JIHOČESKÁ UNIVERZITA V ČESKÝCH BUDĚJOVICÍCH
FILOZOFICKÁ FAKULTA
ARCHEOLOGICKÝ ÚSTAV

BAKALÁŘSKÁ PRÁCE

MIGRATIONS OF HISTORICAL POPULATIONS

ISOTOPIC SIGNATURES IN HUMAN BONES AND THEIR APPLICATION IN ARCHAEOLOGICAL INTERPRETATIONS

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Ročník: 4.

2014

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České Budějovice, 30. dubna 2014

Poděkování

Ráda bych poděkovala panu doc. PhDr. Jaromírovi Benešovi, Ph.D. za odborné vedení mé bakalářské práce. Děkuji za trpělivost a především za ochotu, čas, cenné rady a informace, které mi během psaní práce vřele poskytl.

Anotace

V bakalářské práci pod názvem „*Migrace historických populací. Izotopové signály v lidských kostech a jejich využití v archeologických interpretacích*." je na základě literární rešerše shrnuta jedna z nejvíce používaných výzkumných metod – analýza stabilních izotopů, a to především stronciový izotopový signál v lidských kostech a zubech. Na základě biochemie lidských kosterních pozůstatků izotopová analýza umožňuje archeologům i antropologům zkoumat lidskou migraci a geografický původ lidských populací. Izotopový výzkum spolupracuje s dalšími vědními obory, poněvadž bez jejich použití by nebylo možné dosáhnout příznivých výsledků. Bakalářská práce se zabývá především stronciovým izotopovým signálem v lidských kostech, které jsou dle mého názoru silným prostředkem pro pochopení pravěkých a historických migrací.

Abstract

In the Bachaelor thesis called “*Migration of historical populations. Isotopic signatures in human bones and their application in archaeological interpretations*.“, one of the most used research method – stable isotope analysis, especially strontium isotope signature from human bones and teeth, is summarized on the basis of a literature review. Isotope analysis allows archaeologists and anthropologists to investigate human migration and the geographical origin of human populations based on the biochemistry of human skeletal remains. Isotopic research cooperates with other disciplines, because favorable conclusions could not be made without their use. The Bachelor thesis deals mainly with the strontium isotope signature recorded in human bones which is from my point of view, a strong tool for understanding the human prehistoric and historical migrations.

Content

1 Introduction

As far as where do the roots of our species stretch? Does have our species a far-reaching history, or did we evolve not long ago? What does the human migration mean? How old are the migrations? Why do people migrate? These questions are essential for determination the human migration and its causes and consequences.

Human migration is a process, when individuals or groups leave their birthplace and find a new place for living. Migration is a natural phenomen as old as humans themselves. This process was a natural way of life for members of many societies. The second episode of the “Out of Africa“ phenomen brought the emergence of modern people about. Process of Neolithisation caused the transition from foraging to farming and the origins of domestication. The Migration Period lasting from the 2th to the 6th century contributed to the collapse of the entire Ancient world and the birth of a new – medieval one. In the Middle Ages, the uninhabited European areas were settled via the colonization. In the 17th and 18th century, many people moved due to reformation and religious wars, because of the vision of a better life. A huge wave of migration during the 19th century was terminated, for example, from Europe to the United States (others also to African, South American and Asian colonies). In the 20th century, the politics played an important role; and people may migrate more and more easily than ever before.

To investigate human migration, we have to use several fields of study, such as archaeology, anthropology, geology, hydrology, climatology, geochemistry, archaezoology, biology, linguistics, ethnography, history, genetics, molecular anthropology and many others. In my following text, I aim to determinate bioarcheological traits of human migrations. I focuse on the research of human skeletal remains namely based on the strontium isotope signature as main tool to identify human migrations.

Goals of Bachelor thesis are following: (1) Summary of facilities of the use of study of stable isotopes of elements within the investigation of human residental mobility. (2) Clarification of the principle of the use of some isotopes, and subsequent clarification of limits thus selected analyzes in archaeological and anthropological researchers. (3) To point out suitability and selection of osteological material. (4) Evaluation of the effects of diagenetic processes on human bones and teeth.

(5) Giving examples of the currently investigated archaeological and anthropological questions relating to the issue of human migration. (6) Use of method of the measurement of isotopic signature from samples of human remains. (7) General assessment thus focused studies. (8) Giving results of analyzes, mainly focused on Central Europe.

At the beginning of Bachelor thesis, I try to describe common characteristics of human migrations and their histories. I consider that is quite essential to understand the migration process itself. I deal with the period from the emergence of first humans untill the modern times. The following section describes the stable isotope analysis, and the description of stable isotopes used in the study of human migration. In the final part of my thesis, I pursue the description of strontium isotope signature from human bones and teeth that I consider as the most suitable indicator of the human migration. In this section, I quote accesible studies dedicated the strontium analysis. In conclusion, I summarize the results of strontium studies from many regions, mainly from Central Europe.

2 Human migration

2.1 History of migration studies

To comprehend the migration process itself, it is essential to introduce contexts of migration in relation to other disciplines, a migration definition, why and where human populations were originated, moving, and to describe a migration history.

The study of migration is connected to several archaeological schools. Outline of history of human migration and hereto using of isotopic analysis, it is necessary to mention a concept of bioarchaeology. The bioarchaeology has been developed for a long time into its present form of an independent multidisciplinary science sphere (Beneš, Pokorný 2008).

C*ultural-historical paradigm* included concept of archaeological cultures, which made equal cultures to ethnic groups. There are key questions concerning the cultural-historical paradigm – (1) Where was stretched out the territory of a specific ethnic group? (2) Where it is possible to situate its "homeland"? (3) How ethnic groups spread? Subsequently, the migration, mobility and mutual interaction of archaeological cultures relate with the interest in ethnic interpretation of prehistoric cultures. Sudden cultural changes were interpreted as a result of the arrival of a new population (Neustupný 2010).

The representatives of cultural-historical paradigm are scholars as Gustaf Kossina (1858–1931) and Józef Kostrzewski (1885–1969). Gustaf Kossina was a linguist and professor of German archaeology at the University of Berlin. He was a founder of so called "*Siedlungsarchäologie*" (Settlement archaeology) – identifying the extension of archaeological cultures with local units of Germanic tribes. Józef Kostrzewski studied with Gustaf Kossina in Berlin. Afterwards, he became involved in polemics about the ethnic affiliation of the Lusatian culture with the German archaeologist Bolko von Richthofen. Hans Jürgen Eggers (1906–1975) criticized this approach – a distribution of archaeological traits of different material culture in area cannot be an expresion of the ethnicity, but it could represent also other factors (Neustupný 2010).

Further, the concept of a diffusion developed. The school was based on the fact that technological knowledge, cultural and religious ideas spread from several culturalcivilizational centres in the prehistoric period (since Paleolithic). Another important representative was Vere Gordon Childe, who claimed that the farming cultures spread from the Near East through the Balkan Peninsula to Central and Western Europe (Neustupný 2010).

Bones and teeth are considered by anthropologists as a valuable source of information for interpreting lifeways of past humans. Human skeletