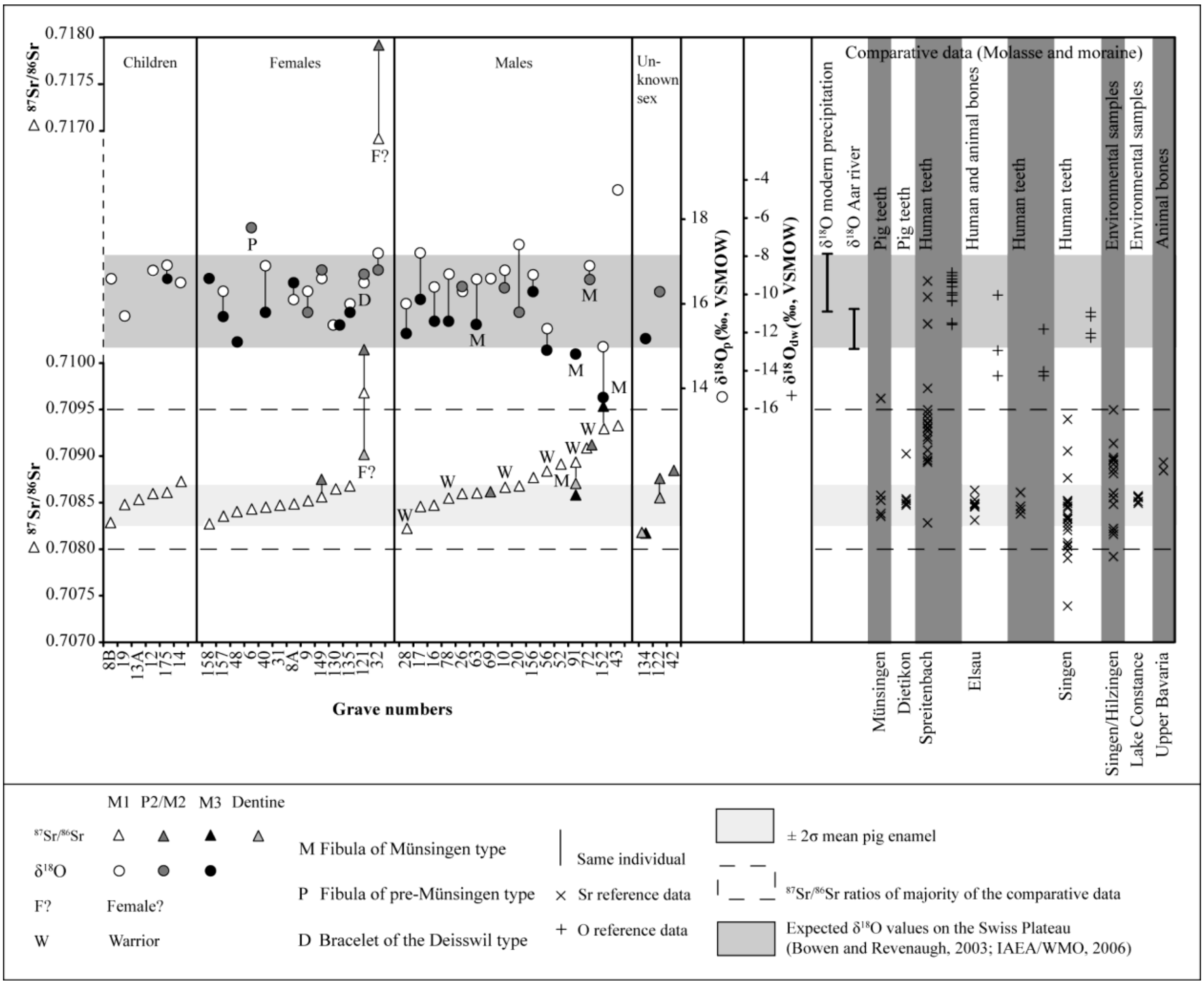

Figure 3.4 Strontium and oxygen isotope ratios of the children, females and males from Münsingen-Rain divided by sex and organised from lower to higher Sr isotope ratios. The $^{87}Sr/^{86}Sr$ values are indicated by a triangle and represent predominately the lower part of the graph. The $\delta^{18}O_p$ values are indicated by a circle and represent mainly the upper part of the graph. Aligned symbols resemble the strontium and oxygen isotope ratios analysed for the same individual. Completely on the right of the graph the comparative data for a molasse and moraine environment is shown.

Bern has slightly more depleted $\delta^{18}O$ values of -10.6‰ to -8.8‰. The nearby located Aar river that is fed by Alpine run-off waters yields $\delta^{18}O$ values of about -12.7‰ (Schürch et al., 2003). In the Alps and its valleys even more depleted $\delta^{18}O$ values, which can get as low as -16.0‰, are typical (Bowen and Revenaugh, 2003; Müller et al., 2003).

Because of isotope fractionation during metabolic processes, the comparison of oxygen isotope ratios of human hard tissues to the isotopic composition of their potential drinking water ($\delta^{18}O_{dw}$) requires data conversion. Therefore, all human phosphate values compiled in the following paragraph are adapted to $\delta^{18}O_{dw}$ using the linear regression equation proposed by Levinson et al. (1987), taking an analytical method bias of 1.4‰ into account (Chenery et al., 2010). The $\delta^{18}O$ values measured in second (M2) and third molars (M3) from the late Neolithic collective burial of Spreitenbach (CH) (range: 15.5‰ [$\delta^{18}O_{dw}$; -11.5‰] to 16.7‰ [$\delta^{18}O_{dw}$; -8.8‰] (Knipper et al., 2012) and early Bronze Age Singen (D) (range: 15.2‰ [$\delta^{18}O_{dw}$; -12.2‰] to 15.8‰ [$\delta^{18}O_{dw}$; -10.9‰] (Oelze et al., 2012a) correspond to the regional precipitation data (cf. **Fig. 3.4**). The enamel of human teeth formed after weaning, as well as animal and human bone samples from medieval Elsau (CH) revealed more scattered and most depleted $\delta^{18}O_p$ values between 14.3‰ [$\delta^{18}O_{dw}$; -14.1‰] and 16.2‰ [$\delta^{18}O_{dw}$; -10.0‰] (Tütken et al., 2008).

3.5. Materials and methods

3.5.1. Sample selection and collection

During the excavation only 77 of the best preserved skeletons were retained by the excavators (Jud, 1998). Among them were approximately 50 individuals with crania, mandibles and teeth. Based on preservation and guided by research questions concerning the establishment of the cemetery and the role of human mobility during the time period of the historically reported “Celtic migrations”, 16 individuals from the potential founder generation (grave groups A1 and A2) and 19 individuals from graves of the LT B phase (4^{th}–3^{rd} century BC) were selected for isotope analyses. Additionally two individuals (graves 42 and 43) from the early phase (LT A) and one child (grave 175) from the later phase of the cemetery (LT C1) were selected (**Fig. 3.1**). Sr isotope measurements were conducted on 38 individuals and O isotope measurements on 34 individuals.

Because no contemporaneous faunal remains were available from the cemetery itself, reference material came from five pig teeth from the nearby Roman site of Münsingen-Gerbegraben (**Table 3.1**). Archaeological domestic pigs are often chosen as comparative samples, because they have likely been kept and fed locally (Bentley, 2004, 2006; Bentley and Knipper, 2005), even though causes of non-local values, such as exchange of single animals or forest pasture that covered several geological units have to be considered during data analysis (e.g. Stephan, 2009; Stephan et al., 2012). Additionally, four human dentine samples were selected to obtain baseline information on the local labile Sr isotope signature**,** as dentine is likely to alter diagenetically and gradually adopt the $^{87}Sr/^{86}Sr$ values of the soil in which it is buried (Budd et al., 2000; Montgomery et al., 2007; Trickett et al., 2003). Because dentine data usually fall between those of the tooth enamel and the burial soil they are only used to confirm the expected local range.

Unless otherwise noted (cf. **Table 3.1**), the earlier formed first molar (M1) was analysed for Sr isotope ratios, to obtain information on the early childhood of the individuals. A second sample was taken from four individuals (graves 32, 72, 121 and 152) who had a deviating Sr isotope composition (**Fig. 3.4**). For one of these individuals (grave 43) further analysis was impossible, as only one sample was available. A second sample was also obtained from a weapon burial (grave 91) and a wealthy female grave (grave 149) to confirm if the deceased were local.

The O isotope analysis was performed on both the M1 and the later formed M2 or M3. The advantage of analysing an earlier and later formed tooth is that the breastfeeding effect becomes visible, as breast milk is more enriched in $\delta^{18}O$ (White et al., 2004; Wright and Schwarcz, 1998). For 22 individuals it was possible to analyse two molars (**Fig. 3.4**). For five individuals (graves 8B, 12, 14, 19 and 43) only an M1 was available, for three individuals (graves 6, 69 and 122) only an M2 and for four individuals (graves 48, 91, 134 and 158) only an M3 could be analysed. No oxygen isotope ratios were analysed for three individuals (graves 13A, 42 and 52).

The surface of each selected tooth was cleaned with a round diamond bur. 20 mg of tooth enamel powder was drilled off and collected in a plastic test tube (Koch et al., 1997; Tütken, 2003). The sample was divided into two aliquots of 10 mg each for Sr and O isotope analysis.

3.5.2. Strontium isotope analysis

The tooth enamel samples were ultrasonically cleaned and rinsed with Milli-Q water and a weak acetic acid (0.1 M, Ca-acetate buffer) to remove diagenetic carbonates. They were dried overnight at 50 °C and ashed for 10 hours at 850 °C in a muffle furnace to remove the remaining organic matter (Price et al., 2000).

In the clean laboratory (Department of Geosciences, University of Tübingen) the samples were transferred into Teflon beakers and dissolved in 500 µl of concentrated HNO_3 overnight at 100 °C on a hot plate. The digested samples were dried and re-dissolved in 3 M HNO_3. Strontium was separated by extraction chromatography with extractive resin (Horwitz et al., 1992). The columns with the extractive resin were pre-conditioned with three loads of 200 µl of 3 M HNO_3. The samples were loaded onto these columns and washed incrementally with a total of 1.25 ml of 3 M HNO_3. Sr was eluted by using three times 200 µl of 0.05 M HNO_3.

All Sr samples were loaded on wolfram filaments and measured on a Finnigan MAT 262 Thermal Ionization Mass Spectrometer (TIMS). Repeated measurements of the international standard for $^{87}Sr/^{86}Sr$ (NBS 987) gave a mean value of 0.710221 ± 0.000055 (1σ, n = 17). All Sr ratios were corrected to a reference value of 0.710248 for NBS 987. Sr blanks had a mean of 190 pg.

3.5.3. Oxygen isotope analysis

The method of Dettman et al. (2001) (modified by Tütken et al., 2006) was applied to obtain silver phosphate for phosphate oxygen isotope ratio measurements. The samples were put in suspension for 24 hours with 2 ml of 2 % NaOCl and for 48 hours with 2 ml of 0.125 M NaOH and rinsed three times with Milli-Q water after each step to remove the organic matter and humic acids (Stephan, 1999, 2000). 800 µl of 2 N HF was added to the dried samples to dissolve them overnight. The resulting CaF_2 was separated from the obtained solution by centrifugation. Two drops of the indicator bromothymol blue were added to the samples to determine its acidity. The samples were then neutralised by adding ca. 150 µl of 25 % NH_4OH. To this solution, 800 µl of 2 N $AgNO_3$ was added to precipitate silver phosphate crystals, which were rinsed four times with Milli-Q water. 0.50 to 0.65 mg of dried (at 60 °C) silver phosphate crystals were weighed into silver capsules and analysed in triplicates.

The oxygen isotope composition was measured with a Thermo-Quest TC-EA connected to a Thermo Quest Delta+XL mass spectrometer at 1450 °C (Department of Geosciences, University of Tübingen). The samples were calibrated to the international standard VSMOW (Vienna Standard Mean Ocean Water) via the laboratory standards TU-1: 21.11‰; TU-2: 5.35‰; 130-0.5-1: -1.13‰ and YR-1a: -5.77‰. Accuracy and reproducibility were monitored by multiple analyses of the standard NBS 120 c, with a mean $\delta^{18}O$ value of 21.9 ± 0.3‰ (1σ, n = 9). All data were corrected to a reference value of 21.7‰ for NBS 120 c (Chenery et al., 2010). The reproducibility was ± 0.3‰ for the $\delta^{18}O$ measurements, unless otherwise noted (cf. **Table 3.1**). The samples are reported in per mil (‰) relative to VSMOW.

3.6. Results

3.6.1. Strontium isotope ratios at Münsingen-Rain

Pig enamel from Münsingen-Gerbegraben provides the spatially closest baseline data for the evaluation of the Sr isotope ratios of human burials at Münsingen-Rain. Four of them yield $^{87}Sr/^{86}Sr$ ratios between 0.7084 and 0.7086 (mean: 0.7085 ± 0.0002 [2σ]). This narrow range corresponds to findings at sites in similar geological settings (cf. **Fig. 3.4**). One pig tooth appeared to be more radiogenic (MÜG5.1: $^{87}Sr/^{86}Sr$ = 0.7096) (**Table 3.1**, **Fig. 3.4**), but still falls into the total variation of comparative data from the pre-Alpine Tertiary and Quaternary sediments. The four human dentine samples, with $^{87}Sr/^{86}Sr$ values between 0.7082 and 0.7090, appeared more scattered than the pig teeth and likely indicate the expected partial alteration during burial.

The human tooth enamel samples vary between 0.7082 and 0.7180. Especially the data of the children and females correspond to the very narrow range of the pig teeth, while the males revealed more scattered and partially more radiogenic $^{87}Sr/^{86}Sr$ ratios. The $^{87}Sr/^{86}Sr$ values of the M1 of 26 individuals, including all children, suggest they were born in Münsingen or in a geologically similar area. Of two individuals (grave 69 and 122) only a later formed tooth was available, which also falls into the range of the local biologically available Sr. Whether these individuals were born in or only moved to this area remains questionable, as no data from the M1 is available. Higher $^{87}Sr/^{86}Sr$ values were observed in nine individuals (graves 32, 42, 43,

Table 3.1 $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ratios of the analysed human (MÜN) and faunal (MÜG) samples from Münsingen-Rain. Sex and age determination after Alt et al. (2005, Fig. 2). The dental notation is according to the FDI-system (Fédération Dentaire Internationale).

Grave	Sample	Period	Sex	Age	Material	Tooth	$^{87}Sr/^{86}Sr$	±2σ	$\delta^{18}O_p$ (‰,VSMOW)	±1σ	$\delta^{18}O_{dw}$ (‰,VSMOW)
6	MÜN6.1	Lt A	F	15-20	Enamel	36	0.708431	10	-	-	-
	MÜN6.2				Enamel	37	-	-	17.8	0.2	-6.5
8A	MÜN8A.1	Lt A	F	21-40	Enamel	46	0.708479	7	16.1	0.1	-10.2
	MÜN8A.2				Enamel	48	-	-	16.5	0.2	-9.3
8B	MÜN8B.1	Lt A	C	07-14	Enamel	36	0.708280	10	16.6	0.1	-9.0
9	MÜN9.1	Lt A	F	15-20	Enamel	46	0.708516	8	16.3	0.2	-9.7
	MÜN9.2				Enamel	47	-	-	15.8	0.3	-10.8
10	MÜN10.1	Lt A	M	15-20	Enamel	26	0.708666	10	16.8	0.3	-8.8
	MÜN10.2				Enamel	27	-	-	16.4	0.1	-9.6
12	MÜN12.1	Lt A	C	07-14	Enamel	36	0.708591	10	16.8	0.1	-8.8
13A	MÜN13A.1	Lt A	C	01-06	Enamel	26	0.708530	10	-	-	-
14	MÜN14.1	Lt A	C	07-14	Enamel	46	0.708722	10	16.5	0.2	-9.4
16	MÜN16.1	Lt A	M	40-60	Enamel	46	0.708473	10	16.4	0.1	-9.7
	MÜN16.2				Enamel	18	-	-	15.6	0.1	-11.4
17	MÜN17.2	Lt A	M	40-60	Enamel	48	-	-	16.1	0.2	-10.2
	MÜN17.3				Enamel	16	0.708462	9	17.2	0.1	-7.9
19	MÜN19.1	Lt A	C	7-14	Enamel	46	0.708470	9	15.7	0.2	-11.2
20	MÜN20.1	Lt A	M	21-40	Enamel	36	0.708683	10	17.4	0.1	-7.3
	MÜN20.2				Enamel	37	-	-	15.8	0.2	-10.9
26	MÜN26.1	Lt A	M	> 61	Enamel	46	0.708599	10	16.3	0.1	-9.7
	MÜN26.2				Enamel	37	-	-	16.4	0.1	-9.5
28	MÜN28.1	Lt A	M	> 60	Enamel	36	0.708221	10	16.0	0.2	-10.4
	MÜN28.2				Enamel	48	-	-	15.3	0.2	-12.0
31	MÜN31.1	Lt A	F	40-60	Enamel	16	0.708468	13	-	-	-
32	MÜN32.1	Lt A	F/M?	40-60	Enamel	46	0.716912	8	17.2	0.1	-7.8
	MÜN32.2				Enamel	47	0.717950	9	16.8	0.3	-8.6
40	MÜN40.1	Lt B1	F	21-28	Enamel	46	0.708446	9	16.9	0.3	-8.5
	MÜN40.2				Enamel	48	-	-	15.8	0.3	-10.9
42	MÜN42.1	Lt A	?	> 60	Enamel	45	0.708847	10	-	-	-
43	MÜN43.1	Lt A	M	41-60	Enamel	46	0.709332	11	18.7	0.2	-4.6
48	MÜN48.1	Lt B1	F	41-60	Enamel	46	0.708396	10	-	-	-
	MÜN48.2				Enamel	38	-	-	15.1	0.1	-12.3
52	MÜN52.1	Lt B1	M	41-60	Enamel	36	0.708914	10	-	-	-
56	MÜN56.1	Lt B	M	41-60	Enamel	16	0.708839	9	15.4	0.1	-11.8
	MÜN56.2				Enamel	38	-	-	14.9	0.2	-12.8
63	MÜN63.1	Lt B1	M	21-40	Enamel	46	0.708605	10	16.6	0.1	-9.1
	MÜN63.2				Enamel	28	-	-	15.5	0.1	-11.4
69	MÜN69.1	Lt B1	M	> 60	Enamel	47	0.708616	9	16.6	0.1	-9.0
72	MÜN72.1	Lt B1	M	41-60	Enamel	26	0.709089	10	16.9	0.2	-8.4
	MÜN72.2				Enamel	27	0.709120	12	16.6	0.2	-9.2
78	MÜN78.1	Lt B	M	21-28	Enamel	36	0.708558	10	16.7	0.1	-8.8
	MÜN78.2				Enamel	38	-	-	15.6	0.1	-11.2
91	MÜN91.1	Lt B1	M	41-60	Enamel	46	0.708934	9	-	-	-
	MÜN91.2				Dentine	46	0.708705	10	-	-	-
121	MÜN121.1	Lt B2	?	40-60	Enamel	46	0.709673	10	16.5	0.1	-9.4
	MÜN121.2				Dentine	46	0.709012	9	-	-	-

Grave	Sample	Period	Sex	Age	Material	Tooth	$^{87}Sr/^{86}Sr$	±2σ	$\delta^{18}O_p$ (‰,VSMOW)	±1σ	$\delta^{18}O_{dw}$ (‰,VSMOW)
	MÜN121.3				Enamel	47	0.710138	9	16.7	0.2	-8.9
122	MÜN122.1	Lt B?	?	41-60	Enamel	27	0.708760	10	16.3	0.3	-9.7
	MÜN122.2				Dentine	17	0.708554	10	-	-	-
130	MÜN130.1	Lt B2	F	40-60	Enamel	46	0.708643	10	15.5	0.1	-11.5
	MÜN130.2				Enamel	28	-	-	15.5	0.2	-11.6
134	MÜN134.1	Lt B2	?	41-60	Enamel	38	0.708174	10	15.2	0.1	-12.1
	MÜN134.2				Dentine	37	0.708181	10	-	-	-
135	MÜN135.1	Lt B2	F	21-40	Enamel	46	0.708672	9	16.0	0.2	-10.4
	MÜN135.2				Enamel	48	-	-	15.8	0.2	-10.8
149	MÜN149.1	Lt B2	F	15-20	Enamel	36	0.708556	8	16.6	0.1	-9.2
	MÜN149.2				Enamel	37	0.708745	9	16.8	0.1	-8.8
152	MÜN152.1	Lt B2	M	40-60	Enamel	46	0.709295	10	15.0	0.1	-12.7
	MÜN152.2				Enamel	38	0.709537	14	13.8	0.2	-15.3
156	MÜN156.1	Lt B2	M	40-60	Enamel	46	0.708768	8	16.7	0.2	-8.8
	MÜN156.2				Enamel	18	-	-	16.3	0.1	-9.8
157	MÜN157.1	Lt B2	F	21-28	Enamel	36	0.708353	10	16.3	0.2	-9.8
	MÜN157.2				Enamel	38	-	-	15.7	0.2	-11.2
158	MÜN158.1	Lt B2	F	21-40	Enamel	46	0.708266	10	-	-	-
	MÜN158.2				Enamel	48	-	-	16.6	0.2	-9.1
175	MÜN175.1	Lt C1	C	07-14	Enamel	46	0.708609	10	16.9	0.1	-8.4
	MÜN175.2				Enamel	47	-	-	16.6	0.3	-9.1
-	MÜG1.1	$1^{st}/2^{nd}$ century AD	?	?	Enamel	RM_2	0.708362	9	-	-	-
-	MUG2.1	$1^{st}/2^{nd}$ century AD	?	?	Enamel	RM_1	0.708532	10	-	-	-
-	MÜG3.1	$1^{st}/2^{nd}$ century AD	?	?	Enamel	RM_2	0.708585	10	-	-	-
-	MÜG5.1	$1^{st}/2^{nd}$ century AD	?	?	Enamel	RM_1	0.709623	10	-	-	-
-	MÜG6.1	$1^{st}/2^{nd}$ century AD	?	?	Enamel	LM_3	0.708390	10	-	-	-

52, 56, 72, 91, 121 and 152), while one individual (grave 134) had slightly lower $^{87}Sr/^{86}Sr$ values. Overall, only the Sr that is bound in the enamel of two females (graves 32 and 121) exceeds the $^{87}Sr/^{86}Sr$ ratios of the biologically available strontium in areas that are dominated by moraine and molasse sediments, while the others are in agreement with the ranges at sites such as Spreitenbach or the Hegau area (Singen/Hilzingen) that are shaped by these geological conditions (Knipper, 2011; Knipper et al., 2012; Oelze et al., 2012a).

3.6.2. Oxygen isotope ratios at Münsingen-Rain

The oxygen isotope ratios ($\delta^{18}O_p$) of all analysed human teeth lie between 13.8‰ and 18.7‰ (mean: 16.2‰ ± 0.8 [1σ]) (**Fig. 3.4**). The range in $\delta^{18}O_p$ is 4.9‰, which is higher than the variation of ca. 1.0‰ observed for individuals drinking from a single water source (Longinelli, 1984) and the range of 2.0‰ among individuals that obtain their drinking water from the same region (e.g. White et al., 2000, 2004). The majority of individuals (n = 31) had $\delta^{18}O$ values that fit to a population that obtained their water sources from rainwater, the Aar river on the Swiss Plateau, or an area with similar climatic conditions. Two individuals (graves 6 and 43) had more enriched and one (grave 152) had more depleted $\delta^{18}O$ values. The corresponding drinking water values ($\delta^{18}O_{dw}$) (cf. Levinson et al., 1987; Chenery et al., 2010) lie between -15.3‰ and -4.6‰ (mean: -9.9‰ ± 1.8 [1σ]).

Seventeen out of the 22 individuals of whom two tooth enamel samples were analysed, had enriched $\delta^{18}O$ values in their M1, which is presumably caused by the breastfeeding effect (White et al., 2004; Wright and Schwarcz, 1998) (**Fig. 3.4**). The highest enrichment of 1.6‰ was observed for a male (grave 20), while the lowest enrichment of 0.2‰ was detected among a female (grave 135). Although a difference above 1.0‰ (n = 6) was not unusual, most individuals (n = 11) had a difference below 1.0‰. Three females (graves 8A, 121 and 149) and one male (grave 26) had a reversed enrichment in their later formed teeth. The intra-individual variation between these teeth was, however, small and within measurement error. One female (grave 130) had no difference between the multiple analysed teeth.

3.6.3. Strontium and oxygen isotope ratios at Münsingen-Rain combined

The narrow $^{87}Sr/^{86}Sr$ range established by the pig teeth and $\delta^{18}O$ values that are expected on the Swiss Plateau were resembled by 25 of the 34 individuals (73.5%) for whom strontium and oxygen isotope compositions were determined (**Fig. 3.4**). Considering the comparative data from other areas, four additional individuals (graves 56, 72, 91 and 134; 11.8%) might have lived in an area dominated by molasse or moraines. Among them were two males (graves 56 and 91) with $\delta^{18}O$ values close to the lower edge of the regional variation. Only five individuals (14.7%; graves 6, 32, 43, 121 and 152) had an isotope composition that clearly differs from the majority of the analysed individuals from Münsingen-Rain. Two females (graves 32 and 121) consumed food from a geological environment with more radiogenic $^{87}Sr/^{86}Sr$ values. The other three individuals obtained their drinking water from water sources that were more enriched (graves 6 and 43) or more depleted (grave 152) in $\delta^{18}O$, whereby the two males (graves 43 and 152) also had slightly higher $^{87}Sr/^{86}Sr$ values. The latter is presumably an indication that not only the water source, but also the food came from a region with a differing isotope composition. It should also be noted that the enriched $\delta^{18}O$ value observed in the M1 of individual 43 is unlikely to be solely explained by the weaning effect, because it is considerably higher than all other M1s.

3.7. Discussion

3.7.1. The founder generation and kinship

The 37 burials of the grave groups A1 and A2 in the north of the cemetery date to its earliest phase (LT A) and most likely represent the founder generation of Münsingen-Rain (Alt et al., 2005) (**Fig. 3.1**). These graves were constructed in the first 20 to 25 years of the cemetery. Depending on the preservation conditions, 16 of these individuals (graves 6, 8A, 8B, 9, 10, 12, 13A, 14, 16, 17, 19, 20, 26, 28, 31 and 32) were either analysed for both Sr and O (n = 14) or only Sr (n = 2) **(Fig. 3.5)**. The individuals from grave 42 and 43 also date to this early phase, but do not directly belong to the founder generation. Three of these individuals (graves 6, 32 and 43) have deviating isotope ratios while all others show very little variation and are overall in agreement with the local and regional data (**Fig. 3.4**). This implies the foundation of the cemetery by a community which already lived in the area before.

Although the morphological characteristics of only one third of the burials could be studied, close relations and an above average homogeneity among the individuals buried at Münsingen-Rain was observed (Alt et al., 2005; Müller et al., 2008; Nicklisch, 2006). Statistical analyses of shared epigenetic traits revealed two groups of individuals who have very likely been biologically related and can be considered “founder families”. Six individuals from these potential families A (graves 8A, 14, 16, 20, 31 and 32) and B (graves 6, 8B, 12, 13A, 17 and 19) were respectively analysed (**Fig. 3.5**). Among the six other analysed individuals (graves 9, 10, 26, 28, 42 and 43), dating to La Tène A, was one young female (grave 9), who was closely connected to both of these families, while three analysed males (graves 10, 26 and 28) were, from a morphological point of view, not directly connected to the supposed families (Alt et al., 2005). The relation of two older males (graves 42 and 43) is unknown due to unfavourable preservation conditions of the teeth. Remarkably, the majority of the individuals with common morphological characteristics also share similar isotope signatures, which are in agreement with an origin from the Aar valley. However, the founder families were not solely composed of individuals from the Swiss Plateau, as two females (graves 6 and 32) grew up elsewhere.

Morphological affinities are not restricted to the potential founder generation, but extent into the later occupation phases, in which more variation among the isotope data has been observed, especially among the males (**Fig. 3.5**). The individuals with shared epigenetic traits either have $^{87}Sr/^{86}Sr$ ratios that fall into the narrow range of the pigs or are slightly higher, but are still consistent with the baseline data from the molasse/moraine sites (graves 52, 56 and 91). Caution is required not to over-interpret limited deviations of the Sr isotope ratios, and to take variation of the isotope composition of the biologically available Sr in the near vicinity of the cemetery into account (**Fig. 3.4**). Two isotopically non-local individuals (graves 43 and 121) were morphologically distinct, while one non-local male (grave 152) of the La Tène B2 period revealed questionable connections to the other individuals. Therefore, isotope and anthropological data are in agreement about the non-local origin of these individuals. Overall, the Sr and O isotope data support the potential familial relations revealed by morphological kinship analyses and argue for a uniform "gene pool" for the individuals buried in Münsingen-Rain.

Furthermore noteworthy are the hereditary cranial deformations (so-called "inclined skull") (Kutterer and Alt, 2008), which occur during the entire period of occupation of the cemetery, thereby alternating between *probable* and *definite* deformations (**Fig. 3.5**). Because four analysed individuals from the earliest phase of the cemetery (graves 14, 20, 31 and 32) only have *probable* deformed skulls, this anomaly may have already been present in the founder generation where the trait accumulates in "family A". The non-local female (grave 32) has a *probable* deformation, and it therefore has to remain open whether she introduced this trait to the Münsingen population. The individuals with a *definite* cranial deformation (graves 40, 91, 130, 134 and 157) occur in La Tène B1 and later, and revealed isotopic ratios that are consistent with the local baseline values (**Fig. 3.5**). This finding underlines the already highlighted biological relations among the Münsingen community that span over several generations.

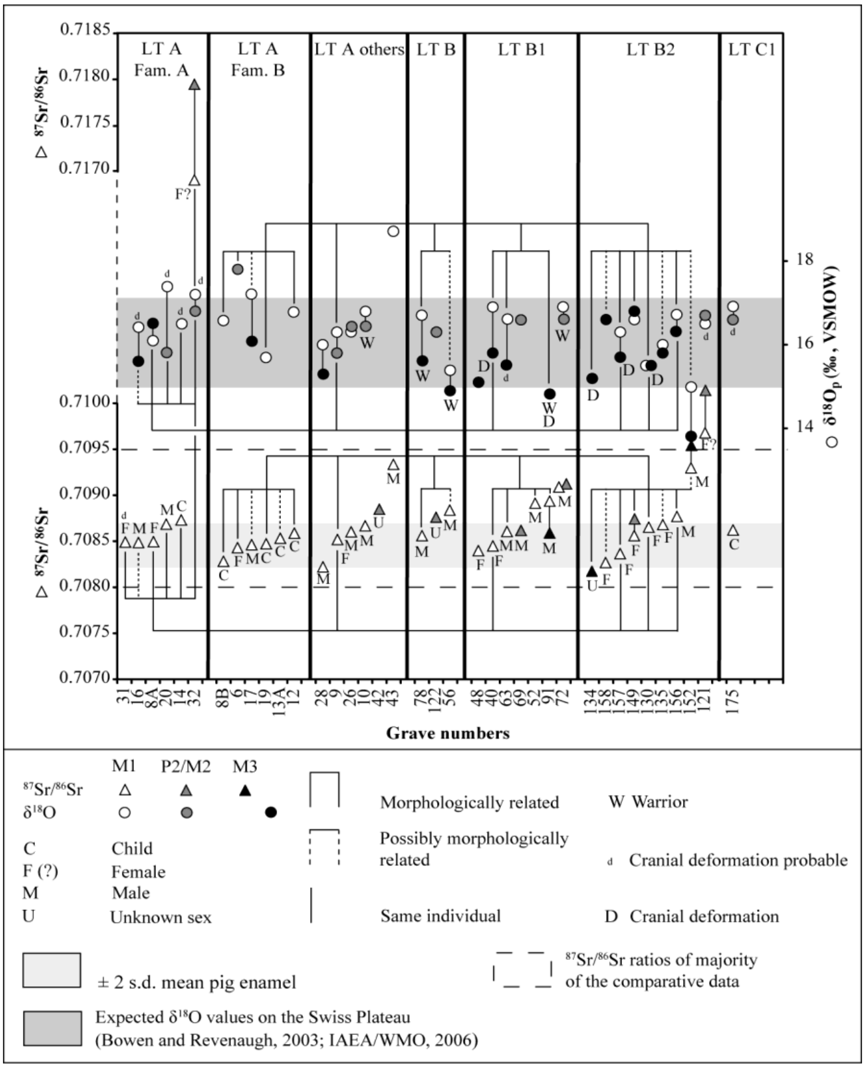

Figure 3.5 Strontium and oxygen isotope ratios of the children, females and males from Münsingen-Rain divided by founder family and time period. The arrangement of the $^{87}Sr/^{86}Sr$ values (triangles) and $\delta^{18}O_p$ values (circles) is as discussed in figure 3.4. Sex determinations are mentioned at the lower part of the graphic, while further characteristics, e.g. warrior and cranial deformations, are mentioned in the upper part of the graphic. All positively related individuals are connected with a solid line, while the questionable related individuals are connected with a striped line.

3.7.2. Sex specific residential changes

The $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values of the children and females predominately match the expected isotope ratios for the Münsingen area (**Fig. 3.4**). The males revealed a dichotomy between those that resemble the isotope ratios of the Swiss Plateau and others with higher $^{87}Sr/^{86}Sr$ values and partly more depleted $\delta^{18}O$ (graves 56, 91 and 152). One possible explanation for obtaining more radiogenic $^{87}Sr/^{86}Sr$ and depleted $\delta^{18}O$ values is the participation of late infant and juvenile boys in seasonal herding of cattle into higher altitudes of the Alps. This might particularly be the case for the male (grave 152) with clearly differing $^{87}Sr/^{86}Sr$ and the most depleted $\delta^{18}O$ values. His isotopic composition is similar to four non-local individuals buried at the early Iron Age cemetery of Magdalenenberg (D) for whom an origin from the northern alpine region was suggested (Oelze et al., 2012b). A precondition of the detection of herdsman-ship in human enamel is the intake of drinking water and food from a higher altitude and geologically different terrain for a sufficiently long time during tooth development. The deviation of the other two males (graves 56 and 91) is only minimal.

Evidence for livestock movements and non-permanent pastures in the Iron Age comes from highly variable $^{87}Sr/^{86}Sr$ values in animal teeth from southwest Germany, dating to the early La Tène period (Stephan, 2009; Stephan et al., 2012). They suggest that farmland was located in the near vicinity of the settlements, while grazing areas were located further afield. Unfortunately, there are no contemporary high-crowned animal teeth from this area available to test this hypothesis directly. However, botanical remains from Arbon Bleiche 3 (Akeret et al., 1999) and Horgen Scheller (Akeret and Jacomet, 1997) as well as pollen data from Egelsee (Wehrli et al., 2007) point to extensive seasonal pasturing, possibly connected with transhumance beginning in the Neolithic.

Another point to stress is the frequent appearance of weaponry in male graves in La Tène cemeteries. In Münsingen-Rain, however, weaponry is rather rare and only selectively assigned. These graves (graves 10, 28, 56, 72, 78 and 91) therefore, belong to the exceptional prestige graves (Alt et al., 2005). The historical sources, supported by the spread of La Tène weaponry, assume that the Celtic warriors of the 4th and 3rd century BC were highly mobile (e.g. Tomaschitz, 2002). The weapon burials from Münsingen revealed Sr isotope ratios within the narrow range of the pig teeth (graves 10, 28 and 78) or slightly more radiogenic (graves 56, 72 and 91), but still consistent with the biologically available Sr of the Swiss Plateau (**Fig. 3.4**). Furthermore, three individuals (grave 56, 78 and 91) share epigenetic traits with other members of the burial community (**Fig. 3.5**). Overall, the weapon burials did not reveal any distinguishable pattern within the spectrum of Sr and O isotope data for males at Münsingen. Two isotopically non-local men (graves 43 and 152), who did not show particular morphological affinity to other individuals, were buried without weaponry. There is no indication that movement during war raids is a convincing explanation for their arrival in Münsingen and inhumation in this cemetery.

The difference between males and females can also be related to the social organisation of the community. There are three females (graves 6, 32 and 121), but six males (graves 43, 52, 56, 72, 91 and 121) that have an isotope composition, which suggests they did not directly come from Münsingen (**Fig. 3.4**). Whether matrilocality, whereby the male moves to the community of the female (Eriksen, 2001), played a role remains questionable, as only few and also not solely males have a diverging isotope composition. Other reasons, as discussed above, for more variance among males are, therefore, suggested as explanation.

3.7.3. Considerations about the origin of the non-local individuals

The majority, 25 of the 34 analysed individuals (73.5%), have Sr and O isotope ratios that are in agreement with an origin from Münsingen (**Fig. 3.4**). Five individuals (graves 42, 52, 56, 72 and 91) with slightly more radiogenic Sr isotope ratios are consistent with other sites on the Swiss Plateau, such as Spreitenbach (Knipper at al., 2012), or the Hegau area (Knipper et al., 2011; Oelze et al., 2012a). They, as well as the individual from grave 134 with less radiogenic Sr isotope ratios, may reflect variation of the isotope composition of the biologically available Sr on molasse and moraine bedrock and point to an origin from the closer environs of Münsingen or the Swiss Plateau landscape in general. The male (grave 152) with the most depleted $\delta^{18}O$ values might also have come from the Swiss Plateau, but obtained his drinking water from another drinking water source. Rivers and springs with an Alpine origin are fed by meltwater that originates from higher altitudes leading to lower $\delta^{18}O$ values compared to rivers that acquire their water from lower altitudes. In the earlier mentioned Swiss Neolithic cemetery of Spreitenbach (Knipper et al., 2012) and the early medieval site of Elsau (Tütken et al., 2008) some samples also yielded more depleted $\delta^{18}O$ values that deviated from the expected $\delta^{18}O$ values of the corresponding area. In these studies the consumption of water with an Alpine origin, e.g. from the Limmat river at Spreitenbach and the Rhine, Rhone or Aar at Elsau, was also proposed as an explanation for these differing values. The $\delta^{18}O$ values of the majority of analysed individuals from Münsingen-Rain also show that drinking water was not restricted to local precipitation or springs, but also included water from the Aar river. As it can be expected that the Aar valley was quite densely populated in the La Tène period, because of its agricultural potential (Alt et al., 2005; Barker, 1985), the Aar river might have been an important water source. Slightly more to the southeast at Lake Brienz for instance $\delta^{18}O$ values of -13.7‰ were measured (Schürch et al., 2003), which might also have been a potential drinking water source and explain the more depleted $\delta^{18}O$ values for the male from grave 152.

The grave goods at Münsingen comprise typical forms of Central Switzerland. The cemetery is especially known for the fibula of the Münsingen type (**Fig. 3.2a**), to which it owes its name, a typical form of the La Tène phase B1 (~ 400 – 250 BC; Kaenel, 1990; Müller, 1998). Prototypes of these fibulae (**Fig. 3.2b**), date to the LT A/B transition (or phase B1a of the La Tène culture; end of the 5^{th}/beginning of the 4^{th} century BC) (Holodnák and Waldhauser, 1984; Möller, 2000). The bracelet of the Deisswill type (**Fig. 3.2c**) is also a local ornament for Switzerland, especially for the Bernese area. The individuals buried with a fibula of the Münsingen (graves 52, 63, 72, 91 and 152), pre-Münsingen type (grave 6) or bracelet of the Deisswil type (grave 121), predominately originate from the Swiss Plateau, two individuals (graves 6 and 121) come from elsewhere.

Beside the two individuals (graves 6 and 121) with characteristic regional grave goods, the teeth of the individuals from grave 32 and 43 have isotope compositions which are uncommon for the Swiss Plateau (**Fig. 3.4**). Noteworthy, is the connection between Switzerland and the Mediterranean, which is expressed in the material culture. Two of the individuals (graves 6 and 43) with differing $\delta^{18}O$ values might have obtained these from Italy (Longinelli and Selmo, 2003) or another area where warmer conditions prevail, e.g. the Spanish coast (Bowen and Revenaugh, 2003). Although the $^{87}Sr/^{86}Sr$ values of both individuals indicate an area with similar geological conditions as the Swiss Plateau, the $^{87}Sr/^{86}Sr$ values for the female (grave 6) are from the M1, while the $\delta^{18}O$ values originate from the M2 (**Table 3.1**). It is therefore unclear if she was born in Münsingen-Rain or in a geologically similar area to which these $\delta^{18}O$ values in her M2 correspond. Although this female, in one of the oldest graves of the cemetery, wears a set of fibulae, which might correspond to the arrival of the first La Tène material in Northern Italy, like in Casalecchio di Reno (Ortalli 1995, pl. 11) and Bologna/Arnoaldi (Vitali 1992, pl. 3) (Hauschild et al., 2013), they are typical for the transition of LT A to LT B in Central Europe. Furthermore she was buried with a hollow bronze ring (**Fig. 3.2d**), which probably belonged to a waist belt, placed in the area of the pelvis (Raftery, 1998). The placement of the ring in this area is rather unusual and was also seen in a burial from a child (grave 12). Pauli (1975) conjectured that these rings are uncommon for women and served in this case as charm for this young woman, who might have died during childbirth. The ring belongs to the older types from the early La Tène period, which is a common grave good throughout Europe. The male (grave 43) was buried without any grave goods.

The two other females (grave 32 and 121) with a differing isotope composition cannot be brought into connection with Italy (**Fig. 3.4**). The first female (grave 32) has $^{87}Sr/^{86}Sr$ values that deviate more than seven standard deviations from the mean strontium isotope data in tooth enamel of the remaining individuals, which are very untypical for the molasse basin. She belongs to one of the oldest individuals from the founder generation that wore solely two relatively simple maintained, undecorated neck rings from bronze wire, as well as identical ones at her wrist and ankle joints. A fibula of the Dux type (**Fig. 3.2e**) was found in the neck region and her body was covered with deciduous teeth from a child (Wiedmer-Stern, 1908). She presumably originated from an area where older rocks, e.g. granite and gneisses with usually $^{87}Sr/^{86}Sr$ values > 0.7100 (Bentley, 2006), dominate the landscape. The other female (grave 121), who was buried with a local ornament, has $^{87}Sr/^{86}Sr$ values that are very common for areas with clastic sediments, e.g. loess, sand- and claystone, which form most of the earth´s surface (cf. Knipper, 2011, Fig. 8.30). However, her $\delta^{18}O$ values indicate an area north of the Alps, where similar climatic conditions prevail as on the Swiss Plateau (Bowen and Revenaugh, 2003).

3.8. Conclusion

The cemetery of Münsingen-Rain, on which at least ten generations were buried, had a long-occupation time of about 240 years. It was founded by an already existing local community, in which only few individuals, both males and females, from elsewhere integrated. The above-average value of the grave goods suggests that Münsingen-Rain was a cemetery for an indigenous social elite group (Müller et al., 2008).

The studied morphological characteristics give the impression of a biological kinship network between the deceased (Alt et al., 2005). These close kinship relations, which connect nearly all of the deceased, show a predominately endogenous marriage policy, which already appeared in the earliest phases of the cemetery. The small size of the community also made exogenous partnerships with persons from probably preselected families necessary. Five individuals (graves 6, 32, 43, 121 and 152), both males and females, appear isotopically non-local and might have joint the community for such reasons. Their isotope composition suggests varying places of origin. These data, therefore, suggests that the families providing partners to Münsingen were not only restricted to the Aar valley (grave 152), but also more distant areas (graves 6 and 43) come into question. The hypothesis of a large extent relational organised community, which stays stable over generations and shows hardly exogamous behaviour, is confirmed by the strontium and oxygen isotope data.

At present several other European Celtic cemeteries are analysed, which will provide a better view on the lifestyle of these La Tène communities. Of special interest is the combination of the data gained from the core and expansion area of the Celts to reveal if the migration of large population groups, as presented by the historical resources, from the western to the eastern part of Europe can be verified.

3.9. Acknowledgements

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4. EVIDENCE FOR "CELTIC MIGRATIONS"? STRONTIUM ISOTOPE ANALYSIS AT THE EARLY LA TÈNE (LT B) CEMETERIES OF NEBRINGEN (GERMANY) AND MONTE BIBELE (ITALY)

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ABSTRACT

Strontium isotope analysis on human remains from the Iron Age (4th/3rd century BC) cemeteries of Nebringen, Germany and Monte Bibele, Italy were carried out to investigate the role of residential changes during the period of the historic "Celtic migrations". From an archaeological perspective, the location of the cemeteries in the Celtic core (Nebringen) and expansion area (Monte Bibele), and the distinctive development of their material culture, suggest that the buried populations had differing mobility rates. On the contrary, the strontium results indicate that only few individuals were mobile or non-local. There is, however, a difference in variation of strontium isotope ratios between the two studied cemeteries, presumably caused by differing geological conditions. In Nebringen changing use of cultivated land in a geologically heterogeneous environment most likely caused varying strontium isotope ratios even within the same jaw, while individual mobility over longer distances can also not be excluded. In Monte Bibele the range of strontium isotope ratios is narrow, and this may be explained by a community living in the same village and using the same agricultural resources. For various prehistoric time periods it has been suggested that some population groups were more mobile than others, for example because they had special social roles. In the two cemeteries studied here, males have slightly more often a non-local birthplace or moved during childhood. In contrast, females had isotope signatures which are more consistent with the local geological environment. Male mobility is, however, not correlated with burial as a warrior, and patrilocal residential patterns were not observed among females. Foreign and local items are found with isotopically local and non-local individuals and objects per se do not indicate descent. The motives for residential changes were, therefore, varied and not constrained to a specific area or population group. The presented dataset provides details on the way of life and land-use in the Celtic communities, for which information is otherwise absent.

Keywords: Iron Age, La Tène, Celtic migrations, Central Europe, Italy, Mobility, Strontium

4.1. Introduction

The second half of the early La Tène period (LT B), ca. 400-250 BC, is generally understood as a historical episode in which large Celtic population groups moved and extended their core Central European living area to eastern, western and southern Europe and even reached Asia Minor (e.g. Collis, 2003; Tomaschitz, 2002). Warriors were thought to be especially highly mobile, but also females moved out of their home communities (Arnold, 2005). Nevertheless, it remains unclear where these conquering armies and migrants came from. The names of tribes mentioned indicate central France and Bohemia (Collis, 2003; Schönfelder, 2010).

Archaeological evidence for European transalpine contacts has been revealed for many periods, starting at least in the Neolithic (e.g. Müller et al., 2003; Pétrequin et al., 2010). Exchange between the ancient civilisations of the Iron Age, e.g. the Mediterranean Greeks and Etruscans, and the area north of the Alps became especially visible around 600 BC. Besides direct imports, objects whose prototypes originated in Greece and Etruria were adapted and integrated into the northern Alpine La Tène style of the fifth and fourth century BC. Imported objects from north of the Alps, such as brooches, arrived already around 600 BC in the Po valley, northern Italy, and Celtic raids and conquests of territories in Italy are reported from around 400 BC by later Roman authors (Tomaschitz, 2002; Hauschild, 2010a). Considering the possibilities to cross the Alps, the western Alpine routes via modern Switzerland should have been used by at least some of these groups.

The written sources on the "Celtic migrations" and the archaeological evidence for transalpine contacts raise questions about the mobility of people at that time. Hitherto it remains unclear what role residential changes played at a local or regional scale and if certain population groups, because of their social position, were more mobile than others. As the old and simple model of mass migration of homogeneous Celtic tribes has recently been questioned by archaeologists and anthropologist (e.g. Arnold, 2005; Hauschild, 2010b; Schönfelder, 2010; Tütken et al., 2008), a research project has been launched using archaeological and isotope analyses to reevaluate questions of residential changes and interregional contacts in several cemeteries in the Celtic core and expansion areas (Hauschild et al., 2013; Scheeres et al., 2013). In this paper, we present Sr isotope data obtained from the human skeletal remains from the Central European cemetery of Nebringen (Germany) and the Mediterranean cemetery of Monte Bibele (Italy), which date to the early La Tène period (fourth/third century BC) (**Fig. 4.1**). These particular cemeteries in the Celtic core (Nebringen) and expansion area (Monte Bibele) were chosen because their location and material culture suggests, from an archaeological perspective, that the buried populations had different mobility rates. The burials of Nebringen are predominately characterised by widespread and typical finds from the early La Tène period, which cannot be brought into connection with one specific area. In Monte Bibele the oldest inhumations (approximately 450-350 BC) are interpreted as Etruscan, while the later ones (starting around the end of the fourth century BC) yielded typical Etruscan and Celtic objects (Vitali, 2008, 2003). In Nebringen no observable changes occurred during the use of the cemetery, while in Monte Bibele new burial customs appear, which point to transalpine contacts. If the Celtic objects were introduced by newcomers, this should be revealed by the Sr isotope data, unless the first generation immigrants came from an area where similar geological conditions prevailed.

Figure 4.1 Topographic map with the location of the studied cemeteries Nebringen and Monte Bibele in Europe (Modified from www.worldatlasbook.com).

Sr isotopes are commonly used to investigate residential changes of people in past populations. Sr is present in minerals and rocks, and its isotope ratios vary with age and lithology (Faure, 1986). As rocks weather, Sr becomes biologically available, enters the food chain and is incorporated into skeletal hard tissues. Because tooth enamel does not change after mineralization (Buddecke, 1981) and is usually very resistant to diagenetic alterations, it reflects the isotope signature of the biologically available Sr in the area in which a person grew up (cf. Bentley, 2006; Ericson, 1985; Price et al., 2002). The tooth crowns represent the $^{87}Sr/^{86}Sr$ ratios of specific formation periods, e.g. $^{87}Sr/^{86}Sr$ values in the first molar (M1) reflect the early childhood, while $^{87}Sr/^{86}Sr$ values in the third molar (M3) reflect later childhood and youth (Hillson, 1996; Schroeder, 1992).

4.2. Archaeological and geological settings

4.2.1. Gäufelden-Nebringen, Baden-Württemberg, Germany

The early La Tène cemetery of Nebringen "Baumsäcker" is located in south-west Germany about 35 km south-west of the modern city of Stuttgart between the Black Forest in the west and the Swabian Alb in the east. After its discovery in 1959, rescue excavations revealed at least 26 burials (21 inhumations, four cremations and a stray find from a destroyed male grave) (Krämer, 1964). The cemetery was used for about 150 years (La Tène [LT] phases B1-B2; 400-250 BC). During five to six generations (duration about 25 years) similar numbers of males and females, as well as children and infants, were buried (**Fig. 4.2**).

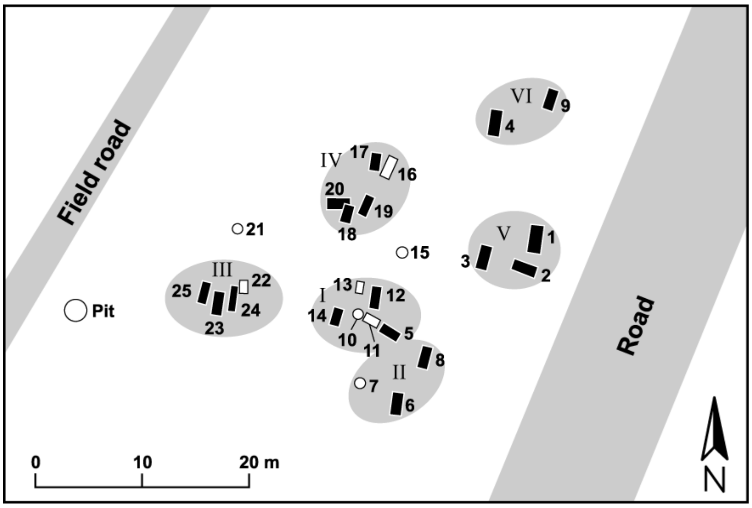


Figure 4.2 The cemetery of Nebringen-Baumsäcker, Germany, with the analysed graves in black. The grave groups I to VI represent the assumed familial groups (Modified from Krämer, 1964).

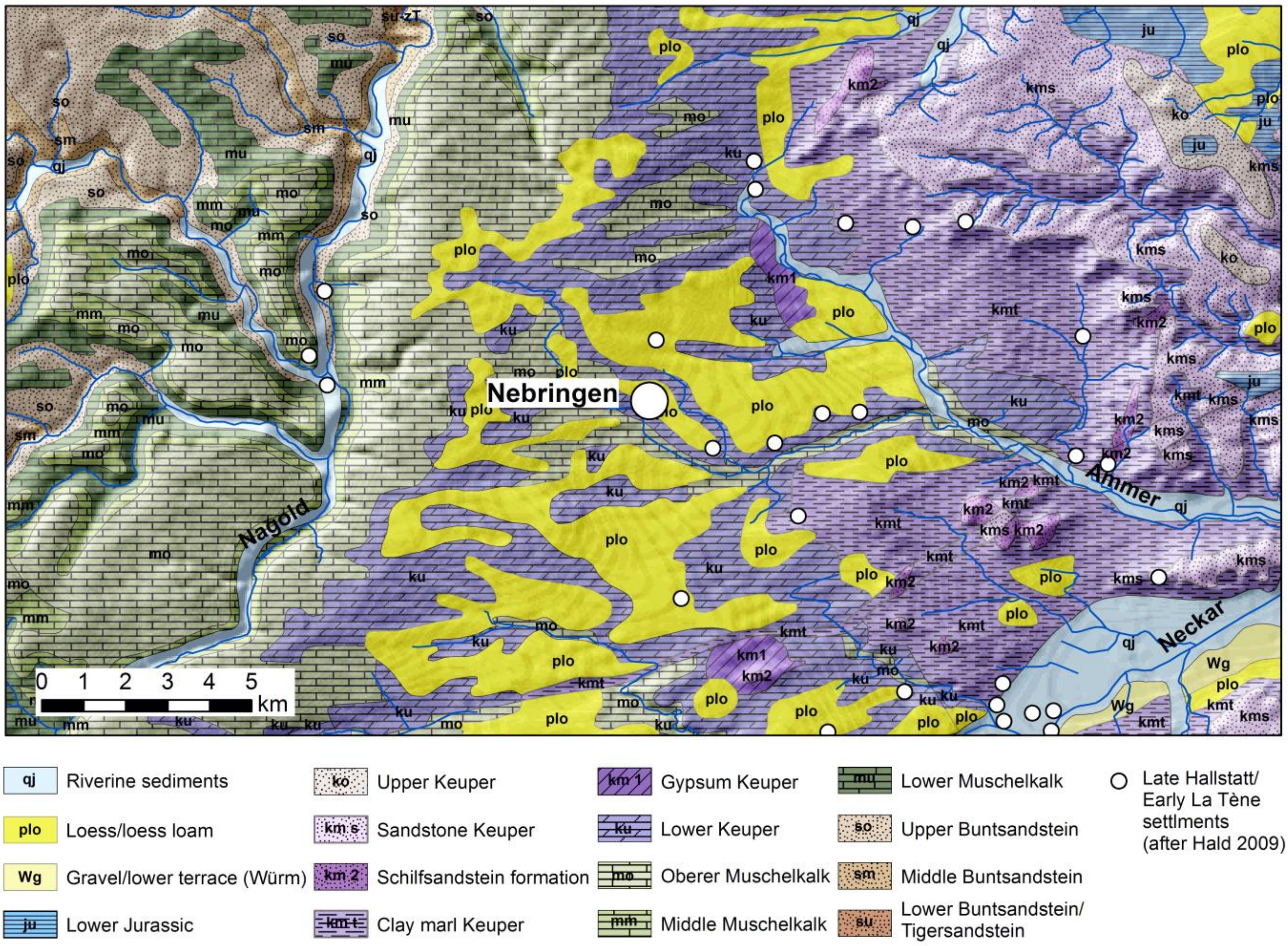


Figure 4.3 Geological map of Nebringen and its surroundings (Digital data layers from: Landesamt Baden-Württemberg, 1998). The big white circle indicates the location of the cemetery.

The landscape of south-west Germany is geologically varied and formed by sedimentary, magmatic and metamorphic rocks (Geyer and Gwinner, 1991). The region has been subject to numerous Sr isotope studies on different materials such as rocks, groundwater, modern plants and human as well as faunal archaeological tooth enamel and bones (e.g. Bentley et al., 2003; Oelze et al., 2012a, 2012b; Price et al., 2006, 2001) that range from the early Neolithic to the Iron Age. This research (summarised in: Knipper, 2011; Stephan, 2009) provides valuable comparative data for the present investigation. Near the site, older geological units are covered by loess and loess loam ($^{87}Sr/^{86}Sr$ of biologically available Sr: ca. 0.7090-0.7100; Bentley and Knipper, 2005; Bentley et al., 2004), but within a few kilometres from the cemetery Upper Triassic sand- and mudstones (*Keuper*) ($^{87}Sr/^{86}Sr$: ca. 0.7085-0.7135; Ufrecht and Hölzl, 2006) and Middle Triassic limestone (*Muschelkalk*) ($^{87}Sr/^{86}Sr$: ca. 0.7080-0.7090; Obertová, 2008) occur as well (**Fig. 4.3**). At a greater distance, the Lower Triassic coloured sandstone (*Buntsandstein*) ($^{87}Sr/^{86}Sr$: 0.711-0.715) composes the bedrock (Matter et al., 1987;

Ufrecht and Hölzl, 2006). These geological units form the framework for the interpretation of the Sr isotope data at Nebringen.

4.2.2. Monte Bibele, Emilia-Romagna, Italy

The massif of Monte Bibele is located in the heart of the Bologna Apennines approximately 30 km south-east of Bologna. The excavations on one of its main peaks, Monte Tamburino, began in 1980 and yielded the largest "Celtic cemetery" so far known in Italy, with approximately 171 grave structures (among which are 123 inhumations and 38 cremations), along with the related Etruscan-Celtic village "Pianella di Monte Savino" (Vitali, 2008, 2003) (**Fig. 4.4**). The cemetery was used from the end of the fifth century BC to the middle of the third century BC, at least four phases can be identified.

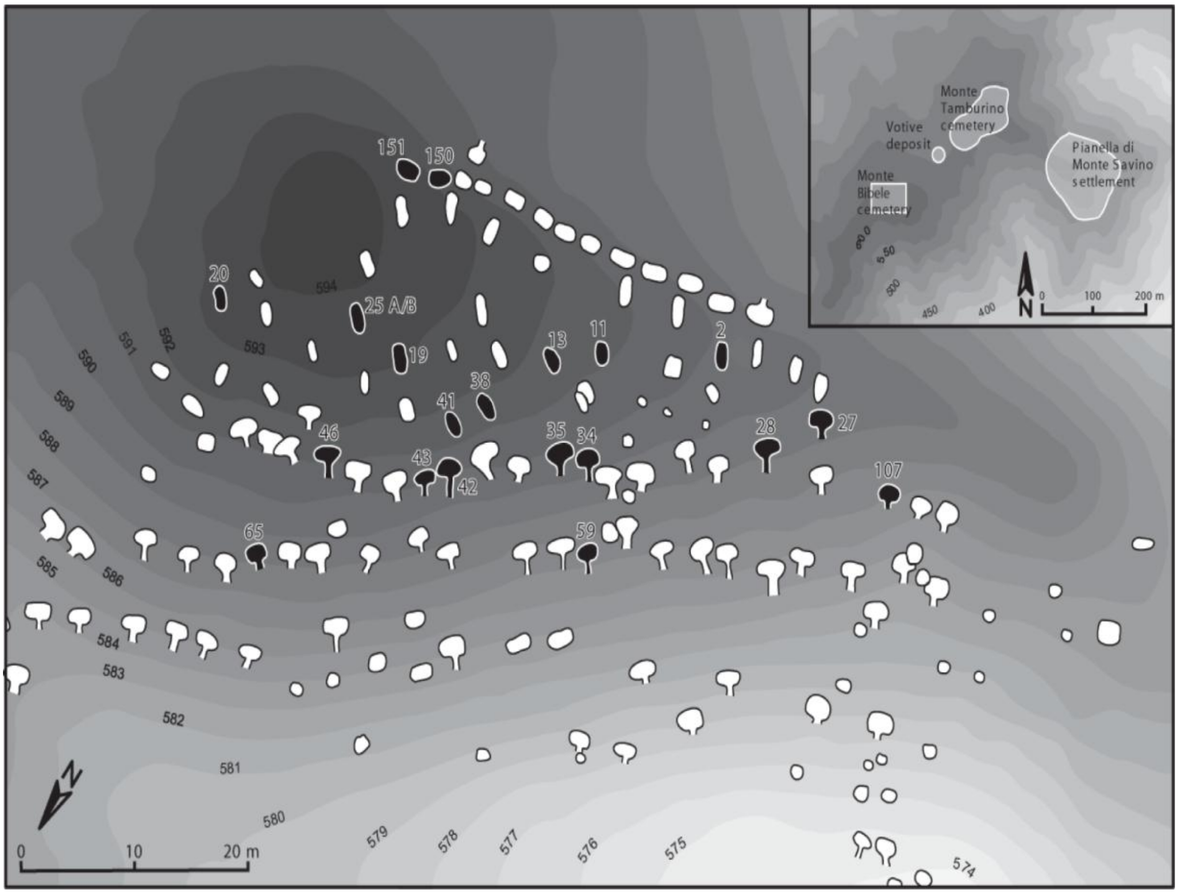
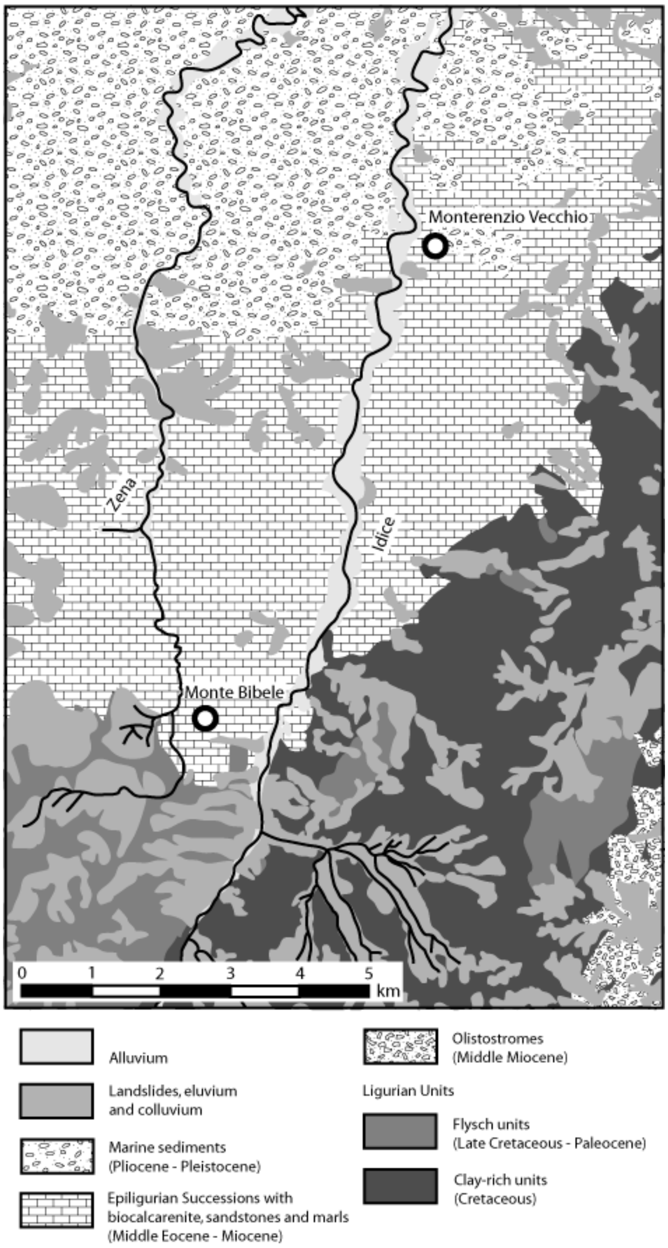


Figure 4.4 The cemetery of Monte Bibele on the peak of Monte Tamburino, with the analysed graves in black and nearby archaeological sites on Monte Tamburino (insert in upper right corner) (Modified from Vitali, 2008).



Geologically, the area around Monte Bibele is dominated by shallow-water sediments of the Epiligurian succession, dating to the Miocene (Tertiary) (Cibin et al., 2002) (**Fig. 4.5**). The Epiligurian succession extends over a large area and consists of a mixture of heterogeneous sedimentary rocks. Among them are fossiliferous fine sandstones, grey marls and biocalcarenite, better known as dune rock or dune limestone. Furthermore, younger marine sediments, dating from the Messinian to the Pleistocene, alternate with older flysch deposits, e.g. marine sandstone, marls and clays from the Ligurian Unit dating roughly from the Cretaceous to the Eocene (Bettelli and Vannucchi, 2003).

Figure 4.5 Simplified geological map of Monte Bibele and its surroundings (Redrawn after ISPRA, 2009). The locations of the cemetery and the settlement of Monterenzio Vecchio to the north-east are indicated by white circles.

Comparative Sr isotope data from this particular region are still very scarce. In central Italy, a study on Pleistocene animal teeth from sedimentary marine carbonates yielded $^{87}Sr/^{86}Sr$ values between 0.7086 and 0.7090 (Pellegrini et al., 2008). This range is relatively narrow, but well comparable with the biologically available Sr isotope ranges in other limestone areas (cf. García-Ruiz et al., 2007; Montgomery et al., 2007). Further away, Pleistocene fossils from slope to deltaic deposits of the Lamone River Valley, approximately 35km east of Monte Bibele, provide $^{87}Sr/^{86}Sr$ values that range from 0.7091 for fossils deposited without substantial freshwater influence, more consistent with open marine Pleistocene water values, to 0.7085, considered to reflect dilution by fluvial water with lower $^{87}Sr/^{86}Sr$ (Vaiani, 2000). These Sr isotope ratios form the framework for the interpretation of our tooth enamel samples.

4.3. Material

The preservation conditions allowed the sampling of 17 out of the 21 inhumations from Nebringen for Sr isotope analysis. Among the analysed individuals were three children, seven females and seven males. They represent predominately juvenile (~13-20 years) (n = 4), adult (~21-40 years) (n = 6) and mature (~41-60 years) (n = 5) individuals, while infants (I; ~0-6 years) (n = 1) and senile (≥60 years) (n = 1) individuals are under-represented (classification after Herrmann et al., 1990) (**Table 4.1**). In order to collect data for the early and later years of childhood, for 16 individuals, two enamel samples from different tooth crowns (M1 and preferably M3) were extracted. Since no animals were buried at the cemetery, five human femur samples were analysed to determine the local strontium isotope signature (**Table 4.1**). In contrast to tooth enamel, bones remodel throughout life and represent the strontium isotope ratios of adulthood (Bentley, 2006), or are adjusted to the isotope ratios of the local labile Sr by diagenetic alteration (Budd et al., 2000; Trickett et al., 2003).

In Monte Bibele, 21 individuals from among the inhumations were sampled. The analysed skeletons comprise two children, eight females, eight males and three individuals with undetermined sex. Adults (~21-40 years) (n = 8) dominate this group, otherwise there are infant II (~7-12 years) (n = 2), juvenile (~13-20 years) (n = 4), mature (~41-60 years) (n = 2) and senile (≥60 years) (n = 3) individuals (**Table 4.1**). The age of two burials could not be determined. Archaeologically, the investigated individuals primarily represent the “second generation” of the cemetery (beginning around 380 BC). Among them were eight burials of both sexes with mixed grave inventories comprising archaeologically local Etruscan objects and archaeologically foreign Celtic elements, such as La Tène weaponry and jewellery (Vitali, 2008) (**Table 4.1**). One sampled female (grave 2) belongs to the purely Etruscan graves that date to the fifth/fourth century BC. Initially, only M1s were sampled. From five individuals with slightly deviating Sr isotope ratios in their M1s, a second tooth (M3) was analysed. Additionally, five human dentine samples were examined to obtain base-line information on the local labile Sr isotope signature, as dentine is likely to alter diagenetically corresponding to the $^{87}Sr/^{86}Sr$ values of the soil in which it is buried. However, several studies

Table 4.1 $^{87}Sr/^{86}Sr$ ratios of the analysed human and faunal samples from Nebringen (NEB) and Monte Bibele (MTB/CAS). The dental notation is according to the FDI-system (Fédération Dentaire Internationale).

Grave	Sample	Period	Sex	Age	Material	Element	$^{87}Sr/^{86}Sr$	±2σ	Grave goods
1	NEB1.1	Lt B1	M	40-55	Enamel	36	0.709265	9	Not characteristic
	NEB1.2				Enamel	28	0.709677	10	
	NEB1.3				Bone	-	0.709388	10	
2	NEB2.1	-	M	25-35	Enamel	37	0.709868	10	Warrior
	NEB2.2				Enamel	38	0.710231	9	
	NEB2.3				Bone	-	0.709014	10	
3	NEB3.1	Lt B1	F	18-20	Enamel	36	0.709999	10	Jewellery
	NEB3.2				Enamel	18	0.709313	10	
4	NEB4.1	Lt B2a	F	50-60	Enamel	36	0.709958	10	Jewellery
	NEB4.2				Enamel	35	0.709675	10	
	NEB4.3				Bone	-	0.709064	10	
5	NEB5.1	Lt B1	M	25-35	Enamel	16	0.709172	10	Warrior
	NEB5.2				Enamel	18	0.709247	10	
	NEB5.3				Bone	-	0.709171	10	
6	NEB6.1	Lt B1	M	30-50	Enamel	36	0.710470	10	Warrior
	NEB6.2				Enamel	38	0.710276	10	
	NEB6.3				Bone	-	0.709311	9	
8	NEB8.1	Lt B1	F	> 60	Enamel	46	0.709950	10	Jewellery
	NEB8.2				Enamel	45	0.710293	10	
9	NEB9.1	Lt B2	M	30-40	Enamel	17	0.709763	10	Warrior
	NEB9.2				Enamel	18	0.709849	10	
12	NEB12.1	Lt B1	F	50-60	Enamel	26	0.709325	10	Jewellery
14	NEB14.1	Lt B2a	F	35-50	Enamel	16	0.709977	10	Jewellery
	NEB14.2				Enamel	18	0.710613	9	
17	NEB17.1	Lt B1	C	05-06	Enamel	65	0.710027	12	Jewellery
	NEB17.2				Enamel	46	0.709866	7	
18	NEB18.1	Lt B2a/b	F	30-50	Enamel	46	0.709791	10	Fibula with drum shaped bow
	NEB18.2				Enamel	48	0.711879	10	
19	NEB19.1	Lt B1	M	55-65	Enamel	16	0.709413	10	Not characteristic
	NEB19.2				Enamel	15	0.709859	9	
20	NEB20.1	Lt B1	C	14-15	Enamel	46	0.710503	10	Not characteristic
	NEB20.2				Enamel	47	0.710771	10	
23	NEB23.1B	Lt B1b/B2a	F	30-40	Enamel	46	0.709258	9	Jewellery
	NEB23.2				Enamel	48	0.709397	10	
24	NEB24.1	Lt B	C	14-15	Enamel	46	0.709751	10	Not characteristic
	NEB24.2				Enamel	47	0.709771	10	
25	NEB25.1	Lt B	M	16-18	Enamel	16	0.709364	10	Not characteristic
	NEB25.2				Enamel	28	0.710513	9	
2	MTB2.1	LT A	F	25-30	Enamel	36	0.708927	9	Local
11	MTB11.1	LT A	?	15-20	Enamel	46	0.708905	8	Local
13	MTB13.1	LT A	?	?	Enamel	16	0.708883	7	-
19	MTB19.1	LT A	F	20-30	Enamel	46	0.709298	10	Local/Umbrian
	MTB19.2				Enamel	48	0.709351	13	
20	MTB20.1	LT A	F	21-40	Enamel	36	0.709229	9	Local/eastern earring
	MTB20.2				Enamel	38	0.709270	14	
25A	MTB25A.1	LT A	M	20-30	Enamel	46	0.708973	10	No grave goods
	MTB25A.3				Dentine	46	0.708890	10	
25B	MTB25B.1	LT A	F	60	Enamel	36	0.709112	10	Local & La Tène

Grave	Sample	Period	Sex	Age	Material	Element	$^{87}Sr/^{86}Sr$	±2σ	Grave goods
27	MTB27.1	LT B1a	F	Ca. 20	Enamel	36	0.709064	10	Local & La Tène
28	MTB28.1	LT B1a	F	20-25	Enamel	46	0.709020	10	Local
34	MTB34.1	LT B1a	M	40-50	Enamel	47	0.709014	10	Local
35	MTB35.1	LT B1a	M	18-20	Enamel	16	0.709414	9	Local & La Tène/warrior
	MTB35.2				Enamel	48	0.709200	7	
	MTB35.3				Dentine	16	0.709032	10	
38	MTB38.1	LT A	M	20-25	Enamel	46	0.708936	10	Local
41	MTB41.1	LT B1b	F	30-35	Enamel	26	0.708964	10	Local
	MTB41.3				Dentine	27	0.708879	10	
42	MTB42.1	LT B1b	M	40-50	Enamel	46	0.709022	10	Local & La Tène/warrior
43	MTB43.1	LT B1b	F	20-25	Enamel	46	0.708937	9	Local & La Tène
	MTB43.3				Dentine	46	0.708964	10	
46	MTB46.1	LT B1b	C	12	Enamel	46	0.708984	10	Local
59	MTB59.1	LT B2	C	10-11	Enamel	46	0.708984	10	Local & La Tène/warrior
65	MTB65.1	LT B2	M	60	Enamel	36	0.709144	7	Local & La Tène
	MTB65.2				Enamel	38	0.709327	13	
107	MTB107.1	LT B1	M	20	Enamel	46	0.709264	10	Local & La Tène/warrior
	MTB107.2				Enamel	48	0.709008	7	
150	MTB150.1	LT B1a	?	?	Enamel	47	0.708896	8	**?**
151	MTB151.1	LT B1a	M	60	Enamel	36	0.708909	9	Local/eastern earring
	MTB151.3				Dentine	38	0.708889	10	Local & La Tène/warrior
-	CAS5.1	400-200 BC	?	?	Enamel	LM^3	0.708935	9	-
-	CAS9.1	400-200 BC	?	?	Enamel	RM^3	0.709071	10	-
-	CAS15.1	400-200 BC	?	?	Enamel	LM^1	0.709022	10	-
-	CAS18.1	400-200 BC	?	?	Enamel	LM^3	0.708901	10	-
-	CAS19B.1	400-200 BC	?	?	Enamel	LM_3	0.708875	10	-

have revealed that variability in diagenesis of dentine can cause differing $^{87}Sr/^{86}Sr$ values in this dental tissue (Budd et al., 2000; Montgomery et al., 2007; Trickett et al., 2003). The result can be a mixed value that usually lies between the $^{87}Sr/^{86}Sr$ values of the tooth enamel and the surrounding soil. Dentine data are, therefore, only used to confirm the expected local range. The biologically available Sr was determined using five pig enamel samples from the contemporaneous village "Pianella di Monte Savino" (cf. CAS-samples **Table 4.1**). Archaeological domestic pigs are often selected for comparative purposes, because they were most likely kept and fed locally (Bentley, 2004, 2006; Bentley and Knipper, 2005). However, possible causes of non-local values, such as the exchange of single animals or forest pasture covering several geological units, must be considered during data analysis (e.g. Stephan, 2009; Stephan et al., 2012).

As a cut-off value, the mean ±2σ of the obtained reference material (human bone in Nebringen and pig enamel in Monte Bibele) was calculated to establish the biologically available Sr (e.g. Bentley et al., 2004; Grupe et al., 1997; Price et al., 2002). Its representativeness for the area was subsequently checked by comparing this range with the available comparative data from the study areas and the distribution of the $^{87}Sr/^{86}Sr$ values of the majority of the analysed individuals. This approach allowed us to identify individuals with a differing, supposedly non-local, Sr isotope composition.

4.4. Method: Sr isotope analysis

The enamel, dentine and bone samples were extracted using a round diamond bur. All tooth enamel, dentine and bone powder was ultrasonically cleaned and rinsed first with Milli-Q water, subsequently with weak acetic acid (0.1 M, Li-acetate buffer) to remove diagenetic carbonates, and then three times with Milli-Q water (Koch et al., 1997; Tütken et al., 2006). They were dried overnight at 50 °C and ashed for 10 h at 850 °C to remove the remaining organic matter (Price et al., 2000). The samples were digested in 500 ml of concentrated HNO_3 overnight at 100 °C on a hot-plate in the clean laboratory (Department of Geosciences, University of Tübingen). Then they were dried down and re-dissolved in 3 M HNO_3. Extraction chromatography with extractive resin (Horwitz et al., 1992) and 3 M HNO_3 was used to separate the Sr from the other elements.

The isotope ratios were determined using a Finnigan MAT 262 Thermal Ionization Mass Spectrometer (TIMS), by loading the extracted samples on tungsten filaments with 1 ml of HNO_3 and 1 ml of Ta-HF activator. The $^{87}Sr/^{86}Sr$ isotope ratios were normalised to $^{86}Sr/^{88}Sr$ = 0.1194 (Nier, 1938). Repeated measurements of the international standard for $^{87}Sr/^{86}Sr$ (NBS 987) gave a mean value of 0.710236 ± 0.000051 (1σ, n = 45). All Sr ratios were corrected to the long-term average value for NBS 987 of 0.710248 (cf. McArthur et al., 1992). Sr blanks were generally lower than 100 pg.

4.6. Results

4.6.1. Nebringen

4.6.1.1. Isotope ratios of the biologically available strontium

The five human bone samples from Nebringen yielded $^{87}Sr/^{86}Sr$ ratios between 0.7090 and 0.7094 (mean: 0.7092 ± 0.0003 [2σ]) (**Table 4.1**, **Fig. 4.6**). This range is relatively narrow in comparison to previous studies of south-west German loess sites, where bone values typically range between about 0.7090 and 0.7100 (cf. Bentley and Knipper, 2005; Bentley et al., 2004; Knipper, 2011, Fig. 9.21). The limited range in Nebringen most likely results from diagenetic adjustment to the isotope ratios of the sediments in which the bones were buried (Feranec et al., 2007). In this case, the samples primarily reflect the $^{87}Sr/^{86}Sr$ values of the direct burial environment, but not the variability of agricultural land-use. In order to avoid an over-interpretation of the tooth enamel data in terms of non-local individuals, an upper limit of 0.7100 was applied for data interpretation. Individuals with differing $^{87}Sr/^{86}Sr$ ratios did not acquire their food sources directly from the loess.

4.6.1.2. $^{87}Sr/^{86}Sr$ values of the human teeth

The Sr isotope ratios of the analysed human tooth enamel samples vary between 0.7092 and 0.7119 (mean: 0.7099 ± 0.0011 [2σ]) (Fig. 6). Most males (n = 4) tend to have Sr isotope ratios in their M1 that correspond to the local range determined by the bones. The majority of the females (n = 5), on the other hand, have $^{87}Sr/^{86}Sr$ ratios in their M1 which lie closer to 0.7100, the upper limit of loess. The latter also applies to the two local children. Furthermore, chronological tendencies have been observed. While the LT B1 samples spread over the whole loess range and beyond, values between 0.7090 and 0.7095 have not been detected in LT B2. Instead, the $^{87}Sr/^{86}Sr$ ratios concentrate between 0.7095 and 0.7100 or are within the range of the nearby more radiogenic *Keuper* (**Fig. 4.3**).

Even though the inter-individual variation of the Sr isotope ratios appears to be high, only the enamel samples of a 30-50 year old male (grave 6) and a 14-15 year old child (grave 20) fall outside the loess range. These Sr values may indicate non-local individuals, or they could have been caused by food derived from agricultural plots on *Keuper*, which occurs in the direct environs of Nebringen (**Fig. 4.6**).

In many cases the differences between the M1 and M3 (or M2/ P2) were small (**Table 4.1**),

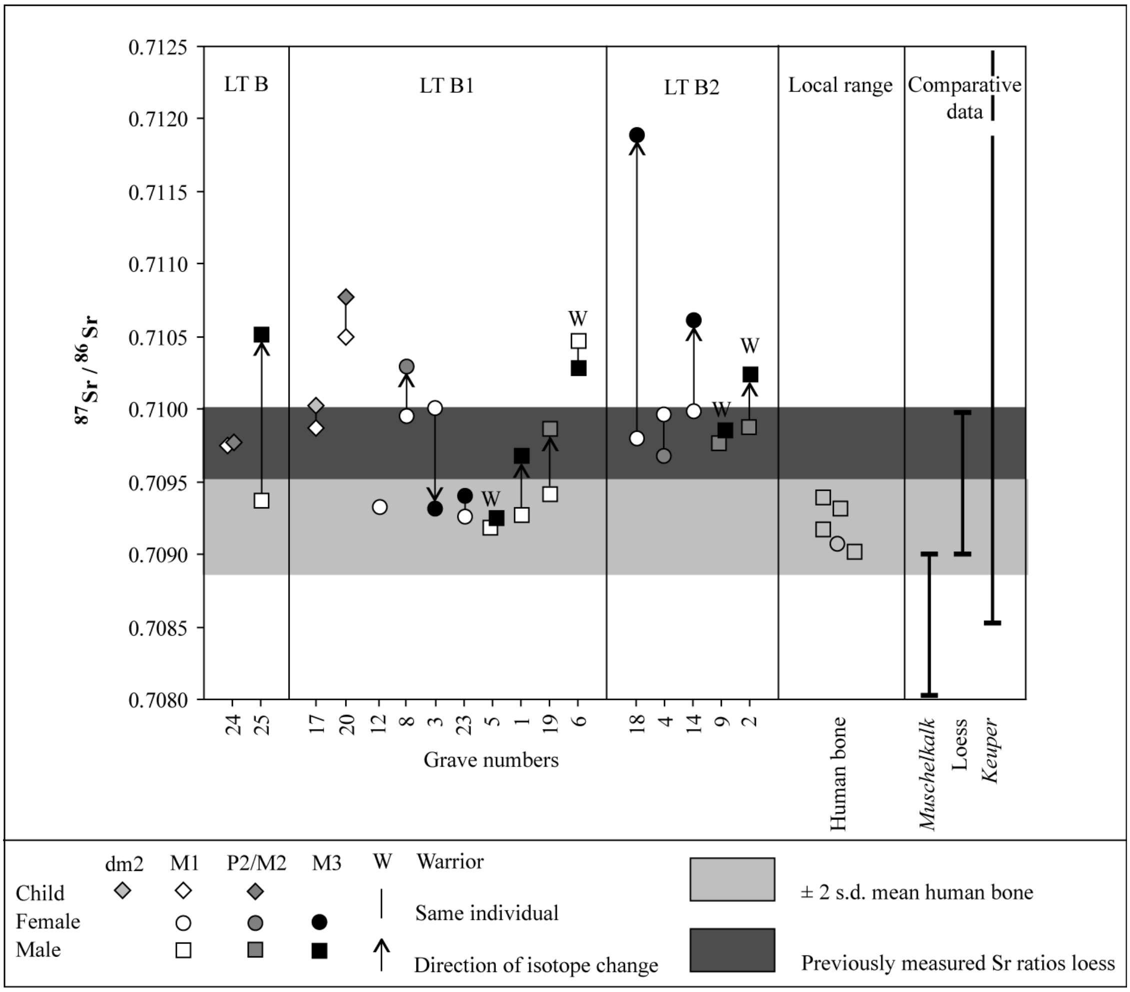


Figure 4.6 Strontium isotope ratios of the children, females and males from Nebringen, divided by time period. Note the more dispersed $^{87}Sr/^{86}Sr$ values in LT B1, and more concentrated $^{87}Sr/^{86}Sr$ values in LT B2. The analysed individuals were organised by sex and from lower to higher Sr isotope ratios. Aligned symbols, connected with a line, indicate the same individual. Arrows were assigned to the individuals with isotope ratios that might indicate changing geological conditions.

but exceeded 0.001 for one male (grave 25) and one female (grave 18). This change is larger than the whole range of loess values in the area. According to their M1s, both individuals may have been born in Nebringen or another locality on loess, and could then have spent time in an area with more radiogenic $^{87}Sr/^{86}Sr$ values, such as the nearby *Keuper*, during their later childhood and youth (cf. M3). A similar, but less pronounced pattern is visible for three other individuals (graves 2, 8 and 14) (**Fig. 4.6**) whose later-forming teeth also yielded $^{87}Sr/^{86}Sr$ ratios above 0.7100. One female (grave 3) and possibly two males (graves 1 and 19) may have exploited multiple/a variety of resources within the loess area, as their $^{87}Sr/^{86}Sr$ values vary between close to 0.7010 and the local range determined by the bones. Overall, differences between the early and late forming enamel have been detected for eight out of 16 individuals (50%) for which two teeth were sampled. However, all Sr isotope ratios are in agreement with the variable local biologically available strontium, which doubtlessly complicates the detection of non-local individuals.

4.6.2. Monte Bibele

4.6.2.1. Isotope ratios of the biologically available strontium

The five pig enamel samples from Monte Bibele yielded $^{87}Sr/^{86}Sr$ ratios between 0.7089 and 0.7091 (mean: 0.7090 ± 0.0002 [2σ; n = 5]), which were very similar to the five human dentine samples (**Table 4.1**, **Figs. 4.7 and 4.8**). An equally narrow range has also been found in five pig enamel samples from the Bronze Age settlement of Monterenzio Vecchio, approximately 5 km to the north-east ($^{87}Sr/^{86}Sr$ range: 0.7089-0.7090; mean: 0.7089 ± 0.0001 [2σ]). The human enamel values which fall outside this range are considered non-local.

4.6.2.2. $^{87}Sr/^{86}Sr$ values of the human teeth

The Sr isotope ratios of the analysed human tooth enamel samples lie between 0.7089 and 0.7094 (mean: 0.7091 ± 0.0003 [2σ]; **Fig. 4.7**). Although the inter-individual variation appears low, also in comparison to Nebringen (**Fig. 4.8**), there are indications for non-local individuals (**Fig. 4.7**). The $^{87}Sr/^{86}Sr$ value in the M1 of the majority (n = 15) of the individuals are well comparable with the narrow range observed in the pig teeth and comparative data, and imply that they were born in Monte Bibele or a geologically similar location. One male (grave 65) with minimally differing $^{87}Sr/^{86}Sr$ values in his M1 is also included in this number. For two additional individuals (graves 34 and 150) only later forming M2s were available, which also fall into this range.

Second tooth enamel samples were analysed for only five individuals, which limits evidence for childhood mobility. The individuals from whom two tooth samples were analysed either had similar $^{87}Sr/^{86}Sr$ values in both analysed teeth (graves 19 and 20), a later formed tooth (M3) that tended to the local range (graves 35 and 107), or shifted to more radiogenic (grave

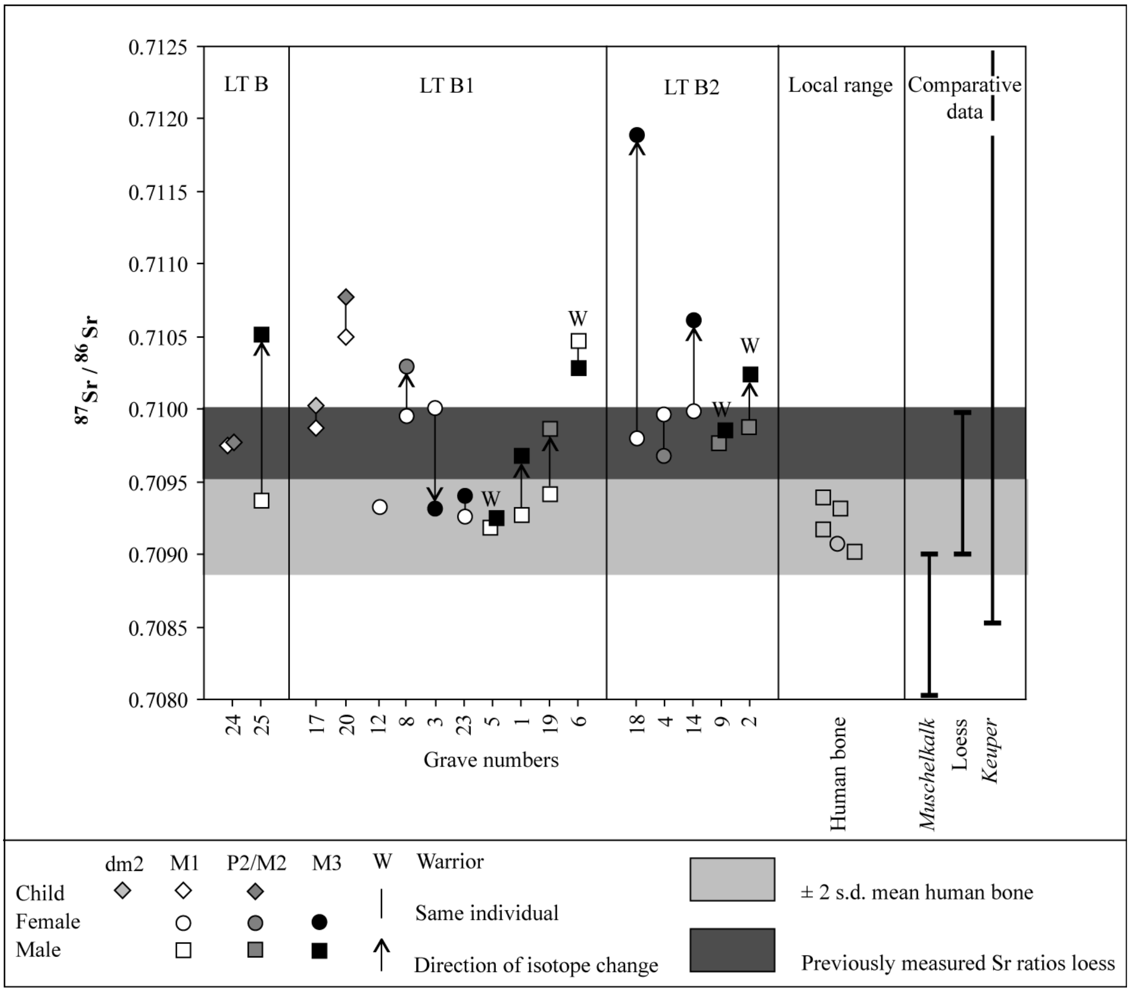


Figure 4.7 Strontium isotope ratios of the selected children, females and males from Monte Bibele, divided by time period. The analysed individuals were organised by sex and from lower to higher Sr isotope ratios. Aligned symbols indicate the same individual. Arrows were assigned to the individuals with isotope ratios that might indicate changing geological conditions.

65) $^{87}Sr/^{86}Sr$ values. The two males (graves 35 and 107) may already have moved to Monte Bibele or a geological similar area during their childhood, while the other male (grave 65) may have been raised elsewhere. Although these individuals have $^{87}Sr/^{86}Sr$ values that deviate little from the local range, and regional data from Italy are scarce, comparative data from areas with similar geological conditions (**Fig. 4.7**) also show very narrow Sr isotope ranges. Four (graves 19, 20, 35 and 107) out of the 21 analysed individuals (19%) were therefore considered to have been born non-locally.

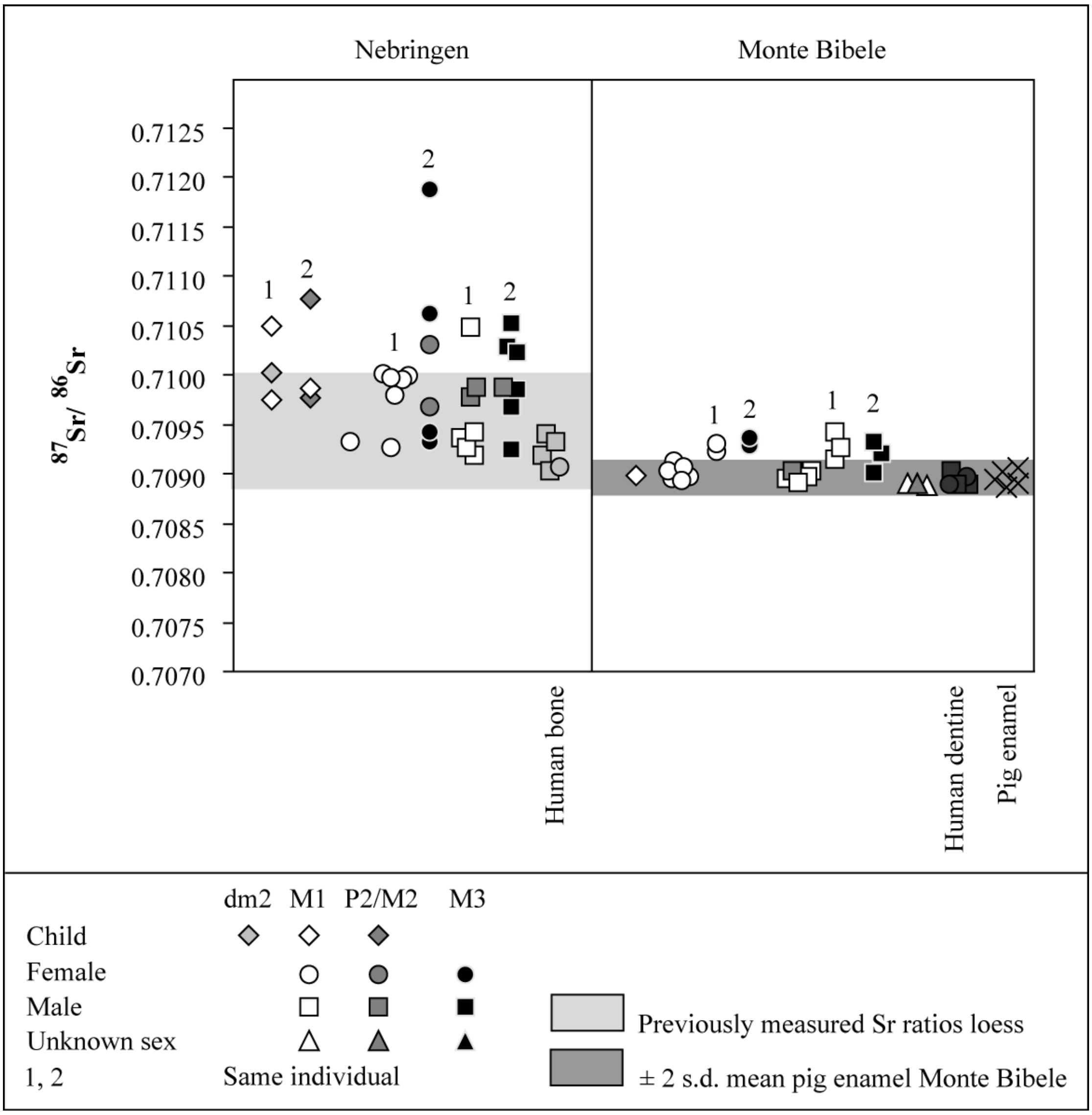


Figure 4.8 Strontium isotope ratios of the analysed human and faunal samples from Nebringen (left) and Monte Bibele (right) combined. Previously measured Sr isotope ratios in loess after Knipper, 2011.

4.7. Discussion

Although the identification of non-local individuals at Nebringen is hindered by the heterogeneous geological conditions near the site, while in Monte Bibele the homogeneous geological conditions might obscure the actual number of foreigners, both datasets indicate low proportions of non-local individuals (**Figs. 4.6-4.8**). The low frequency of 19% at Monte Bibele is comparable to the previously studied contemporaneous Swiss cemetery of Münsingen-Rain, where a frequency of 14.7% has been observed (Scheeres et al., 2013). Sr isotope studies on other time periods also yielded low numbers of non-local individuals, for example from the middle Neolithic in the Netherlands (Swifterbant culture; Smits et al., 2010) or early medieval central Germany (Knipper et al., 2012a), while higher frequencies of over 20% non-locals have for instance been found in early Neolithic south-west Germany (Bentley et al., 2004) and Roman Britain (Chenery et al., 2011). Although the cemeteries of the present study date to the period of the historic “Celtic migrations” (Tomaschitz, 2002), strontium isotope analysis did not reveal extraordinarily high numbers of non-local individuals.

4.7.1. Mobility, land use and community structures

The majority (88%) of the analysed individuals from Nebringen appear to have been born or raised in a loess environment, whereby the differing isotope ratios within the same jaws may reflect individual mobility or, most likely, land-use patterns. In most of the individuals with noteworthy differences between early and late forming teeth, which exceed the $^{87}Sr/^{86}Sr$ ratios of the loess (graves 2, 8,14 and 25), the Sr isotope ratios of the M3s (respectively M2) are similar to the two individuals (graves 6 and 20; **Fig. 4.6**) who have $^{87}Sr/^{86}Sr$ values which correspond to the *Keuper* range. Because loess and more radiogenic *Keuper* alternate in the near surroundings of the cemetery (**Fig. 4.3**), these data may either reflect residential changes or alternating land-use strategies within a few kilometres distance from the cemetery. Cultivated land plots may have changed frequently, even within a few years (alternating Sr isotope ratios within the same jaw), or fluctuated gradually, as attested by the different data distributions of the LT B1 and LT B2 samples. Although the archaeological evidence for Iron Age occupation of the area has recently been reviewed (Hald, 2009), no larger contemporary settlements are known. Instead, small scatters of surface finds point to small hamlets or single farmsteads. Contemporary information on land-use strategies in south-west Germany comes from animal teeth, dating to the early La Tène period (Stephan et al., 2012). They showed similarly variable $^{87}Sr/^{86}Sr$ values, which were interpreted to reflect pasturage on loess, *Muschelkalk* and *Keuper*. Such dispersed settlement and husbandry strategies in a geologically heterogeneous environment may result in a variation of Sr isotope ratios of human teeth that does not necessarily - but may possibly - reflect residential changes over long distances.

Similarly to Nebringen, in Monte Bibele most (81%) of the analysed individuals appear to originate from the area and only very few samples indicate a non-local origin or movement during childhood (**Fig. 4.7**). In contrast to Nebringen, an associated settlement site has been located near Monte Bibele ("Pianella di Monte Savino"; Vitali, 2008, 10; **Fig. 4.4**). The relatively narrow range in the Sr isotope ratios of the human teeth (**Fig. 4.8**) might be explained not only by residence in the same village, but also by usage of the same agricultural resources. However, another cause for the lack of variation might be the homogeneous geological conditions in the hinterland of this site, which could conceal individuals who acquired their food from more distant areas.

4.7.2. Strontium isotopes and kinship relations

In Nebringen, kinship analyses reveal some familial relations among the buried individuals (Scholz et al., 1999), which can be integrated with the Sr isotope data. Six distinct grave groups in Nebringen already led Krämer (1964) to assume familial relations among the deceased (**Fig. 4.2**). Although it is methodologically questionable, an ancient DNA (aDNA) and morphological study revealed that grave group III (grave 23: mother, graves 24 and 25: children), with a possible father in grave group V (grave 1), may represent a "family" (Scholz et al., 1999). The Sr isotope ratios of these individuals are very similar and consistent with the loess range (**Fig. 4.6**). Only the $^{87}Sr/^{86}Sr$ value of the M3 of the possible child (grave 25) points to the consumption of food from a more radiogenic, presumably *Keuper*, area during youth. No kinship analysis has been performed on the deceased buried at Monte Bibele.

In both cemeteries, females are usually consistent with the isotope ratios of the local biologically available strontium, with few indications of mobility, and evidence for non-local birth or movement during childhood has been found somewhat more frequently for the males (**Figs. 4.6-4.7**). This contradicts findings in other prehistoric time periods in which more variability among the females pointed to patrilocal residential patterns (cf. Bentley, 2007; Haak et al., 2008; Knipper et al., 2012b). The present database is too small to exclude patrilocality, but as yet it does not provide any evidence for it.

4.7.3. Residential changes of Celtic warriors

Greek and Roman authors attest that Celtic warriors of the fourth and third century BC were highly mobile and participated as mercenaries in nearly all military conflicts (Tomaschitz, 2002; Hauschild, 2010c). Additionally, the spread of Celtic weaponry throughout Europe either proves the mobility of the Celtic mercenaries, or an appreciation of the effectiveness of Celtic swords. In Nebringen, being buried with weapons does not always correlate with an indication of mobility (**Fig. 4.6**). The Sr isotope data of the four warriors differ among each other, but overall correspond well to the heterogeneous geological environment of the cemetery and may therefore reflect alternating land-use patterns rather than individual mobility. In Monte Bibele, two warriors changed their residency during childhood (graves 35 and 107) and three have Sr isotope ratios within the local range (graves 42, 59 and 151). Overall, warriors do not seem to be more often of non-local origin than males buried without weaponry. Nevertheless, it is noteworthy that the data are based on tooth enamel which forms during childhood. It is therefore methodologically impossible to identify men who returned to their home communities after participating in military raids as young adults.

4.7.4. Combining archaeological evidence and isotope data

Most burials in Nebringen contain typical finds of the early La Tène phase LT B1b-B2 (350-280 BC). One female (grave 18) is of special interest. Her M3 yielded the most radiogenic $^{87}Sr/^{86}Sr$ value of this study (Fig. 6). Although the *Keuper* located nearby could have caused such high values, no other individual has comparable $^{87}Sr/^{86}Sr$ ratios. Even if one assumes that the investigated community cultivated different land plots, this result is conspicuous. An early La Tène fibula with a drum shaped bow belonging to her costume is also noteworthy. Similar pieces are known from the middle Danube area and the Carpathian Basin, e.g. from Gyoma-Egei halom (kom. Békés) in south-east Hungary and from Fântânele-Dâmbul Popii (jud. Mureş) in Romania (Maráz, 1977; Rustoiu, 2008), which make a connection to the eastern La Tène area most likely (Hauschild et al., 2013). The woman may have obtained the fibula when she spent her later childhood and youth away from Nebringen. However, these Sr isotope ratios occur in a wider geographical region and are not exclusive to these particular areas. They can neither confirm nor exclude residency in the areas where archaeological analysis suggests connections.

In Monte Bibele, one local female (grave 2) belonged to the purely Etruscan graves of the “first generation”, while all other studied individuals represent the “second generation”. Eight of these analysed individuals were buried with a combination of Etruscan and Celtic objects which suggest connections between Central Europe and the Mediterranean area. The Sr isotope ratios of their teeth vary and do not point to a common place of origin. This suggests that these Celtic objects were not introduced by one population group which maintained close connections to the Monte Bibele community. Their possessors came from areas with similar or slightly differing Sr isotope ratios. In some cases (graves 35, 65 and 107), the $^{87}Sr/^{86}Sr$ values indicate residential changes during childhood, while other examples are consistent with the local isotope range (graves 25B, 27, 42, 59 and 151). The M1s of the males in graves 35 and 107 as well as the M3 from grave 65 are similar to the isotope ratios of the non-local females in graves 19 and 20 which did not contain any mixed grave sets (**Fig. 4.7**). Grave 19 contains hand-made pottery suggesting an origin in the Central Italian region of Umbria. Monte Bibele, like the cemetery of Monterenzio Vecchio on the other side of the valley (Bondini et al., 2005), has common elements with the Umbrians, whose territory in the Apennine area reaches up the Sillaro valley, at the foot of Monterenzio Vecchio. Some of the impasto pottery types of the necropolis and of the settlement of Monte Bibele reflect these communities of Central Italian origin. The other female (grave 20) could have had connections to south-east Europe, for example the Great Hungarian Plain, as her grave set contained one specific earring characteristic for that region (Kemenczei, 2001/2002; Hauschild et al., 2013). The Sr isotope ratios do not contradict these observations of connections with distant areas, but are not at all exclusive for the suggested areas of origin. In Umbria, marine carbonates and sandstones with $^{87}Sr/^{86}Sr$ values between 0.7081 and 0.7095 ($^{87}Sr/^{86}Sr$ values from the Arno River Basin; Nisi et al., 2008) occur, and human bones from the Great Hungarian Plain yielded $^{87}Sr/^{86}Sr$ values from about 0.709-0.710 (Giblin, 2011, 2009). As many areas have corresponding Sr isotope ranges, the individuals with comparable radiogenic Sr isotope data can only be judged as non-local or mobile during childhood, but where they came from and whether they travelled from the same or different places remains questionable.

4.8. Conclusion

Although the Celtic communities studied in this project appeared mainly local, the Sr isotope data of some single individuals, both males and females, deviated from the majority of the analysed individuals. There is, however, no indication that specific population groups had more varied isotope compositions than others, e.g. warriors, or females who followed patrilocal residential norms. The motives for the detected movements, therefore, seem to be varied. Residential changes were also not only confined to the Celtic expansion area, instead individuals were moving within their own region, irrespective of being the core or expansion area. However, the prevailing geological conditions might have obscured this picture, as more variable $^{87}Sr/^{86}Sr$ values are observed in the heterogeneous environment of Nebringen than in the homogeneous conditions of Monte Bibele.

Objects and ideas also seem to have been exchanged freely: for example mixed Celtic-Etruscan grave sets have been found with local and non-local individuals in Monte Bibele. The provenance of these exchanged grave goods combined with the Sr isotope data can give an indication of an individual's origin. But in this case it can only be argued that if the mixed grave sets herald the arrival of newcomers, they came from different areas with isotope ratios that could not be distinguished from the other analysed individuals buried at Monte Bibele. The lack of foreign objects providing information about the exact origin of the buried men and women, and the occurrence of similar $^{87}Sr/^{86}Sr$ values in different areas, thereby hamper precise determinations of an individual's birth place. Nevertheless, the data presented here represent an important contribution to a better understanding of the period of "Celtic migrations".

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5. "CELTIC MIGRATIONS"? – FACT OR FICTION? STRONTIUM AND OXYGEN ISOTOPE ANALYSIS OF THE CZECH CEMETERIES OF RADOVESICE AND KUTNÁ HORA IN BOHEMIA

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ABSTRACT

Strontium and oxygen isotope analysis of human remains from the early La Tène (4th/3rd century BC) Czech cemeteries of Radovesice I, Radovesice II and Kutná Hora were conducted to investigate the importance of residential changes during the period of the historic "Celtic migrations". In the initial phases (LT A/B) the grave goods of these cemeteries are typical for the core area of the La Tène culture, while around 300 BC (LT B2) an alteration occurs and typical Bohemian styles arise, and connections to Moravia and the Danubian region become visible. The strontium isotope ratios are highly varied, whereas the oxygen isotope data are more homogeneous. Because the geological properties of the landscapes around the sites are variable and complex, most of the observed variations among the Sr isotope ratios may have been caused by agricultural practices, such as regularly changing farming land. Nevertheless, there are some individuals who differ completely from the regional isotopic baseline values and this suggests that at least a small part of the community migrated, and this does not seem to be correlated with any particular phase of the

La Tène period. Remarkably, it is mainly men who seem to be of non-local origin, and particularly those men buried as warriors. Females, on the other hand, appear to have been more closely bonded to the Bohemian region. Whether the “foreign” individuals with differing isotopic compositions came from Moravia or the Danubian region remains debatable.

Keywords: La Tène, Celtic migrations, mobility, strontium, oxygen

5.1. Introduction

In Central Europe, the 4th to 3rd century BC are understood to be the time of the „Celtic migrations". The historical record gives the impression of large population groups migrating from their main Central European homeland to eastern, western and southern Europe, even as far as Asia Minor (e.g. Collis, 2003; Tomaschitz, 2002). Archaeological evidence also reveals a uniform spread of flat inhumation cemeteries and typical sex-related burial customs – for example males were buried with weaponry and females were accompanied with sets of jewellery – throughout continental Europe (Krämer, 1985). Although the expansion of the distribution of the La Tène style and burial practice are ascribed to the Celts, it is now believed that this was not only caused by migration (Fitzpatrick, 1996), but is rather a sign of increased individual mobility and the adoption of new styles and practices (Frey, 1995). Nevertheless it remains uncertain how these residential relocations occurred and if this mobility was restricted to specific population groups or concerned complete households.

In this study strontium (Sr) and oxygen (O) isotope data of human teeth from the Bohemian cemeteries of Radovesice I "Vápenka", Radovesice II "Na Vyhlidce", and Kutná Hora "Karlov" will be presented to provide information on the role of residential changes and mobility rates (**Fig. 5.1**). More than 400 sites of the La Tène period are known in Bohemia and indicate a densely populated landscape (Waldhauser, 2001, 1987). Beside small cemeteries with up to a dozen graves, larger necropolises with more than 100 inhumations point to longer used sites (LT B1-C1) and larger settlement communities, sometimes even with specialised craftsmen (Waldhauser, 1993). According to the archaeological record, the La Tène culture seems to spread from north-west (earliest sites in LT A/B) to south Bohemia (earliest sites in LT B/C) (Michálek, 1990). The oldest flat inhumation cemeteries in north-west and central Bohemia start in LT B1a and are characterized by the so-called pre-Dux-fibula (Möller, 2000). From LT B1b onwards, flat cemeteries also appear in eastern Bohemia. Southern Bohemia has only very few graves of LT B1-C1, mainly cremations and secondary graves in older (Ha D/LT A) tumuli (Salač, 2005; Waldhauser, 1987). However, this discrepancy in the archaeological record might have been caused by the fact that La Tène flat inhumation cemeteries are less likely to be discovered in south Bohemia, where most of the land is covered by forest, than in the north, with its intensive agriculture and building activity caused by industry, open cast mining and road construction.

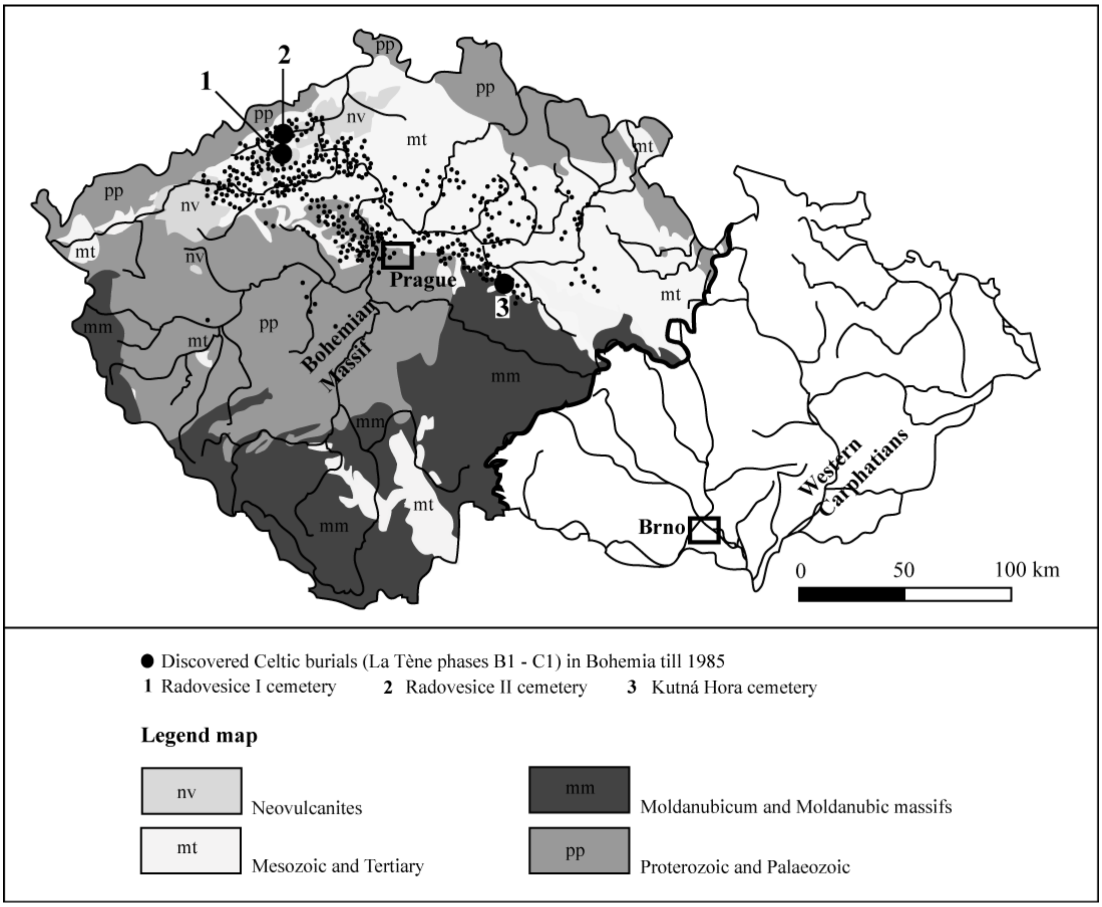


Figure 5.1 Simplified geological map with the distribution of La Tène cemeteries in Bohemia (Modified from Sucharovà et al., 2012; Svoboda et al., 2011; Waldhauser, 1987). Note the concentration of cemeteries near streams, especially in the northern part of Bohemia. The numbers 1, 2 and 3 indicate the cemeteries of Radovesice I, Radovesice II and Kutná Hora.

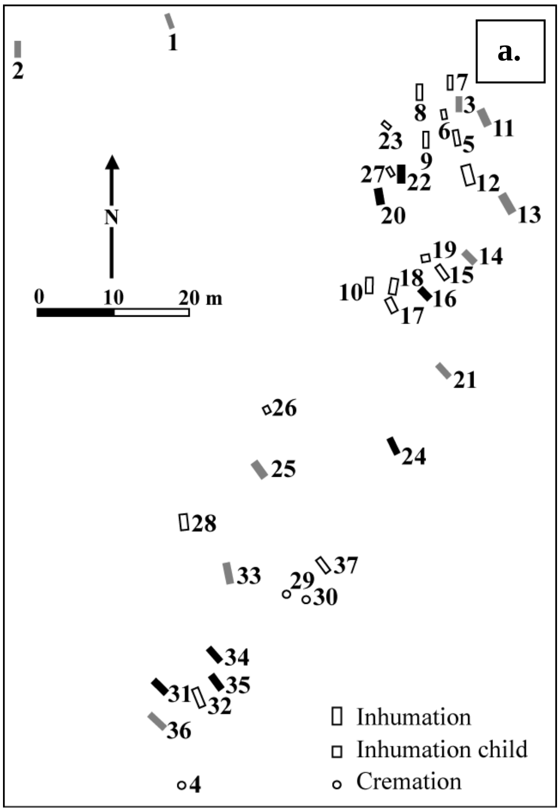
The cemeteries of Radovesice I, Radovesice II and Kutná Hora were used for several generations, and contain significant grave inventories dating to the phase LT B (380-250 BC). During this time, population growth and decline is generally linked with migration, which must have had an impact on the social structure and settlement patterns (Dobesch, 1996; Stöllner, 1998; Valentová and Sankot, 2012). Changing burial rites, such as the use of flat graves instead of tumuli, might also explain the apparent population decline, as it affects the archaeological visibility of sites. While the burial ritual and selection of grave goods in LT A and B1 indicate that Bohemia (western Czech Republic) and Moravia (eastern Czech Republic) belong to the core area of the La Tène culture, a regional development of jewellery starts in LT B2, especially in eastern Bohemia. During this phase a typical Bohemian La Tène style evolves that has connections to Moravia and the Danubian region. Close contacts between Bohemia and southern Bavaria are also known, for example at the site of Dornach (Lkr. München), where foreign objects mainly come from Bohemia. At Dornach, Sr isotope analysis suggests the presence of non-local individuals from Bohemia, and this seems to be confirmed by the archaeological distribution of a specific form of bracelets (Eggl, 2007, 2003; Vohberger, 2007).

$^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopes in tooth enamel are widely used in studies of migration and mobility of past populations (e.g. Evans et al., 2006; Mitchell and Millard, 2009). Because tooth enamel does not alter after mineralisation (Buddecke, 1981), it provides information about the location where an individual spent his or her childhood (cf. Ericson, 1985). The specific formation periods of tooth enamel are mirrored in the tooth crowns, e.g. first molars (M1) reflect early childhood, while third molars (M3) reflect later childhood and youth (Schroeder, 1992). As plants have the highest Sr concentration and therefore the greatest impact on the Sr isotope composition of skeletal tissues (Bentley, 2006; Price et al., 2002), strontium mainly represents the geological origin of the consumed plants by an individual. Oxygen is predominately derived from drinking water, which is related to local precipitation (Longinelli, 1984; Luz et al., 1984). The specific Sr isotope ratio of a locality is determined by the age and rubidium (Rb) content of the bedrock, as the radiogenic isotope ^{87}Sr originates from the radioactive decay of ^{87}Rb (Capo et al., 1998). The oxygen isotope composition depends on the fractionation of ^{18}O versus ^{16}O during evaporation, condensation and precipitation in the hydrological cycle (e.g. Gat, 1996). Variations in O isotope composition in precipitation are caused by temperature, elevation and distance from the sea (Bowen and Revenaugh, 2003).

5.2. Archaeological setting

The cemeteries of Radovesice I (RAD I) and II (RAD II) are located in north-west Bohemia, only 950 m distant from each other, 6 km south-west of the town of Teplice in the foreland of the Ore Mountains. Radovesice I, with 34 inhumation and three cremation graves, was discovered in 1976 (Waldhauser, 1993, 1987) (**Fig. 5.2a**). North-east of Radovesice I, Radovesice II with 23 inhumation graves was excavated in 1981 (**Fig. 5.2b**) (Budinský and Waldhauser, 2004). Both cemeteries were in use at the same time (La Tène phases B-C; ca.

380-200 BC). In 1972, rescue excavations in advance of brown coal mining had already revealed a prehistoric settlement north-west of Radovesice I, which was particularly intensively occupied from the early Hallstatt (Ha C) to the late La Tène period (LT D1). The settlement area of Radovesice II was never discovered and probably has already been destroyed by subsequent building work since the Middle Ages (Budinský and Waldhauser, 2004). It remains unclear if the cemeteries represent a single or two distinct populations (Waldhauser, 1999).



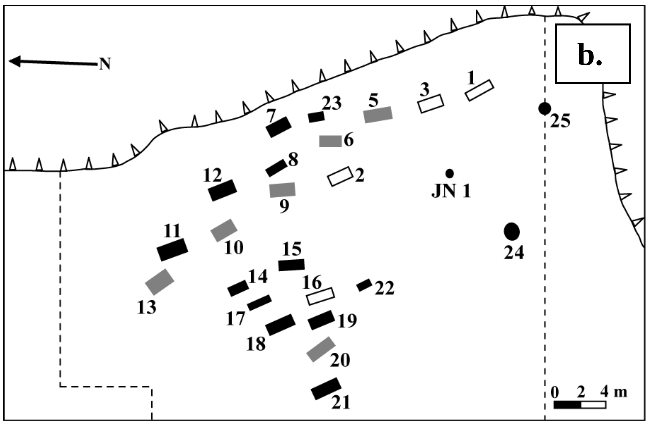


Figure 5.2b. The cemetery of Radovesice II “Na Vyhlidce” with the analysed graves in black and grey. The grey graves represent the analysed individuals with a $^{87}Sr/^{86}Sr$ difference of > 0.001 between the two analysed tooth enamel samples. JN1 contained a set of non-anatomically deposited bones of a single adult, and the numbers 24 and 25 represent storage pits (Modified from Budinský and Waldhauser, 2004).

Figure 5.2a. The cemetery of Radovesice I “Vápenka” with the analysed graves in black and grey. The grey graves represent the analysed individuals with a $^{87}Sr/^{86}Sr$ difference of > 0.001 between the two analysed tooth enamel samples (Modified from Waldhauser, 1987).

Rescue excavations in 1988/89 revealed the cemetery of Kutná Hora (KUT), located on the southern fringe of the Elbe valley, approximately 65 km east of Prague. A total of 48 inhumation graves and one cremation were recovered, while four to six graves were most likely destroyed by construction activities (**Fig. 5.3**) (Valentová, 1991; Valentová and Sankot, 2012). The cemetery dates to La Tène B, with most finds belonging to the LT B1b-B2a period

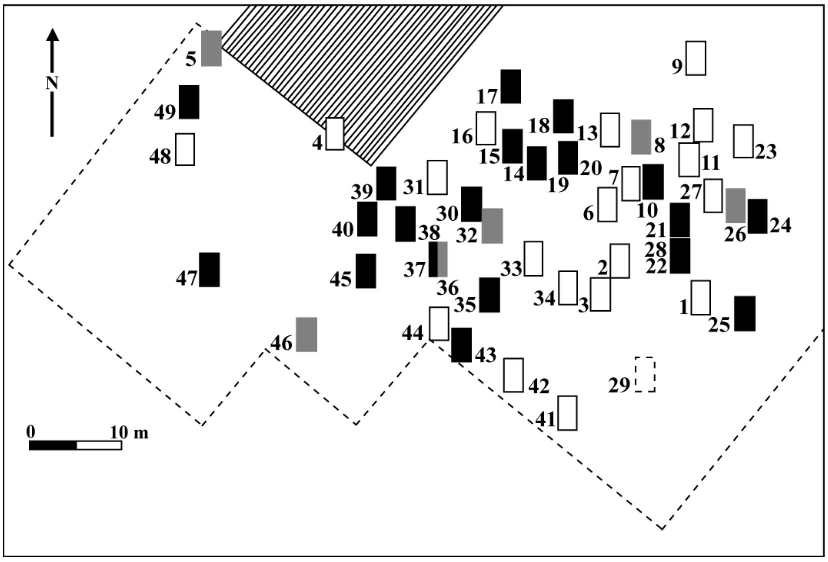


Figure 5.3 The cemetery of Kutná Hora “Karlov” with the analysed graves in black and grey. The grey graves represent the analysed individuals with a $^{87}Sr/^{86}Sr$ difference of > 0.001 between the two analysed tooth enamel samples (Modified from Valentová, 1993).

(350-300 BC). No objects related to the presence of a settlement were found here (Budinský and Waldhauser, 2004).

5.3. Geological setting

North-west Bohemia consists of a complex mixture of marine and terrestrial sediments (Dallmeyer et al., 1995), which alternate with old plutonic and metamorphic rocks, as well as with more recent volcanic rocks (CGS, 2003). The Tertiary deposits, e.g. coal to clayey coal, which were once to be found in the area of the cemeteries of Radovesice, were exploited by coal and lignite mining (e.g. Sucharovà et al., 2012). In the direct surrounding of the sites Cretaceous (Upper Turonian) marls and clay-containing lime-stones comprise the subsurface; on top of this patches of loess are deposited, with layers of black and brown earth (Waldhauser, 1993) (**Fig. 5.4**). These marine sediments alternate with Quaternary riverine deposits. Within a few kilometres from these cemeteries small areas of basaltic rocks occur. Furthermore, Precambrian and Palaeozoic rocks appear at the north-west and west of the cemeteries (CGS, 2003). The graves were dug into calcareous loess and fine grained sand, which were deposited in the Quaternary (Budinský and Waldhauser, 2004).

Kutná Hora lies directly south of the Cretaceous Basin and is situated in the Kutná Hora Crystalline Complex, which is part of the Moldanubian Zone of the Bohemian Massif (Synek and Oliveriová, 1993). The bedrock of this landscape is characterized by Proterozoic and

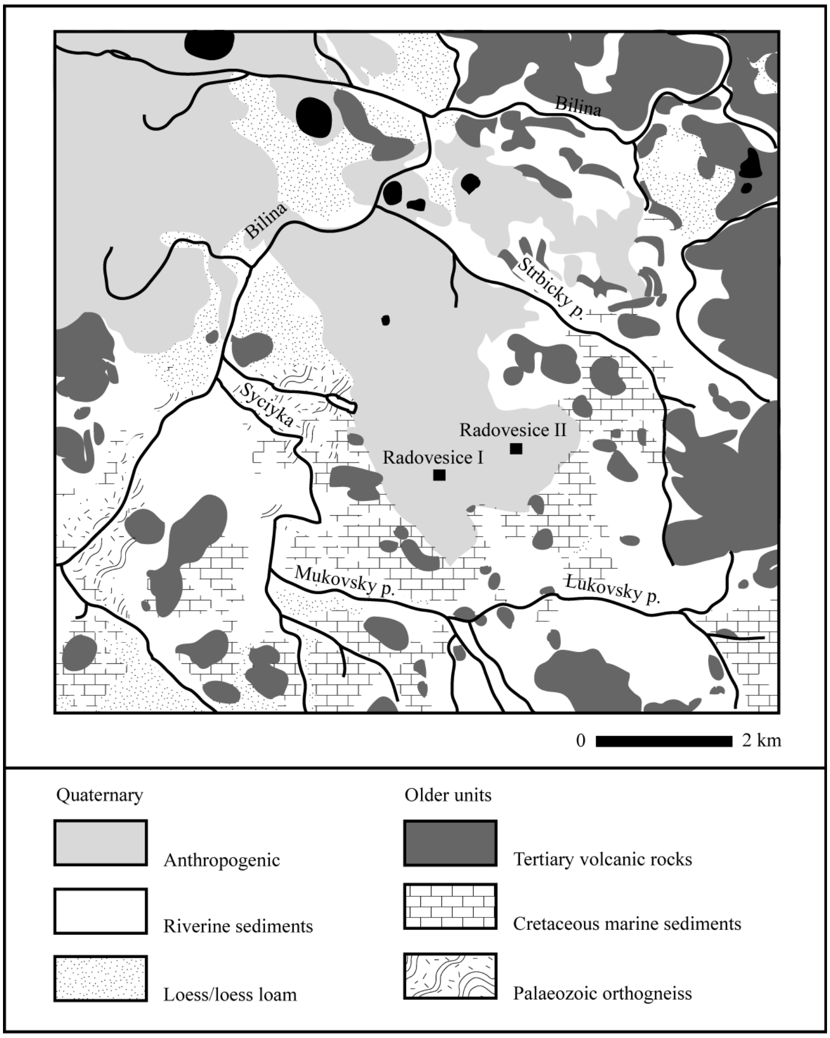


Figure 5.4 Simplified geological map of Radovesice and its surroundings (Modified from CGS, 2003). The cemeteries are indicated by black squares.

Palaeozoic rocks (Cháb et al., 2007), which occur to the north/north-west and south/south-west of the site (**Fig. 5.5**). The direct surroundings of Kutná Hora are dominated by Quaternary fluvial and loess loam deposits (CGS, 2003), as well as Cretaceous terrestrial freshwater and marine sediments (Cháb et al., 2007; Synek and Oliveriová, 1993). The burials were dug into loess (Valentová, 1991).

Sr isotope data from these regions of the Czech Republic are scarce. Therefore, evidence about the isotope ratios of the biologically available strontium have to be obtained from

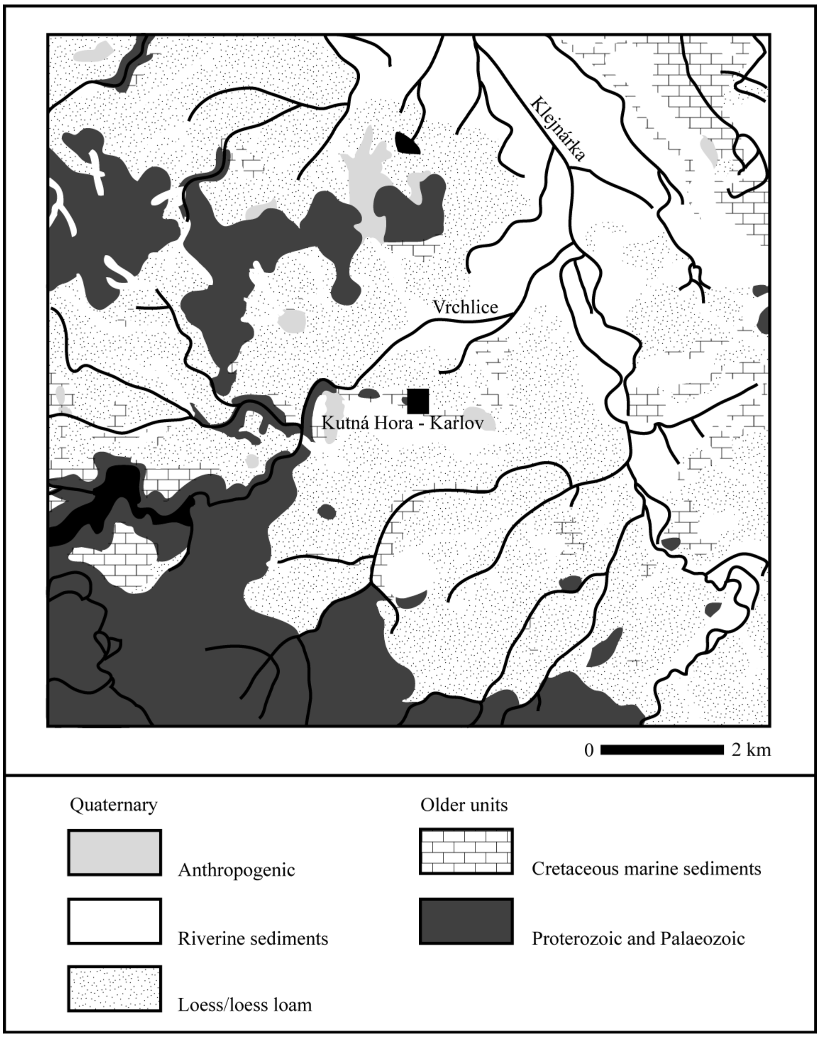


Figure 5.5 Simplified geological map of Kutná Hora and its surroundings (Modified from CGS, 2003). The black square represents the cemetery of Kutná Hora.

studies on different materials, such as rocks, soils, shells, and archaeological human and animal samples from other regions with similar geological conditions. The strontium isotope ratios from Cretaceous marine sediments typically lie between 0.7074 and 0.7077 (Veizer et al., 1999, 1997). Basaltic rocks have the lowest $^{87}Sr/^{86}Sr$ values (0.702 – 0.706), while the most variable and highest $^{87}Sr/^{86}Sr$ values (>0.710 – 0.750) occur among granites and gneisses (e.g. Bentley, 2006; Price et al., 2002). $^{87}Sr/^{86}Sr$ ratios of the biologically available Sr in loess can vary considerably and lie between approximately 0.7080 and 0.7100 (e.g. Bentley et al., 2003, Price et al., 2004). Human and animal remains studied from different loess-dominated areas in the Czech Republic also yielded varied Sr isotope data. $^{87}Sr/^{86}Sr$ values between 0.7093 (bone; Knezeves) and 0.7104 (bone; Moravska Nova Ves) were obtained from local Bell Beaker individuals (Price et al., 2004). Three animal bones from the early Bronze Age cemetery of Praha 9 − Miškovice yielded $^{87}Sr/^{86}Sr$ values between 0.7100 and 0.7106 (Knipper, in press). At the Neolithic cemetery of Vedrovice the local individuals

Table 5.1 $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ ratios of the analysed human samples from Radovesice I (RAD I), Radovesice II (RAD II) and Kutná Hora (KUT). Bold samples indicate individuals with a $^{87}Sr/^{86}Sr$ difference of > 0.001 between the multiple analysed teeth. The dental notation is according to the FDI-system (Fédération Dentaire Internationale).

Grave	Sample	Period	Sex[ab]	Age[ab]	Material	Element	$^{87}Sr/^{86}Sr$	± 2σ	$\delta^{18}O_{p\ VSMOW}$	± 1σ	$\delta^{18}O_{dw}$
1	**RADI 1.1**	< Lt A	M	40-50	enamel	36	0.711403	9			
	RADI 1.2				enamel	38	0.709080	10	16.7	0.1	-8.9
	RADI 1.3				femur	-	0.708320	10			
2	**RADI 2.1**	< Ha D-Lt A	M	18-25	enamel	46	0.706177	10			
	RADI 2.2				enamel	48	0.709622	14	15.6	0.2	-11.3
	RADI 2.3				femur	-	0.708503	9			
3	RADI 3.1	Lt B1b/B1c	F	26-45	femur	-	0.709004	8			
	RADI 3.2				enamel	16	0.711147	8			
	RADI 3.3				enamel	18	0.709441	10	16.2	0.1	-9.9
11	RADI 11.1	Lt B1b/B1c	?	30-50	femur	-	0.709236	8			
	RADI 11.2				enamel	47	0.711528	8			
	RADI 11.3				enamel	48?	0.713767	11	15.1	0.1	-12.3
13	**RADI 13.1**	Lt B2b/C1a	M	26-45	enamel	46	0.710841	9			
	RADI 13.2				enamel	27	0.712111	10	15.8	0.1	-10.8
14	**RADI 14.1**	Lt B1c	F	26-45	enamel	46	0.710264	16			
	RADI 14.2				enamel	48	0.706754	10	16.2	0.1	-9.9
16	RADI 16.1	Lt B1/B2	M	26-45	femur	-	0.708286	10			
	RADI 16.2				enamel	46	0.710549	10			
	RADI 16.3				enamel	38	0.709890	10	16.2	0.0	-9.9
20	RADI 20.1	Lt B1a/B1b	?	20-50	enamel	47	0.712519	8	16.5	0.1	-9.4
21	**RADI 21.1**	Lt B2a/B2b	F	30-40	enamel	46	0.711923	9			
	RADI 21.2				enamel	35	0.709666	11	16.4	0.0	-9.6
22	RADI 22.1	Lt B1b/c/B2	M	26-45	enamel	46	0.707948	9			
	RADI 22.2				enamel	38	0.708604	9	17.1	0.0	-8.0
24	RADI 24.1	Lt B2a	F?	20-40	enamel	36	0.710234	12			
	RADI 24.2				enamel	37	0.710477	10	17.2	0.1	-7.8
25	**RADI 25.1**	Lt B2b	?	25-40	enamel	46	0.711151	10			
	RADI 25.2				enamel	47	0.709664	9	15.9	0.1	-10.6
31A	RADI 31A.1	Lt B2b/C1a	F?	?	enamel	26	0.708850	10			
	RADI 31A.2				enamel	48	0.708415	14	16.1	0.1	-10.3
31B	RADI 31B.1	Lt B2b/C1a	F?	?	enamel	36	0.708301	10			
	RADI 31B.2				enamel	47	0.708240	9	16.7	0.0	-9.0
33	**RADI 33.1**	LT B2b/C1a	M?	20-50	enamel	47	0.713758	8			
	RADI 33.2				enamel	25	0.712546	11	16.5	0.2	-9.3
34	RADI 34.1	?	?	26-45	enamel	26	0.710160	9			
	RADI 34.2				enamel	47	0.710564	10	16.1	0.1	-10.3
35	RADI 35.1	?	?	26-45	enamel	36	0.709204	10	16.8	0.2	-8.6
36	**RADI 36.1**	Lt C1a	F?	?	enamel	26	0.711001	10			
	RADI 36.2				enamel	27	0.712265	11	16.6	0.1	-9.1
5	**RADII 5.1**	Lt B2a	?	20-30	enamel	26	0.707581	10			
	RADII 5.2				enamel	37	0.710517	9	15.9	0.1	-10.7
6	**RADII 6.1**	Lt B2a	C	>10	enamel	46	0.709930	7			
	RADII 6.2				enamel	17	0.707523	9	16.1	0.1	-10.2
7	RADII 7.1	Lt B2a	M	26-45	enamel	46	0.709645	10			
	RADII 7.2				enamel	28	0.709637	8	16.7	0.1	-8.9
8	RADII 8.1	Lt B2a	F?	26-45	enamel	46	0.711834	10			

Grave	Sample	Period	Sex[ab]	Age[ab]	Material	Element	$^{87}Sr/^{86}Sr$	± 2σ	$\delta^{18}O_{p\ VSMOW}$	± 1σ	$\delta^{18}O_{dw}$
	RADII 8.2				enamel	27	0.712624	9	15.5	0.2	-11.5
9	**RADII 9.1**	Lt B2a	M	30-40	enamel	46	0.710371	10			
9	**RADII 9.2**				enamel	48	0.715253	10	16.1	0.1	-10.2
	RADII 9.3				femur	-	0.708941	9			
10	**RADII 10.1**	Lt B2b	?	13-17	enamel	16	0.709994	10			
	RADII 10.2				enamel	28	0.708145	9	16.8	0.1	-8.8
	RADII 10.3				femur	-	0.708286	9			
11	RADII 11.1	Lt B2b	M	13-17	enamel	46	0.708308	10			
	RADII 11.2				enamel	28	0.707838	8	16.6	0.0	-9.2
12	RADII 12.1	Lt B2b	F?	40-50	femur	-	0.708629	7			
13	**RADII 13.1**	Lt B2b	M?	40-50	enamel	17	0.713389	10			
	RADII 13.2				enamel	18	0.712402	9	15.3	0.1	-11.9
14	RADII 14.1	Lt B2b	M?	20-30	enamel	26	0.708480	9			
	RADII 14.2				enamel	38	0.708274	10	14.8	0.1	-13.1
15	RADII 15.1	Lt B2a	F?	40-50	enamel	46	0.711422	10			
	RADII 15.2				enamel	47	0.711349	10	16.9	0.1	-8.4
17	RADII 17.1	Lt B2b	M	40-50	enamel	26	0.708856	11			
	RADII 17.2				enamel	48	0.708244	10	16.2	0.2	-10.0
18	RADII 18.1	Lt B2b	M	26-45	enamel	46	0.710311	10			
	RADII 18.2				enamel	48	0.710105	8	15.8	0.1	-10.9
	RADII 18.3				femur	-	0.708863	9			
19	RADII 19.1	Around Lt B2a?	M	50-60	enamel	16	0.709398	10			
	RADII 19.2				enamel	17	0.709820	9	16.2	0.1	-10.1
20	**RADII 20.1**	Around Lt B2a?	?	20-30	enamel	36	0.707615	10			
	RADII 20.2				enamel	37	0.710223	7	16.8	0.1	-8.7
	RADII 20.3				femur	-	0.708870	9			
21	RADII 21.1	Around Lt B2a?	M	40-50	enamel	26	0.714935	10			
	RADII 21.2				enamel	37	0.714470	10	16.1	0.1	-10.2
22	RADII 22.1	Lt B2a	M?	40-60	enamel	46	0.711106	10			
	RADII 22.2				enamel	38	0.710375	10	16.5	0.1	-9.3
23	RADII 23.1	Lt B2a	C	> 11	enamel	26	0.708965	11			
	RADII 23.2				enamel	48	0.708016	12	16.2	0.1	-10.1
5	**KUT 5.1**	Lt B2?	M	26-45	enamel	46	0.710109	9			
	KUT 5.2				enamel	28	0.713111	10	16.5	0.2	-9.4
8	**KUT 8.1**	Lt B2b	F	26-45	enamel	46	0.711325	9			
	KUT 8.2				enamel	48	0.708214	10	16.8	0.1	-8.7
10	KUT 10.1	Lt B2?	M	50-60	enamel	36	0.709728	7			
	KUT 10.2				enamel	38	0.710671	11	16.7	0.0	-8.8
	KUT 10.3				femur	-	0.709772	10			
14	KUT 14.1	Lt B2	M	26-45	enamel	46	0.710330	9			
	KUT 14.2				enamel	48	0.710588	12	15.6	0.1	-11.4
15	KUT 15.1	Lt B2	M	50-60	enamel	36	0.709818	10			
	KUT 15.2				enamel	38	0.710614	10	14.9	0.1	-12.7
17	KUT 17.1	Lt B1	M	30-50	enamel	46	0.709879	10			
	KUT 17.2				enamel	48	0.710007	9	15.3	0.1	-11.9
18	KUT 18.1	Lt B2	M	26-45	enamel	46	0.709035	10			
	KUT 18.2				enamel	48	0.709228	9	17.3	0.1	-7.6
19	KUT 19.1	Lt B2	M	50-60	enamel	26	0.708729	10	16.8	0.0	-8.6
20	KUT 20.1	Lt B2b	F	50-60	enamel	36	0.710877	10			
	KUT 20.2				enamel	18	0.710561	10	16.1	0.1	-10.3

Grave	Sample	Period	Sex[ab]	Age[ab]	Material	Element	$^{87}Sr/^{86}Sr$	± 2σ	$\delta^{18}O_{p\ VSMOW}$	± 1σ	$\delta^{18}O_{dw}$
21	KUT 21.1	Lt B1/B2	F	20-30	enamel	46	0.710140	9			
	KUT 21.2				enamel	47	0.710243	10	17.0	0.1	-8.3
22	KUT 22.1	Lt B2	M	40-50	enamel	46	0.709873	7			
	KUT 22.2				enamel	28	0.709340	8	16.3	0.1	-9.9
	KUT 22.3				humerus	-	0.709686	7			
24	KUT 24.1	Lt B2	F	26-45	enamel	36	0.712462	10			
	KUT 24.2				enamel	27	0.712399	9	16.3	0.1	-9.8
25	KUT 25.1	Lt B2/C1	M	20-30	enamel	46	0.710247	10			
	KUT 25.2				enamel	48	0.709853	10	16.4	0.1	-9.6
26	**KUT 26.1**	Lt B2a	F	40-50	enamel	46	0.708418	10			
	KUT 26.2				enamel	48	0.713694	9	15.9	0.1	-10.5
28	KUT 28.1	Lt B2a	C	03-04	enamel	16	0.710044	10			
30	KUT 30.1	Lt B2	?	20-30	enamel	46	0.709305	10			
	KUT 30.2				enamel	18	0.709242	9	16.5	0.2	-9.4
32	**KUT 32.1**	Lt B1c	F	30-40	enamel	36	0.712764	8			
	KUT 32.2				enamel	38	0.714689	10	17.2	0.1	-7.8
35	KUT 35.1	Lt B1c	F	26-45	enamel	47	0.711046	10			
	KUT 35.2				enamel	48	0.711558	9	16.1	0.0	-10.2
36	**KUT 36.1**	Lt B2b	?	26-45	enamel	46	0.709700	10			
	KUT 36.2				enamel	48	0.711757	9	16.7	0.1	-9.0
37	KUT 37.1	Lt B2	?	26-45	enamel	46	0.712289	10			
	KUT 37.2				femur	-	0.710021	10			
38	KUT 38.1	Lt B2	M	20-30	enamel	16	0.711455	10			
	KUT 38.2				enamel	28	0.712105	9	17.1	0.0	-8.1
	KUT 38.3				femur	-	0.710655	10			
39	KUT 39.1	Lt B1b	F	26-45	enamel	46	0.710020	10			
	KUT 39.2				enamel	28	0.710154	11	16.2	0.0	-10.1
40	KUT 40.1	?	M	40-60	humerus	-	0.710134	10			
43	KUT 43.1	Lt B1c	F	26-45	enamel	46	0.709758	10	16.2	0.1	-9.9
45	KUT 45.1	Lt B1c	F	26-45	enamel	15	0.711198	10	17.0	0.1	-8.3
46	**KUT 46.1**	Lt B2a	F	26-45	enamel	26	0.709708	10			
	KUT 46.2				enamel	38	0.711217	15	16.2	0.2	-10.0
47	KUT 47.1	Lt B1	F	40-50	enamel	46	0.711884	10	17.3	0.1	-7.6
49	KUT 49.1	Lt B1b	F	20-30	enamel	16	0.710395	9			
	KUT 49.2				enamel	48	0.709991	10	17.1	0.1	-8.1

[a] Age and sex of the skeletal remains from Radovesice were determined by Waldhauser (1987), Le Huray and Schutkowski (2005) and partly re-evaluated by P. Veleminsky (pers. comments 2012).

[b] Age and sex of the skeletal remains from Kutná Hora were determined by Valentová and Sankot (2012), Le Huray and Schutkowski (2005) and partly re-evaluated by P. Veleminsky (pers. comments 2012).

cluster with their $^{87}Sr/^{86}Sr$ values in tooth enamel between 0.7108 and 0.7115 (Richards et al., 2008). This local range coincides with dentine samples with $^{87}Sr/^{86}Sr$ values between 0.7110 and 0.7114, which were also analysed for this cemetery.

5.4. Meteorological context

The Czech Republic has a temperate continental climate, with relatively hot summers and cold, snowy winters (Tolasz, 2007). Its location in the interior of the European continent makes it meteorologically far more stable than areas under greater influence of the Atlantic, which is reflected in very little change in weighted annual mean $\delta^{18}O$ values in this area (Darling, 2004). The mean annual $\delta^{18}O$ in modern precipitation shows $\delta^{18}O$ values predominately between -9‰ and -8‰ for the Cretaceous Basin of the Czech Republic. The prevailing $\delta^{18}O$ values for the surrounding hilly landscape of the Bohemian Massif are between -10‰ and -9‰ (Bowen and Revenaugh, 2003; IAEA/WMO, 2006). Other studies on ground and surface water in Karany, 30 km northeast of Prague (Buzek et al., 2006), groundwater samples from the Bohemian Cretaceous Basin (Corcho Alvarado et al., 2011) and surface bog water in the northern and western Czech Republic (Novák et al., 2005) also yield $\delta^{18}O$ values between ca. -10‰ and -8‰. Some higher mountain ranges, for example Sněžka, have more depleted $\delta^{18}O$ values between -11‰ and -10‰ (Bowen, 2012; Bowen and Revenaugh, 2003). $\delta^{18}O$ values > -8‰ are unusual for the Czech Republic. They are more common in warmer southern regions, such as Italy (Longinelli and Selmo, 2003). $\delta^{18}O_{dw}$ values below -11‰ are also exceptional. Such depleted $\delta^{18}O$ values are more characteristic for areas where cooler climate conditions prevail (e.g. Dansgaard, 1964; Darling, 2004) or mountainous areas with higher elevations.

Human tooth enamel samples from Praha 9 – Miškovice yield $\delta^{18}O_p$ (phosphate) values between 15.9‰ and 17.6‰. These $\delta^{18}O_p$ values were converted to $\delta^{18}O_{dw}$ (drinking water) values through the equation of Levinson et al. (1987), taking a method bias correction of 1.4‰ (Chenery et al., 2010) into account. The calculated $\delta^{18}O_{dw}$ values lie between -10.6‰ and -7.0‰, whereby the value of -7.0‰ was derived from a first molar and is possibly influenced by the consumption of breast milk (White et al., 2004; Wright and Schwarcz, 1998). This figure should be disregarded, because it does not solely reflect $\delta^{18}O_{dw}$ values. Based on the data of human tooth enamel and water, it is expected that the regional variation in $\delta^{18}O$ for the Czech Republic lies between ca. -10.6‰ and -8.0‰.

5.5. Materials and methods

5.5.1. Sample selection and collection

The preservation conditions allowed the sampling of 18 out of the 34 inhumations from Radovesice I and 17 out of the 23 inhumations from Radovesice II. From Kutná Hora 27 out of the 48 inhumations were selected according to archaeological criteria. Two individuals (graves RAD II 12 and KUT 40) were not included in this number, as instead of tooth enamel only a bone sample was taken. Among the analysed individuals from Radovesice I were seven females, six males and five individuals with undetermined sex, the majority of whom was adult (~21-40 years) (n = 14) (classification after Herrmann et al., 1990) (**Table 5.1**). One individual reached maturity (~41-60 years), while the age of three individuals was indefinable. In Radovesice II two children, two females, ten males and three individuals with undetermined sex were studied. The number of infant II (~7-12 years) and juvenile (~13-20 years) individuals (n = 2 for both) is equal, while the rest were adult (~21-40 years) (n = 7) or mature (~41-60 years) (n = 6). The selection in Kutná Hora was composed of slightly more females (n = 13) than males (n =10), as well as one child and three individuals with undetermined sex. Adults (~21-40 years) (n = 19) formed the majority, followed by mature (~41-60 years) (n = 7) and infant I (~1-6 years) (n = 1) individuals.

Two enamel samples from different tooth crowns (preferably M1 and M3) were extracted for Sr isotope analysis in order to collect data for the early and later years of childhood (**Table 5.1**). For O isotope analysis, preferably the later formed teeth (second premolar (P2), second (M2) and third molar (M3)), were sampled, as the earlier formed teeth (M1) usually record a breastfeeding effect, which can lead to an enrichment in ^{18}O (White et al., 2004; Wright and Schwarcz, 1998). Since no animal teeth were available, five human bone samples from each cemetery were analysed to determine the biologically available Sr (**Table 5.1**). They consist predominately of femora, except for two humeri (graves KUT 22, 40). Bone remodels throughout life and represents the Sr isotope ratios of adulthood (Bentley, 2006). In archaeological contexts, bones are frequently overprinted by Sr from the burial environment and therefore exhibit the Sr isotope ratios of the local labile Sr (Horn and Müller-Sohnius, 1999; Montgomery, 2002).

As a cut-off value, the mean ± 2σ of the sampled human bones was calculated to establish the biologically available Sr (e.g. Ezzo et al., 1997; Price et al., 1994). It has been realised that bones, due to their susceptibility to post-burial contamination, might underestimate the local range (e.g. Horn and Müller-Sohnius, 1999), as they tend to resemble the $^{87}Sr/^{86}Sr$ values of the soil in which they are buried (Feranec et al., 2007). Tooth enamel on the other hand corresponds to the diet obtained during tooth mineralisation (Price et al., 2002). However, bones form a useful baseline (Bentley, 2006). By comparing the calculated local range with the available comparative data from the study area and comparable regions, its representativeness was double-checked. This approach allowed us to identify individuals with a differing, possibly non-local, Sr isotope composition.

5.5.2. Sr isotope analysis

The sample preparation followed Scheeres et al. (2013a, 2013b) and will shortly be summarised here. Tooth enamel and bone powder was extracted using a round diamond bur. Two aliquots of ~10 mg for Sr and O isotope analysis were collected in 2 ml plastic tubes.

For Sr isotope analysis, all tooth enamel and bone samples were ultrasonically cleaned with Milli-Q water and weak acetic acid (0.1 M, Li-acetate buffer), and ashed for 10 hours at 850°C. The Sr was extracted by means of extraction chromatography in the clean laboratory (Department of Geosciences, University of Tübingen). The Sr isotope composition was determined with a Finnigan MAT 262 Thermal Ionisation Mass Spectrometer (TIMS). Repeated measurements of the international standard for $^{87}Sr/^{86}Sr$ (NBS 987) gave a mean value of 0.710255 ± 0.000042 (1σ, $n = 47$). All Sr ratios were normalised to the long-term average value for NBS 987 of 0.710248. Sr blanks were generally lower than 100 pg.

5.5.3. O isotope analysis

The sample preparation followed Scheeres et al. (2013b) and will be outlined briefly here.

For O isotope analysis, the tooth enamel samples were freed of organic matter and humic acids by cleaning them with 2 ml of 2 % NaOCl and 2 ml of 0.125 M NaOH. The cleaned samples were dissolved in 800 µl of 2 N HF overnight. The solution containing the PO_4^{3-} ions was neutralised with ca. 150 µl of 25 % NH_4OH. 800 µl of 2 N $AgNO_3$ were added to obtain silver phosphate crystals of which 0.50 to 0.65 mg were weighed three times into silver capsules. The O isotope composition was established with a Thermo-Quest TC-EA connected to a Thermo-Quest Delta+XL mass spectrometer (Department of Geosciences, University of Tübingen). The samples were calibrated to the international standard VSMOW (Vienna Standard Mean Ocean Water) via the laboratory standards TU-1: 21.11‰; TU-2: 5.35‰; 130-0.5-1: -1.13‰ and YR-1a: -5.77‰. Accuracy and reproducibility were monitored by multiple analyses of the standard NBS 120 c, with a mean $\delta^{18}O$ value of 22.2 ± 0.1‰ (1σ, n = 8) and corrected to a reference value of 21.7‰ for NBS 120 c (e.g. Chenery et al., 2010). The reproducibility for the $\delta^{18}O$ measurements was generally ± 0.3‰, unless otherwise noted (**Table 5.1**). The results are reported in per mil (‰) relative to VSMOW.

In order to compare the measured $\delta^{18}O_p$ values with $\delta^{18}O$ in modern precipitation, the $\delta^{18}O_p$ values have to be converted to $\delta^{18}O_{dw}$ (drinking water). The $\delta^{18}O_{dw}$ values were calculated with the Levinson et al. (1987) equation taking an analytic method bias of 1.4‰ (Chenery et al., 2010) into account.

5.6. Results

5.6.1. Isotope ratios of the biologically available strontium

The five human bone samples from Radovesice I yielded $^{87}Sr/^{86}Sr$ ratios between 0.7083 and 0.7092 (mean: 0.7087 ± 0.0009 [2σ]) (**Table 5.1**, **Fig. 5.6**). Radovesice II had similar $^{87}Sr/^{86}Sr$ ratios in the five human bone samples, lying between 0.7083 and 0.7089 (mean: 0.7087 ± 0.0005 [2σ]). In order not to underestimate the biologically available Sr, the mean ± 2σ (0.7087 ± 0.0007) of the 10 analysed bones was taken. One child from Radovesice II (grave 23) yielded $^{87}Sr/^{86}Sr$ values between 0.7090 (M1) and 0.7080 (M3) which are in agreement with the $^{87}Sr/^{86}Sr$ values in bone. The $^{87}Sr/^{86}Sr$ ratios of the five human bone samples from Kutná Hora are higher and lay between 0.7097 and 0.7107 (mean: 0.7101 ± 0.0008 [2σ]) (**Table 5.1**, **Fig. 5.7**). Here also one child (grave 28), with a $^{87}Sr/^{86}Sr$ value of 0.7100 in the M1, matches the $^{87}Sr/^{86}Sr$ values in bone.

European loess is very often of local origin with the source material less than several tens of kilometres away (Frechen et al., 1999). Differing Sr isotope ratios in loess are, therefore, caused by the different rock sources that contribute to the loess (e.g. Nehlich et al., 2009). This is presumably also the case for the deviating bone ranges between Radovesice and Kutná Hora. $^{87}Sr/^{86}Sr$ values between ca. 0.7085 and 0.7104 were measured in loess of the Danubian corridor (cf. Bentley et al., 2012 for references), which corresponds well with the bone ranges presented here. $^{87}Sr/^{86}Sr$ values as low as 0.7080 are known from areas where loess mixes with marine carbonates (cf. Price et al., 2004). The slightly higher upper limit ($^{87}Sr/^{86}Sr$:

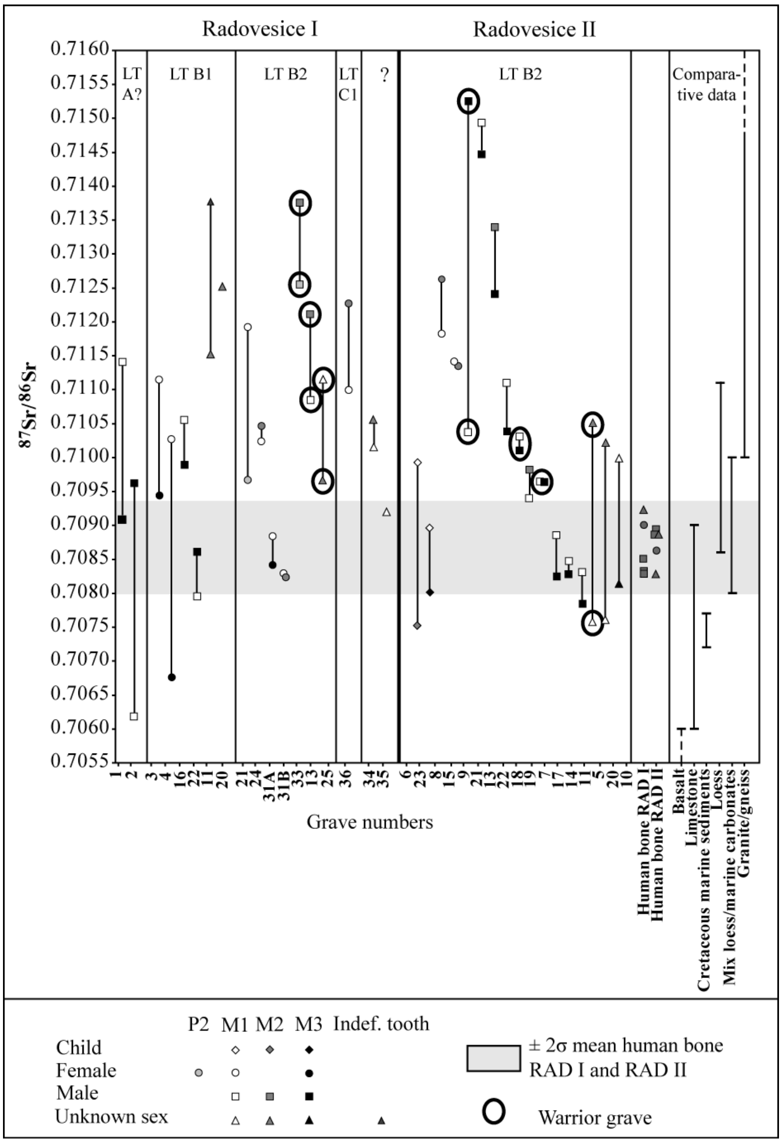


Figure 5.6 Strontium isotope ratios of the selected children, females and males from Radovesice I and Radovesice II, sorted by time period. The analysed individuals were organised by sex and from higher to lower Sr isotope ratios.

0.7108) of the bone range of Kutná Hora is in agreement with the upper limit of the biologically available Sr, established from three animal bones, from the loess environment of Praha 9 – Miškovice, approximately 57 km west of Kutná Hora (Knipper, in press). It also comprises the lowest $^{87}Sr/^{86}Sr$ value measured for the local individuals of the Czech cemetery Vedrovice, whereas the highest $^{87}Sr/^{86}Sr$ value of these individuals is more radiogenic and lies at 0.7115 (Richards et al., 2008). In Radovesice, Cretaceous marine sediments, with generally lower Sr isotope ratios, most likely played a more important role in the depositional history. This is also brought forward as an argument for the lower $^{87}Sr/^{86}Sr$ ratios of loess in the Danubian corridor of which the main sources are Alpine carbonates (Bentley et al., 2012). Bones primarily represent the $^{87}Sr/^{86}Sr$ values that can be expected directly at the cemeteries. Especially in a geologically heterogeneous environment such as Bohemia, they may underestimate the range of variation in Sr isotope ratios for the cultivated agricultural land.

5.6.2. $^{87}Sr/^{86}Sr$ values of the human teeth from Radovesice I and II

The Sr isotope ratios of the human enamel samples from Radovesice I vary between 0.7062 and 0.7138 (mean: 0.7102 ± 0.0036 [2σ]). In Radovesice II they range from 0.7075 to 0.7153 (mean: 0.7102 ± 0.0042 [2σ]) (**Fig. 5.6**). Both males and females reveal a broad range, including very low and very high values, which are hard to interpret in terms of “local” descent and upbringing. The lowest (grave RAD I 2) and highest (RAD II 9) $^{87}Sr/^{86}Sr$ ratios were observed in the tooth enamel of two males. Although no clear chronological tendencies were observed, it is noteworthy that the lowest $^{87}Sr/^{86}Sr$ values only occur in the earliest phases (LT A?/LT B1) of Radovesice I (graves 2, 14).

In both cemeteries, only six individuals fall with one (graves RAD I 1, 3, 35, RAD II 10, 11, 19) or both tooth enamel samples (graves RAD I 22, 31A, 31B, RAD II 14, 17, 23) into the bone range (**Fig. 5.6**). This includes two individuals (graves 3 and 22) from Radovesice I and one from Radovesice II (grave 19), who lay with at least one value very close to the isotopic variation of the bones. The enamel of the first molars of only four individuals (22.2%) from Radovesice I and five individuals from Radovesice II (29.4%) reveal $^{87}Sr/^{86}Sr$ ratios that are comparable to the bone data. During childhood three individuals (graves RAD I 1, 3, RAD II 10) changed their isotopic composition from more radiogenic Sr isotope ratios (M1) to the bone range (M3). The Sr isotope ratios in the M1 show that more than half of the analysed

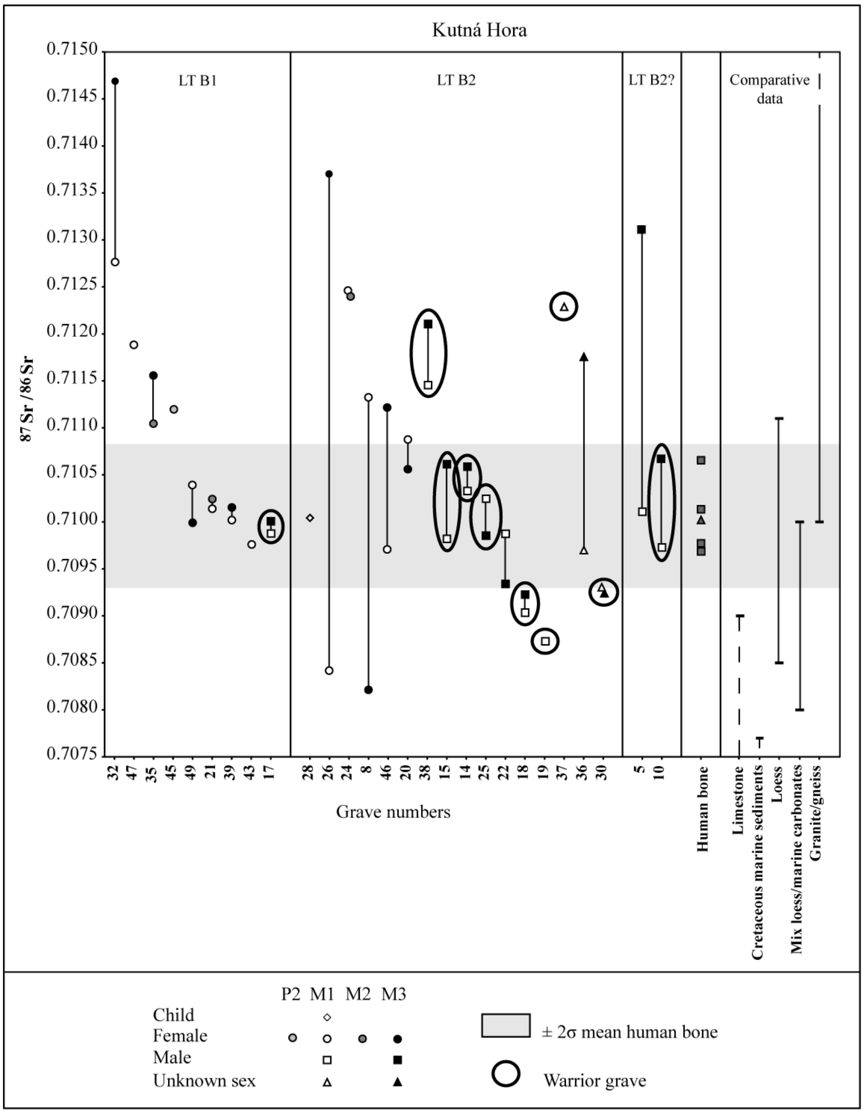


Figure 5.7 Strontium isotope ratios of the selected children, females and males from Kutná Hora, divided by time period. The analysed individuals were organised by sex and from higher to lower Sr isotope ratios.

individuals differ from the bone range in Radovesice I (11 out of 18 individuals; 61.1%) and II (11 out of 17 individuals; 64.7%). Of three individuals (graves 11, 20, 33; 16.7%) from Radovesice I and one individual (grave 13; 5.9%) from Radovesice II it can only be said that they had a deviating isotope signature in their later formed teeth.

Apart from the inter-individual variation of the Sr isotope ratios, the intra-individual variation between the M1 and M3 (or M2/P2) is also high (**Table 5.1**, **Fig. 5.6**). A difference of > 0.001 was noticed in 10 out of the 16 individuals from Radovesice I of whom two tooth enamel samples were analysed (62.5%). In Radovesice II this number was six out of the 17 analysed individuals (35.3%). This cut-off value of 0.001 was observed by Price et al. (1998) – amongst others – as a significant difference between the analysed tooth enamel and bone sample of individuals who migrated during life. In Radovesice the Sr isotope ratios changed to less (graves RAD I 1, 3, 14, 21, 25, RAD II 6, 10, 13) or more radiogenic (graves RAD I 2, 11, 13, 33, 36, RAD II 5, 9, 20) values. The amount of individuals with higher or lower $^{87}Sr/^{86}Sr$ values in their earlier or in their later formed teeth is evenly distributed.

5.6.3. $^{87}Sr/^{86}Sr$ values of the human teeth from Kutná Hora

The Sr isotope ratios of the human enamel samples from Kutná Hora vary between 0.7082 and 0.7147 (mean: 0.7106 ± 0.0027 [2σ]) (**Fig. 5.7**). More males tend to cluster around the bone range, while the females include the lowest and highest Sr isotope ratios. Individuals with $^{87}Sr/^{86}Sr$ values below the established bone range only appear in LT B2.

The first molars of more than half of the analysed individuals from Kutná Hora match the bone range (n = 16; 59.3%), which includes the individuals from grave 20 and 30, who lay very close to the isotopic variation of the bones (**Fig. 5.7**). Among them are three individuals (graves 5, 36, 46) with a considerably more radiogenic $^{87}Sr/^{86}Sr$ ratio in the M3 than in the M1, pointing to changing geological conditions during their childhood. Nine out of 27 analysed individuals (33.3%) differ with their Sr isotope ratios from the range established by the bones. For two individuals (graves 35 and 45; 7.4%) it can only be noted that they have a differing isotope signature in their later formed teeth, as only later formed teeth were available for analysis.

In Kutná Hora both the inter-individual variation of the Sr isotope ratios and the intra-individual variation between the M1 and M3 (or M2/P2) is less than in the cemeteries of Radovesice (**Table 5.1, Fig. 5.7**). Here six individuals out of the 21 from whom two tooth enamel samples were analysed (28.6%) have a difference of > 0.001. The Sr isotope ratio of most of these individuals (graves 5, 26, 32, 36, 46) is shifted towards more radiogenic values, while one individual (grave 8) has a less radiogenic ratio.

5.6.4. $\delta^{18}O$ values of the human teeth from Radovesice I and II

The $\delta^{18}O_p$ ratios of the human tooth enamel samples from Radovesice I vary between 15.1‰ and 17.2‰ (mean: 16.3‰ ± 0.5 [1σ]) and in Radovesice II from 14.8‰ to 16.9‰ (mean: 16.1‰ ± 0.6 [1σ]) (**Fig. 5.8**). The range in $\delta^{18}O_p$ for both Radovesice I and II is 2.1‰, which is a typical variation among individuals who obtain their drinking water from the same region (e.g. White et al., 2004, 2000). Overall, there is little difference between the $\delta^{18}O$ values of males and females. The lowest (grave RAD II 14) and highest (grave RAD I 24) $\delta^{18}O_p$ ratios were observed in the tooth enamel of respectively a male and female (**Table 5.1**). The corresponding drinking water values ($\delta^{18}O_{dw}$) (Levinson et al., 1987; Chenery et al., 2010) lie between -12.3‰ and -7.8‰ (mean: -9.7‰ ± 1.1 [1σ]) for Radovesice I. In Radovesice II they vary between -13.1‰ and -8.5‰ (mean: -10.2‰ ± 1.2 [1σ]). No chronological tendencies are observed.

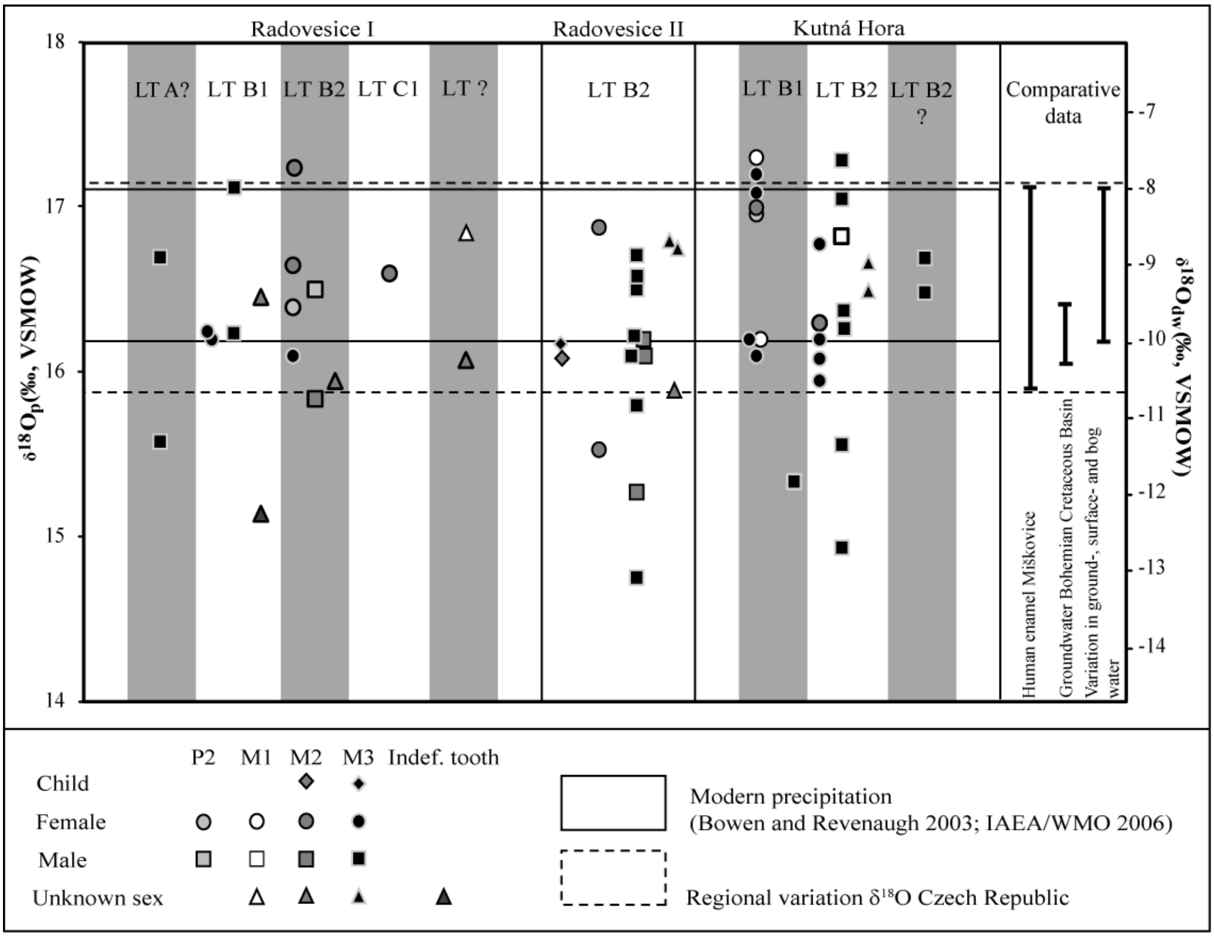


Figure 5.8 Oxygen isotopes ratios of the selected children, females and males from Radovesice I, Radovesice II and Kutná Hora, sorted by time period. The analysed individuals were grouped according to sex.

5.6.5. $\delta^{18}O$ values of the human teeth from Kutná Hora

In Kutná Hora the $\delta^{18}O_p$ ratios of the analysed human tooth enamel samples vary between 14.9‰ and 17.3‰ (mean: 16.5‰ ± 0.6 [1σ]) (**Fig. 5.8**). The range in $\delta^{18}O_p$ for Kutná Hora is 2.4‰, which is slightly larger (0.3‰) than in Radovesice, but still acceptable for individuals acquiring their drinking water sources from the same region (e.g. White et al., 2004, 2000). In the dataset two distinct groups are observed among the females; one group has $\delta^{18}O_p$ values between 15.9‰ and 16.3‰, while the other group yielded $\delta^{18}O_p$ values between 16.8‰ and 17.3‰. The differences between these female groups are statistically significant (Two-sample Mann-Whitney test: $Z = -3.025$, $p < 0.002$). Most males correspond to the $\delta^{18}O_p$ values observed for the females; however, three males (graves KUT 14, 15, 17) have clearly more depleted $\delta^{18}O_p$ values (**Table 5.1**). The converted $\delta^{18}O_{dw}$ ratios from Kutná Hora range between -12.7‰ and -7.6‰ (mean: -9.5‰ ± 1.3 [1σ]). No chronological tendencies are found in the dataset.

5.6.6. $^{87}Sr/^{86}Sr$ values and $\delta^{18}O$ values of the human teeth combined

In Radovesice nine out of the 35 analysed individuals (25.7%) resemble the $^{87}Sr/^{86}Sr$ range established by the human bones and $\delta^{18}O$ values that are expected for the Czech Republic (**Fig. 5.9**). This also includes an individual (grave RAD I 3) with Sr isotope ratios close to this range. An additional nine individuals correspond to the expected $^{87}Sr/^{86}Sr$ values for loess in the Czech Republic. This also applies to four other individuals with more depleted $\delta^{18}O$ values (graves RAD I 2, RAD II 5, 18) or more enriched $\delta^{18}O$ values (grave RAD I 24). The enamel of one individual (grave RAD II 14) revealed a Sr isotope ratio within the bone range of the site, but has a more depleted $\delta^{18}O$ value. Eight individuals coincide with the regional variation in $\delta^{18}O$, of whom the majority ($n = 5$) have more radiogenic $^{87}Sr/^{86}Sr$ values, whereas three individuals have less radiogenic $^{87}Sr/^{86}Sr$ values. In total four individuals (graves RAD I 11, 13, RAD II 8, 13) fall completely outside the determined Sr and O ranges. All these individuals have more radiogenic $^{87}Sr/^{86}Sr$ values and more depleted $\delta^{18}O$ values.

In Kutná Hora nine out of the 25 individuals (36.0%) correspond to the $^{87}Sr/^{86}Sr$ range established by the human bones and $\delta^{18}O$ values that are expected for the Czech Republic (**Fig. 5.10**). One individual (grave KUT 30) is included, as it has Sr isotope ratios close to this range. Two further individuals coincide with the expected $^{87}Sr/^{86}Sr$ values for loess in the Czech Republic. Three individuals (graves KUT 14, 15, 17) have enamel Sr isotope ratios within the bone range of the site and more depleted $\delta^{18}O$ values. Eight individuals correspond to the regional variation in $\delta^{18}O$, most of whom (n = 6) have more radiogenic $^{87}Sr/^{86}Sr$ values, while two individuals have less radiogenic $^{87}Sr/^{86}Sr$ values. A total of three individuals fall completely outside the established Sr and O ranges. All these individuals have more enriched $\delta^{18}O$ values, while two individuals have more radiogenic (graves KUT 32, 47) and one individual (grave KUT 18) has less radiogenic $^{87}Sr/^{86}Sr$ values. Among them is the female (grave KUT 47) of whom only a M1 was available for analysis.

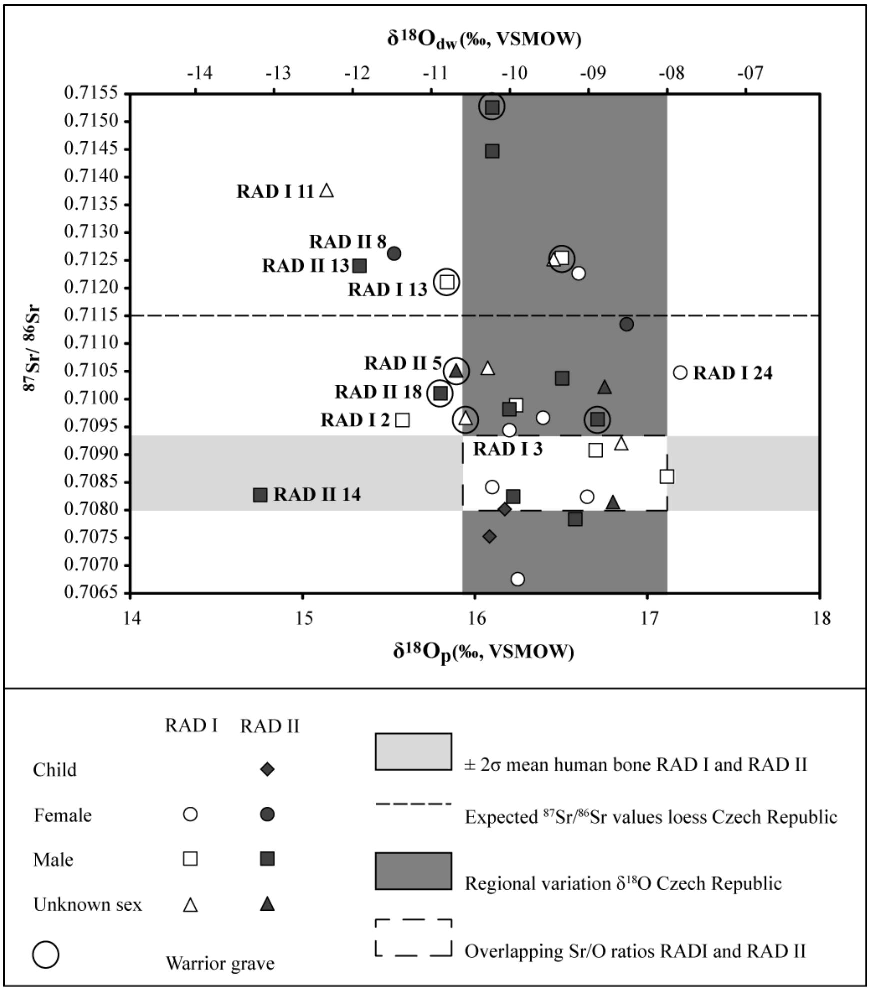


Figure 5.9 Strontium and oxygen isotope ratios from Radovesice I (white symbols) and Radovesice II (grey symbols) combined. Sample numbers are added to the individuals that are specifically discussed in the text.

Considering the comparative data (**cf. Figs. 5.6-5.7**) it is assumed that the majority of individuals, respectively 26 out of the 35 analysed individuals (74.3%) in Radovesice and 19 out of the 25 analysed individuals (76.0%) in Kutná Hora (**cf. Figs. 5.9-5.10**), came from different geological regions in Bohemia. Among them are 18 individuals (51.4%) from Radovesice and 11 individuals (44%) from Kutná Hora with values which match the regional isotope ranges of the Bohemian loess landscape. In Radovesice most individuals (n = 9; 25.7%) with deviating isotope compositions tend to have more depleted $\delta^{18}O$ values, whereas in Kutná Hora the individuals (n = 6, 24.0%) with deviating $\delta^{18}O$ values are equally distributed between more depleted (n = 3) or more enriched (n = 3) $\delta^{18}O$ values.

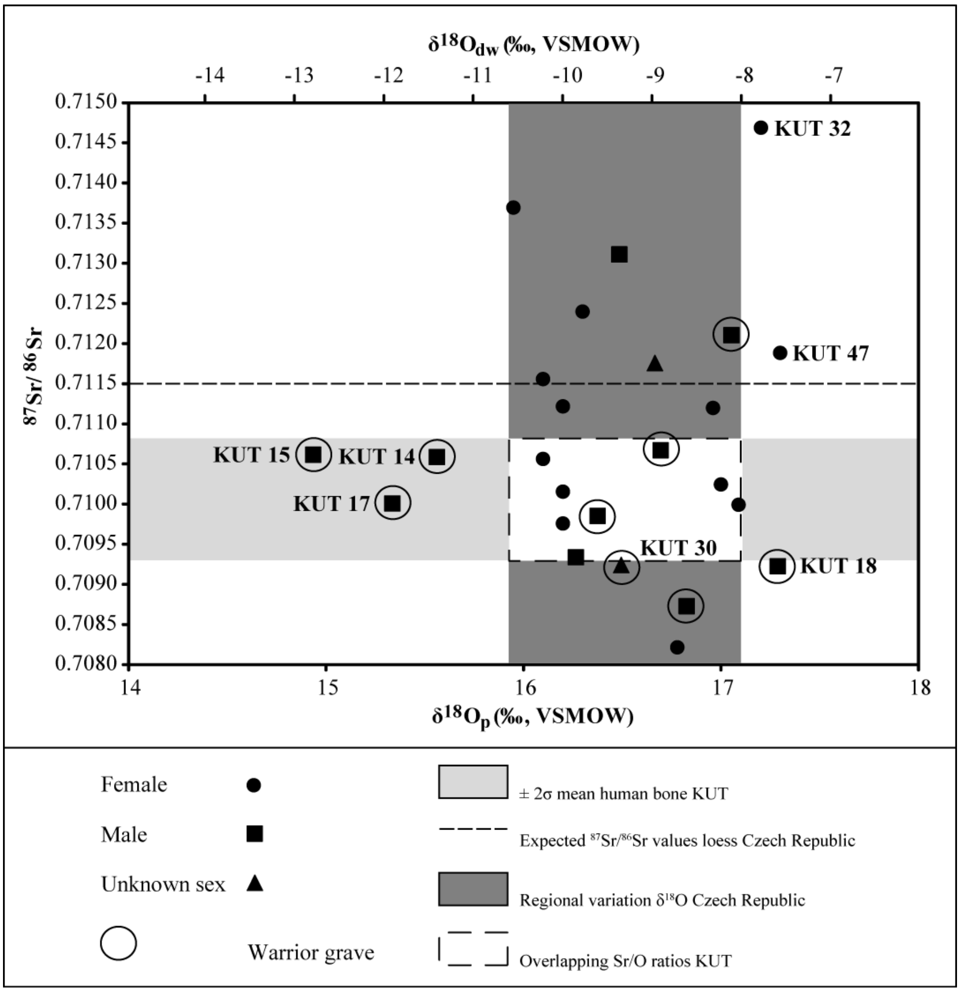


Figure 5.10 Strontium and oxygen isotope ratios from Kutná Hora combined. Individuals that are explicitly discussed in the text are indicated by their sample number.

5.7. Discussion

5.7.1. Sex-specific residential changes and non-local warriors

The isotopic composition of the enamel samples from the studied cemeteries is variable, but is largely in agreement with the regional variation that can be expected in Bohemia (**Figs. 5.9-5.10**). Similarly, considerable heterogeneity of $^{87}Sr/^{86}Sr$ data has been found among the burials in the early Iron Age monumental tumulus of the Magdalenenberg (Schwarzwald-Baar-Kreis, D) (Oelze et al., 2012) and in the context of the early La Tène "princely" site of the Glauberg (Wetteraukreis, D), where conical pits revealed the skeletal remains of more than two dozen informally buried people (Knipper et al., 2014). The previously studied contemporaneous cemeteries of Münsingen-Rain (Kt. Bern, CH) and Monte Bibele (prov. Bologna, I) show less variation and few non-local individuals, whereas Nebringen (Baden-Württemberg, D) reveals more varied Sr isotope ratios (Scheeres et al., 2013a, 2013b; Hauschild et al., 2013).

The majority of males in Radovesice (n = 13/16) and Kutná Hora (n = 7/10) fall outside the local ranges (**Figs. 5.9-5.10**). Among them are all the analysed weapon burials from Radovesice (n = 7). This number includes two individuals with undetermined sex (graves RAD I 3, RAD II 5), who were buried with weapons. In Kutná Hora six out of the nine analysed individuals buried with weaponry yield deviating isotope compositions. Noteworthy is the fact that one male from Radovesice II (grave 14) and three males from Kutná Hora (graves 14, 15, 17) have $^{87}Sr/^{86}Sr$ values that are in agreement with the isotope ranges of bones from the cemetery, but have more depleted $\delta^{18}O$ values. These men presumably moved to or came from another area with similar $^{87}Sr/^{86}Sr$ values, but obtained their drinking water from more depleted sources. This observation is in agreement with the high mobility rates likely for Celtic warriors. Greek and Roman authors describe the highly mobile Celtic warriors of the 4th and 3rd century BC, who participated as mercenaries in nearly all the military conflicts known in the Mediterranean area (e.g. Tomaschitz, 2002; Schönfelder, 2007). The few warriors in Kutná Hora who fall within the overlapping Sr and O ranges were either not recognised as non-local because they had $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values comparable to the cemetery or they came home to their place of origin after participating in military raids. Tooth enamel only incorporates strontium during childhood and therefore does not provide information on possible movements during adulthood.

Most females in Radovesice (n = 6/9) and Kutná Hora (n = 8/13) also deviate from the local ranges (**Figs. 5.9-5.10**). This high number of females with differing isotope ratios may be an indication of patrilocal residential patterns. Patrilocality is a social system in which a woman resides in the community of her spouse (Eriksen, 2001). Several studies on other prehistoric periods (cf. Haak et al., 2008; Knipper et al., 2012) also show a prevalence of females with a non-local origin. In the contemporary cemeteries of Nebringen (Germany), Monte Bibele (Italy) (Scheeres et al., 2013a) and Münsingen-Rain (Switzerland) (Scheeres et al., 2013b; Hauschild et al., 2013), on the other hand, local females prevailed.

Social differences were also observed in male and female burials. In the cemeteries studied here, males between 20 and 50 years of age were generally buried with weaponry (Sankot, 1993; Waldhauser 1987, 1977) and some elderly women were particularly richly equipped. The latter include the females in graves 39, 43 and 47 from Kutná Hora (cf. Valentová and Sankot, 2012). For the weapon burials this presumed higher social status was accompanied by higher $\delta^{15}N$ values, which indicates more frequent meat consumption (Le Huray and Schutkowski, 2005). Although most warriors are scattered more or less randomly throughout the cemetery, the three warriors from Kutná Hora with more depleted $\delta^{18}O$, but $^{87}Sr/^{86}Sr$ values comparable to the bone range (graves 14, 15, 17), are buried close together at the cemetery. This also applies to two other warriors (graves 18 and 19) with comparable isotope ratios that are situated next to these graves (**Table 5.1**, **Fig. 5.3**). Possibly, these men originated from the same area or had some kind of connection, which especially concerns graves 14, 15, 18 and 19, which date to the same time period and were found most closely together. One of these warriors (grave 19) had a spear with a long iron head that has several parallels in the Danubian region (Valentová and Sankot, 2012). It is possible that both warriors from grave 18 and 19 were mobile warriors who came from the Danubian region. Noteworthy is also the fact that more depleted $\delta^{18}O$ values are more common among males, while females mostly resemble the regional isotope variation in Bohemia. This suggests that the majority of females came from the region, whereas some of the males might have come from another area, or were more mobile.

5.7.2. Childhood mobility ($^{87}Sr/^{86}Sr$ values)

Evidence for residence in different geological settings is also observed in the significant differences in Sr isotope ratios in multiple analysed teeth from the same individuals. This gives the impression that a large part of the community not only spent some time elsewhere, but also did not directly come from the area they were buried in. A similar pattern has been observed in the early La Tène cemetery of Nebringen (south-west Germany), where 50% (eight out of 16 individuals) of the individuals had different $^{87}Sr/^{86}Sr$ values in their early and later forming enamel (Scheeres et al., 2013a; Hauschild et al., 2013). The observed differences were explained either by varying land use strategies in the heterogeneous geological environment or by residential changes. Although the Sr isotope ratios appear scattered and no clear clusters of individuals are visible in the dataset, there are no individuals who could not have obtained their $^{87}Sr/^{86}Sr$ values in the studied areas. It is therefore assumed that the complex geology of Bohemia, where a variety of geological units intersect, contributed to a large extent to the dispersed Sr isotope ratios observed (cf. Price et al., 2004).

Childhood mobility could, however, also have played a role in the lives of some individuals, especially for those with aberrant $\delta^{18}O$ values, and the ones with a difference of > 0.001 between the Sr isotope ratios of two analysed teeth. From the dataset it appears that both males and females, and even one child (grave RAD II 6), are concerned, suggesting that this phenomenon was not restricted to specific population groups. If it is assumed that these individuals were mobile, it might be an indication that whole families changed their residency. This would confirm the idea contained in the ancient written sources, and proposed for the period of the historic “Celtic migrations”, that mass migrations of entire population groups regularly took place (Tomaschitz, 2002). Another possible explanation for the presumably high mobility rate among children is the social structure of the La Tène communities, in which hierarchy seems to have played an important role (e.g. Livius, [Ab urbe condita V]; Polybios, [Historiai II]; Ceasar, [Commentarii de bello Gallico I, 31, 7; VI, 12]). Both historical sources from medieval Ireland (a kind of ethnographic model) and Caesar describe the system of allegiance fosterage. This alliance consisted of a child being nursed and educated by one foster family or successive fosterers to generate mutual trust between superiors and inferiors. The social role a child had to fulfil in the La Tène community also influenced its education, for example noble boys learned horse riding and the girls sewing, while more humble boys were taught skills of animal husbandry and the girls grinding flour. Fosterage could have lasted from infancy until marriage, i.e. fourteen years for a girl and seventeen for a boy (Champion, 1996; Parkes, 2006). Although a fosterage parenting system in the Iron Age is not yet proven, it could explain the observed variation, caused by children growing up under different geological conditions.

5.7.3. Community structures and considerations about the origin of non-local individuals

Characteristic locations for Hallstatt and La Tène settlements in Bohemia are characterized by fertile loess soils covered with black and brown earth and proximity to water courses, ensuring optimal conditions for agriculture (e.g. Budinský and Waldhauser, 2004; Waldhauser, 1993). Principally the north-west, the north-east, the east, and the centre of Bohemia are most densely populated and appear to meet these requirements (**Fig. 5.1**). Important technological improvements of the Iron Age, such as iron ploughshares, made food production more efficient (Fries, 1995). The exploitation of heavier, more nutrient-rich valley bottom soils became possible and more people could be fed with less manpower. These technological developments might have caused more flexibility in selecting farming land, which might have been inevitable in this densely populated region. Although the majority of the settlements and cemeteries of the La Tène period can be found in the loess regions of Bohemia, the loess covers and is adjacent to different geological units, such as young volcanic rocks and older Proterozoic and Palaeozoic rocks, which might have contributed to the loess. Many La Tène sites are also known from this surrounding area (cf. **Fig. 5.1**; Waldhauser, 1993, Fig. 5). In the Neolithic cemetery of Vedrovice the generally higher upper limit of $^{87}Sr/^{86}Sr$ values for the local individuals from this loess site were explained by a greater contribution from Precambrian and Palaeozoic rocks (Richards et al., 2008). At least part of the diversity of the isotopic data of the studied cemeteries might be explained by a dispersed settlement structure in the La Tène period. The alternating Sr isotope ratios within the same jaw might have been caused by regularly changing farming land in this geologically diverse landscape.

Considering the complex geology of the Czech Republic, where young and old geological units alternate or overlap, combined with the $\delta^{18}O$ values in modern precipitation, the impression arises that most individuals came from various Bohemian regions. However, around 400-300 BC colder and more humid climatic conditions, with an estimated drop in temperature of ~2°C (Büntgen et al., 2011), prevail, which might have evoked the "Celtic migrations" (e.g. Maise, 1998; Nortmann and Schönfelder, 2009). This development is associated with an alteration of the material culture. In the initial phase (LT A and B1) the burial customs resemble those of the core area of the La Tène culture. Around 300 BC (LT B2) these customs were replaced by a distinctive Bohemian La Tène style. Bohemia now shows closer connections to Moravia and the Danubian region and Bohemian items are now clearly recognizable as foreign objects in Bavaria (Eggl, 2003). The question is, whether increased mobility or trans-regional contacts and trade routes (e.g. Waldhauser, 2002) caused this change. The analysed individuals from Radovesice I and Kutná Hora dating to these time periods (LT B1 and LT B2-C1) appear equally varied and the dataset rather depicts three communities where most individuals, regardless of time period, age or sex, regularly lived under different geological conditions. Although the impression arises of a highly mobile community, similar variation was also observed in other studies based on isotopic data from the Czech Republic (e.g. Knipper, in press; Price et al., 2004; Richards et al., 2008). Noteworthy is also the fact that the excavated settlement site of Radovesice I showed a continuous development since the Hallstatt period, which was also observed for many other settlements excavated in north-west Bohemia (Budinský and Waldhauser, 2004; Waldhauser, 1977). There are, therefore, no signs of disruption caused by a movement of large parts of the population. The previously discussed females forming two groups of $\delta^{18}O$ values in Kutná Hora also show a wide variety in $^{87}Sr/^{86}Sr$ values, ranging from 0.7098 to 0.7137 for the group with more depleted $\delta^{18}O$ values and between 0.7082 and 0.7147 for the group with more enriched $\delta^{18}O$ values. It is therefore proposed that the diversified geology rather than a "foreign" origin affected the isotopic data – and this is supported by the dispersed settlement structure discussed above. It is suggested that the females in the same group had similar drinking water sources in the same region, but nevertheless lived under differing geological conditions. Although no clear groups appear in Radovesice, similar $\delta^{18}O_p$ with differing $^{87}Sr/^{86}Sr$ values occur, which might be explained in the same way. An origin from Moravia and the Danubian region can of course not be excluded. However, many other European areas with comparable $^{87}Sr/^{86}Sr$ (e.g. Voerkelius et al., 2010) and $\delta^{18}O$ values (Bowen and Revenaugh, 2003; IAEA/WMO, 2006) also come into question. It is proposed that the observed variation most likely was only partly caused by migrations and that intensified contacts with other communities might just as well be responsible for the observed change in the material culture. Possible migrants are those individuals which fall completely outside the expected isotope ranges (graves RAD I 11, 13, RAD II 8, 13) and presumably the individuals with more depleted $\delta^{18}O$ values (graves RAD I 2, RAD II 5, 14, 18, KUT 14, 15, 17).

Although a vast majority of individuals have a combination of Sr and O isotope ratios resembling the regional variation of Bohemia, there are some noteworthy findings (**Figs. 5.9-5.10**). The three individuals (graves RAD I 4, RAD II 6, 11) from Radovesice with the lowest $^{87}Sr/^{86}Sr$ values presumably derived their Sr from geologically young volcanic rocks (**Table 5.1, Fig. 5.6**). Marine carbonates most likely contributed to the lower $^{87}Sr/^{86}Sr$ values of the individuals (graves KUT 8, 19, 30) (**Table 5.1, Fig. 5.7**) from Kutná Hora. In Radovesice individuals with $^{87}Sr/^{86}Sr$ ratios between 0.7094 (the upper limit of the bone range at Radovesice) and 0.7115 (the upper limit of the local range at the loess site of Vedrovice; cf. Richards et al., 2008) might have come from another loess area (graves RAD I 3, 16, 21, 25, 34, RAD II 7, 15, 19, 20, 22). This also applies for the individuals from Kutná Hora (graves KUT 43, 49) which yield $^{87}Sr/^{86}Sr$ values between 0.7108 (the upper limit of the bone range at Kutná Hora) and 0.7115 (the upper limit of the local range at the loess site of Vedrovice; cf. Richards et al., 2008). The remaining individuals in Radovesice and Kutná Hora with $^{87}Sr/^{86}Sr$ values > 0.7115 presumably had some input from Palaeozoic and Precambrian rocks to their diet (Richards et al., 2008). These rock formations can be found in upland regions to the north, west and south (Bentley and Knipper, 2005). The variation among the individuals with more radiogenic $^{87}Sr/^{86}Sr$ values suggests that they were exposed to these Palaeozoic and Precambrian rocks to different extents. In addition to the majority of individuals which correspond to the regional $\delta^{18}O$ values in the Czech Republic, $\delta^{18}O_{dw}$ below -11‰ are exceptional. Such depleted $\delta^{18}O$ values (< -10‰) are known from the northern Czech Republic, for example precipitation collected in the Ulhířská catchment, Jizera Mountains (Šanda et al., 2009), and rainfall at the site of Ocean (Novák et al., 2005), but are also observed in other mountainous areas, such as the Alps (e.g. Müller et al., 2003; Schürch et al., 2003) or Carpathians (Bowen, 2012; Bowen and Revenaugh, 2003). Even though $\delta^{18}O_{dw}$ above -8‰ does not appear to be common for the Czech Republic, it should be noted that $\delta^{18}O$ data from this area are scarce and the deviation from the expected regional variation in $\delta^{18}O$ are minimal. An origin from a more southerly region can of course not be excluded, but many other factors that can influence the oxygen isotope composition, for example calculation errors in the conversion (Chenery et al., 2010; Pollard et al., 2011), seasonality (Gat, 1996; Higgins and MacFadden, 2004) and food preparation (Daux et al., 2008), should also be considered.

5.8. Conclusion

Although there is no doubt that the isotope data of the studied cemeteries show a high degree of diversity, it is assumed that migration cannot be the only explanation for the observed variation. Considering the very complex geology of Bohemia and the Czech Republic in general, the Sr isotope ratios most likely reflect these heterogeneous geological conditions. The O isotope ratios, on the other hand, are less varied. They most likely correspond to different drinking water sources within the Bohemian region. As the majority of individuals correspond with the expected regional variation in Bohemia, it is assumed that the observed variation in isotope ratios is to a large extent caused by a dispersed settlement structure within the heterogeneous geological environment. The large difference (> 0.001) in $^{87}Sr/^{86}Sr$ values within the same jaw are thereby explained by regularly changing farming land in the densely populated and agriculturally favourable Bohemian landscape.

Residential changes cannot be completely excluded and certainly played a role in some cases. This especially applies to the individuals with an isotopic composition that deviates from the expected regional variation for this area. Whether these individuals came from Moravia or the Danubian region, with which a connection in material culture is observed, remains debatable. Other regions also come into question, as these isotope ratios are not restricted to these areas.

"Celtic migrations" can only partly explain the high diversity in the datasets. Instead of mass migration of whole family groups, it is suggested that these migrations concerned only a small part of the community. It is assumed that the males with more depleted $\delta^{18}O$ values than the expected regional variation in $\delta^{18}O$ for the Czech Republic are concerned. Particularly, but not exclusively, those men buried as warriors appear non-local. Females, on the other hand, are generally more consistent with the expected regional variation in Bohemia. This suggests that some males came from other areas or travelled more in different areas, whereas females were more tied to the Bohemian region.

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6. CONCLUSIONS

The main goal of this research was to obtain more insight on the role of residential changes during the period of the "Celtic migrations". This has been accomplished by archaeologically and isotopically analysing ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) individuals buried at several Early La Tène cemeteries located in different European regions. The conclusions drawn from this study will be addressed in this chapter.

6.1. Mobility and migration in Early La Tène Europe

The cemeteries studied here date to the 4th to 3rd century BC, historically known as the period of the "Celtic migrations". According to the classical authors a time of mass migration of large population groups that extended their main Central European living area to eastern, western and southern Europe, even as far as Asia Minor (e.g. Collis, 2010; Tomaschitz, 2002), a development also observed in the archaeological record by a uniform spread of the La Tène culture throughout continental Europe. The isotopic analysis revealed however that the majority of the analysed individuals either came from the area they were buried in or from the area surrounding the cemetery. In Münsingen-Rain this applies to 85.3% (n = 29/34), in Nebringen to 88.2% (n = 15/17) and in Monte Bibele to 81% (n = 17/21) of the analysed individuals. A clear exception is formed by Radovesice and Kutná Hora, with respectively frequencies of 74.3% (n = 26/35) and 76% (n = 19/25). At these Czech cemeteries the $^{87}Sr/^{86}Sr$ values of nearly a quarter of the analysed individuals suggest they might have come from different geological units surrounding the sites, whereas the $\delta^{18}O$ values clearly deviate and indicate they originated from elsewhere. Additionally, it appeared from the multiple analysed teeth from the same individuals buried at Nebringen, Radovesice and Kutná Hora that a local origin was not inextricably linked to living in just one place. The deviation in $^{87}Sr/^{86}Sr$ values between the early and later forming teeth suggest that of the analysed individuals 50% (n = 8/16) from Nebringen, 48.5% (n = 16/33) from Radovesice and 28.6% (n = 6/21) from Kutná Hora might have changed their residency at a later stage in life. However, as there are no individuals that could not have obtained these differing $^{87}Sr/^{86}Sr$ values from the studied areas, not necessarily residential changes, but also alternating land-use strategies might have caused this observed variation.

For some individuals the archaeological evidence showed a connection to La Tène cemeteries in the Celtic core area, as well as to northern Italy and the eastern expansion area (Hauschild et al., 2013). In most cases these observed long-distance relationships between the cemeteries could isotopically not be verified, as the measured $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values cannot be ascribed to just one specific locality. Of specific interest concerning this matter is the cemetery of Monte Bibele, where the strongest indication of a connection between Central Europe and the Mediterranean area exists. At this cemetery a transition from purely Etruscan to mixed grave inventories of archaeologically local Etruscan objects and archaeologically foreign La Tène elements is observed. The assumption that these Celtic objects were introduced by one population group should, however, be rejected as the Sr isotope ratios in the teeth of the individuals buried with such a grave set did not point to a common place of origin. The concerning individuals either came from Monte Bibele or an area with similar or slightly differing Sr isotope ratios (cf. **Chapter 4**). Intended $\delta^{18}O$ analysis can most likely shed some light on this matter, as for two individuals (graves 6 and 43) buried at Münsingen-Rain the $\delta^{18}O$ ratios suggest they spent time in the Mediterranean area (cf. **Chapter 3**). Hitherto it seems that the spread of the La Tène culture was not only caused by the movement of population groups from one specific area, but it is assumed that beside mobility of some single individuals, the exchange of objects and ideas also played an important role. Residential changes also appeared not to be confined to the Celtic expansion area, but instead the individuals studied here were moving within their own region, irrespective of being the core or expansion area. This study clearly illustrates the essence of an interdisciplinary approach, whereby archaeological and bioarchaeometric data are combined, as it provides important insights into the connection between exchanged grave goods and the individuals buried with them. Additionally, it should be underlined that historical sources have to be interpreted and applied carefully, as migration between the Celtic core and expansion area cannot be rejected, but seemed not to have occurred regularly.

The cemeteries studied here yielded very different strontium isotope results. The datasets from Münsingen-Rain and Monte Bibele appear far less varied than those from Nebringen, Radovesice and Kutná Hora. These observed differences might partly be explained by the demographical structures of these burial communities. In Münsingen-Rain morphological kinship analysis showed biological relatedness among a vast majority of the analysed individuals (Alt et al., 2005). The isotopic analysis also revealed that the individuals with common morphological characteristics shared similar isotope signatures that were in agreement with an origin from the Aar Valley. It was, therefore, suggested that this cemetery was founded by an already existing local community, in which only few males and females from elsewhere integrated (cf. **Chapter 3**). Near the cemetery of Monte Bibele, an associated settlement site was discovered (Vitali, 2008). The observed narrow range in Sr isotope ratios might be explained by residence in the same settlement and usage of the same agricultural resources (cf. **Chapter 4**). The settlement area of Nebringen was never discovered and only small scatters of surface finds are known from this area, which rather point to small hamlets or single farmsteads. At the Czech cemeteries, only a settlement was discovered for Radovesice I. However, the fertile soils of both south-west Germany and Bohemia appeared to be very densely populated during prehistoric times. In contrast to Münsingen-Rain and Monte Bibele, the surrounding areas of these sites are characterised by complex, heterogeneous geological conditions. As the majority of the individuals in Nebringen and the Czech cemeteries correspond to the expected isotope values of the studied areas, regularly changing land plots might have contributed to the observed variation (cf. **Chapters 4-5**).

An often mentioned motive for the "Celtic migrations" is deteriorating climatic conditions leading to a colder and more humid climate around 400 BC (cf. Grove, 1979; Kromer and Friedrich, 2007; Magny et al., 2009). In the pollen record this is shown by the abandonment of marginal areas. However, archaeological evidence shows that prehistoric communities were able to change to lower subsistence levels, causing no dramatic interruptions in material culture (Tinner et al, 2003). Compared to present-day values the estimated drop in temperature of ~2°C (Büntgen et al., 2011) and an increase in precipitation of ±10-20% (Gutiérrez-Elorza and Peña-Monné, 1998; Lamb, 1977) were small. It was estimated that a decline in ~2°C can alter the $\delta^{18}O$ values in rainwater by 1.14‰ (cf. Dansgaard, 1964, 0.57‰ per 1°C). In tooth enamel this equates to a depletion of ± 0.39‰ (Levinson et al., 1987; Chenery et al., 2010). This expected depletion in $\delta^{18}O$ values was not noticed in the oxygen isotope data from Münsingen-Rain (cf. **Chapter 3**) and the Czech cemeteries (cf. **Chapter 5**). Beside that, no higher mobility rates were detected during this period (LT A-LT B1). The present dataset is, however, small and part of the observed mobility might have been caused by climate change. It appears, however, not to be the paramount motive, as mobility was not restricted to this time period.

In summary, it can be concluded that the old doctrines of mass migration of homogeneous Celtic tribes that abandoned their main Central European homeland for the expansion areas should be falsified. It appears that residential changes certainly played a role in everyday life, but apparently only on a limited scale.

6.2. Sex specific residential changes and non-local warriors

In Münsingen-Rain, Nebringen and Monte Bibele most females are consistent with the isotope ratios of the local biologically available strontium. The females of the Czech cemeteries, on the other hand, yield predominately deviating isotope ratios that resemble the regional isotope variation in Bohemia. This variability among these females, which was also noticed in other prehistoric time periods (cf. Bentley, 2007; Haak et al., 2008; Knipper et al., 2012), might point to patrilocal residential patterns. In this social system the woman settles in the community of her spouse (Eriksen, 2001). For this specific period high mobility rates are also ascribed to Celtic warriors that participated in nearly all military conflicts (Tomaschitz, 2002). Although the males in these studied cemeteries have more varied isotope ratios than the females, this is not always correlated with burial as a warrior. The males buried with weaponry at the Czech cemeteries, on the other hand, occur highly mobile. In summary, it can be concluded that at the cemeteries studied here males had slightly more often a non-local birthplace or moved during childhood, whereas females were local or originated from the region. Only for the Czech cemeteries this might be related to warfare and exogamy. This study also showed no indications that whole families participated in these migrations, as predominately adults changed their residency, whereas the few analysed children were generally local.

6.3. Perspectives

The data presented here comprise one of the largest databases on the Early La Tène period of Europe and consequently forms an important basis for future studies on this subject. In addition, it provides useful comparative data for both thoroughly researched areas, such as Germany, and less-well studied areas, such as the Czech Republic and Italy. However, from the study of Münsingen-Rain and the Czech cemeteries the importance of supplementing Sr isotope analysis with O isotope analysis became apparent. Its strength lies in the fact that $\delta^{18}O$ ratios are not influenced by homogeneous or heterogeneous geological conditions and assist in the determination whether the geology conditions or rather provenance influenced the Sr isotope data. This not only leads to a better understanding and overview of the available data, but also reveals matters that would otherwise stay unnoticed. The obtained Sr isotope data from Nebringen and Monte Bibele would also greatly benefit from their contribution, as it was noticed how difficult it was to distinguish local from non-local individuals. Elaborating these datasets with O isotope data would, therefore, provide new insights on the actual mobility rates among the individuals buried at these cemeteries. Beside that, the integration of the isotope data from the remaining French, Austrian, Hungarian and Romanian cemeteries will further complete the picture on the period of the "Celtic migrations". Additionally, ancient DNA analysis applied to these last mentioned cemeteries will complement the data on which individuals were outsiders to the community (Karimnia, in progress; Warnberg, in prep). On-going archaeological analysis of the grave sets can provide further knowledge on the provenance of exchanged grave goods (Hauschild, in prep). The combination of all this gained information might provide a breakthrough in long-lasting questions and debates about the mobility of the "Celts".

7. SUMMARY

The period of the historic “Celtic migrations” has archaeologically already been studied extensively, but the long-lasting question whether mass migration or increased individual mobility caused the spread of the La Tène culture throughout continental Europe persists. Ambiguities about the actual processes behind the observed expansion in the 4th and 3rd century BC are transmitted by the classical authors, who describe mass migration of large population groups that extended their main Central European living area to eastern, western and southern Europe, even as far as Asia Minor.

Archaeological and isotopic ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) analyses of individuals buried at the Early La Tène cemeteries of Nebringen (Germany), Münsingen-Rain (Switzerland), Monte Bibele (Italy) and the Czech cemeteries of Radovesice I, Radovesice II and Kutná Hora were, therefore, carried out to investigate the importance of residential changes during this time period. The bioarchaeometric data showed that most analysed individuals either came from the area they were buried in or from the surrounding area of the cemetery. An exception was formed by the Czech cemeteries, where nearly a quarter of the studied individuals appeared isotopically non-local. A local origin was, however, not inextricably linked to living in just one place, as in Nebringen, Radovesice and Kutná Hora a high amount of individuals had differing $^{87}Sr/^{86}Sr$ values between the early and later forming teeth. This suggests that these individuals changed their residency later in life. There are, however, no individuals that could not have obtained these deviating $^{87}Sr/^{86}Sr$ values from the studied areas, and not necessarily residential change, but also alternating land-use strategies might have caused this observed variation.

For some of the non-local individuals in these cemeteries, the archaeological record revealed long-distance relationships between the Celtic core and expansion area; based on the utilized bioarchaeometric methods such a connection, except for two individuals buried at Münsingen-Rain, could not be established. It, therefore, seems that the spread of the La Tène was not only caused by the movement of single individuals, e.g. in the context of migration initiated by marriage, but also by the exchange of objects and ideas. Residential changes were also not restricted to the Celtic expansion area, but it seems that individuals were moving

within their own region, irrespective of being the core or expansion area. This study clearly illustrates the essence of an interdisciplinary, integrative research approach, whereby archaeological and bioarchaeometric data are combined, as both biological and cultural issues are taken into account. Additionally, it should be underlined that historical sources have to be interpreted and applied carefully, as migration between the Celtic core and expansion area did occur, but not to the extent described by the classical authors.

The observed differences between the less varied isotopic ratios of the analysed individuals from Münsingen-Rain and Monte Bibele and the highly varied isotopic ratios of the analysed individuals from Nebringen, Radovesice and Kutná Hora can partly be explained by the very unique demographical structure of these burial communities. Morphological kinship analysis in Münsingen-Rain demonstrated biological relatedness among most of the analysed individuals. These related individuals also shared similar isotope signatures, which suggest an origin from the surrounding Aar Valley. This cemetery was, therefore, most likely founded by an already existing local community, in which only few individuals from elsewhere integrated. In the vicinity of the cemetery of Monte Bibele, an associated settlement site was discovered. The observed narrow range in $^{87}Sr/^{86}Sr$ values suggests that the deceased not only shared this settlement, but also cultivated the same land plots. For Nebringen, Radovesice and Kutná Hora a dispersed settlement structures is assumed, as these agriculturally favourable landscapes were densely populated during prehistoric times. In contrast to Münsingen-Rain and Monte Bibele, the surrounding area of these sites are characterised by complex, heterogeneous geological conditions. As the majority of the individuals in Nebringen and the Czech cemeteries correspond to the expected isotope values of the studied areas, regularly changing land plots might have contributed to the observed variation.

Hitherto it appears that the often mentioned deteriorating climate conditions around 400 BC were not the paramount motive for mobility, as residential changes were not confined to this period. Additionally, residential changes were not restricted to specific population groups. There are, for instance, no clear indications that whole families were involved, as predominately adults seemed mobile, whereas the few analysed children are generally local. Only in the Czech cemeteries a trend is emerging. Predominately males, including the males buried as warrior, had more often a non-local birthplace or moved during childhood, whereas females were local or originated from the region. The latter might be an indication of patrilocality.

In summary, this study falsifies the old model of mass migration of homogeneous Celtic tribes that exchanged the Celtic core for the expansion area. It certainly appears that mobility played a role in everyday life, but was only confined to a small part of the population.

8. ZUSAMMENFASSUNG

Die Zeitspanne der historisch überlieferten „Keltischen Wanderungen" ist archäologisch bereits intensiv untersucht, aber die Frage, ob Massenwanderungen oder erhöhte individuelle Mobilität für die Ausbreitung der Latènekultur in Kontinentaleuropa verantwortlich sind, bleibt bestehen. Die Unklarheiten über die tatsächlichen Prozesse hinter der beobachteten Expansionen im 4. und 3. Jh. v. Chr. gehen auf klassische Autoren zurück, die die Ausweitung des mitteleuropäischen Kernraums der Kelten nach Ost-, West- und Südeuropa, sogar bis nach Kleinasien, Massenwanderungen großer Bevölkerungsgruppen zuschreiben.

Um die Bedeutung des Wohnortswechsels während dieser Zeitspanne zu untersuchen, wurden in dieser Arbeit archäologische und isotopische ($^{87}Sr/^{86}Sr$ und $\delta^{18}O$) Analysen an Individuen durchgeführt, die auf den früh-latènezeitlichen Gräberfeldern von Nebringen (Deutschland), Münsingen-Rain (Schweiz), Monte Bibele (Italien) und den tschechischen Gräberfeldern von Radovesice I, Radovesice II und Kutná Hora bestattet wurden. Die Isotopendaten zeigen, dass die meisten analysierten Individuen entweder aus dem Ort an dem sie beigesetzt wurden oder aus der näheren Umgebung stammten. Eine Ausnahme bilden die tschechischen Gräberfelder, wo fast ein Viertel der untersuchten Individuen zugewandert sein müssen. Eine lokale Herkunft war jedoch nicht untrennbar verbunden mit einen Aufenthalt an nur einem Ort, da die Gräberfelder von Nebringen, Radovesice und Kutná Hora einen hohen Anteil von Individuen enthielten bei denen die $^{87}Sr/^{86}Sr$ Werte der während der Kindheit und dem Jugendalter gebildeten Zähne nicht deckungsgleich waren. Dies deutet darauf hin, dass diese Individuen während der Zeit der Zahnontogenese ihren Wohnort gewechselt haben müssen. Unter diesen Individuen gab es jedoch keine Individuen mit Sr-Isotopenverhältnissen, die nicht mit dem variablen, biologisch verfügbaren Strontium dieser Regionen übereinstimmten. Deswegen konnten nicht nur Wohnortswechsel, sondern auch die Wirtschaftsweise und die Landnutzung zu dieser beobachteten Variation beigetragen haben.

Für einige der als nicht lokal bestimmten Individuen dieser Gräberfelder lassen deren Grabbeigaben Fernbeziehungen zwischen dem keltischen Kern- und Expansionsgebiet vermuten; ein derartiger Zusammenhang konnte anhand der benutzten bioarchäometrischen Methoden, außer im Fall von zwei Individuen aus Münsingen-Rain, nicht hergestellt werden. Prinzipiell scheint es wahrscheinlich, dass die Ausbreitung der Latènekultur nicht nur durch die Migration von einzelnen Individuen, z. B. im Rahmen einer durch Heirat initiierten Migration, sondern auch durch den Austausch von Objekten und Ideen stattgefunden hat. Die Wohnortwechsel waren sicher auch nicht allein auf das keltische Expansionsgebiet beschränkt, aber es erscheint viel eher wahrscheinlich, dass die hier untersuchten Individuen, sowohl im Kern- als auch im Expansionsgebiet der Kelten, vor allem jedoch in ihren heimischen Regionen mobil waren. Diese Studie verdeutlicht durch die Kombination archäologischer und biogeochemischer Methoden die Bedeutung und den Stellenwert eines interdisziplinären, integrativen Forschungsansatzes, da dieser grundsätzlich sowohl biologische wie kulturelle Fragestellungen berücksichtigt. In diesem Zusammenhang ist zu betonen, dass die Verwendung historischer Schriftquellen prinzipiell eine sorgfältige Quellenkritik beinhalten muss. Im vorliegenden Fall muss man davon ausgehen, dass Migrationen zwischen dem keltischen Kern- und Expansionsgebiet stattgefunden haben, aber nicht in dem hohen Umfang, wie ihn die klassischen Autoren berichten.

Die beobachteten Unterschiede zwischen den homogeneren Strontiumisotopenverhältnissen der Individuen aus Münsingen-Rain und Monte Bibele, und den sehr unterschiedlichen Werten der Individuen aus Nebringen, Radovesice und Kutná Hora können teilweise aus der sehr spezifischen demographischen Struktur der Gräberfeldgemeinschaften erklärt werden. Morphologische Verwandtschaftsanalysen in Münsingen-Rain liefern Hinweise für eine biologische Verwandtschaft zwischen der Mehrzahl der analysierten Individuen. Diese verwandten Individuen zeigen auch vergleichbare Isotopensignaturen, die eine Herkunft aus dem umliegenden Aar-Tal nahe legen. Das Gräberfeld wurde demzufolge wahrscheinlich von einer bereits existierenden Gemeinschaft gegründet, in die nur wenige nicht-lokale Individuen aufgenommen wurden. Im Fall von Monte Bibele sprechen die Isotopendaten dafür, dass die Menschen, die zu Lebzeiten wohl die zugehörige Siedlung bewohnten, ihre Nahrung von denselben landwirtschaftlichen Nutzflächen bezogen. Für Nebringen, Radovesice und Kutná Hora werden aufgrund des festgestellten Isotopensignaturen weiter zerstreut liegende Siedlungsstrukturen postuliert. Diese Gebiete waren in prähistorischer Zeit zur Landwirtschaft gut geeignet und dicht besiedelt. Im Gegensatz zu Münsingen-Rain und Monte Bibele zeichnet sich das nähere Umland dieser Fundplätze durch komplexe, heterogene geologische Bedingungen aus. Die ermittelten Sr-Werte der Individuen streuen gemäß der diversen lokal-geologischen Gegebenheiten, was dafür spricht, dass die Nahrung von wechselnden Agrarflächen stammt.

Die Beweggründe für die beobachteten Wohnortwechsel bleiben jedoch weiter unklar. Die in diesem Zusammenhang oft genannte Verschlechterung des Klimas um 400 v. Chr. spiegelt sich nicht in Form erhöhter Mobilitätsraten in den bioarchäometrischen Ergebnissen wieder, sodass diese Wetterveränderung wohl kaum eine entscheidende Rolle spielte. Diese Studie zeigt auch, dass Mobilität nicht in allen Fällen auf bestimmte Bevölkerungsgruppen beschränkt war. So gibt es z. B. keine klaren Hinweise darauf, dass ganze Familien migrierten, da hauptsächlich Erwachsene mobil erscheinen, während die wenigen untersuchten Kinder in der Regel lokalen Ursprungs sind. Lediglich bei den tschechischen Gräberfeldern zeichnet sich ein spezifischer Trend ab. Dort sind es überwiegend Männer, vor allem als Krieger eingestufte Männer, die mehrheitlich fremde Isotopensignaturen auf weisen. Daneben streuen die Signaturen der Frauen innerhalb des regionalen Wertespektrum, was als Indiz für Patrilokalität gewertet wird.

Zusammenfassend widerlegt diese Studie alte Lehrmeinungen hinsichtlich der Behauptung von Massenwanderungen homogener keltischer Volksstämme, die ihre Wohnsitze in den Kerngebieten aufgaben und in die Expansionsgebiete auswanderten. Ganz sicher haben lokale Mobilität und überregionale Migration eine Rolle im Alltag der Kelten gespielt, aber allem Anschein nach fand dies nur in beschränktem Ausmaße statt.

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11. PUBLICATIONS

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12. CONFERENCE CONTRIBUTIONS

Oral presentations

Scheeres, M., Knipper, C., Schönfelder, M., Hauschild, M., Siebel, W., Alt, K.W. 2013. Bioarchaeometric investigations ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) of the La Tène burial community of Münsingen-Rain, Switzerland. 19th EAA Annual Meeting, Pilsen, Czech Republic.

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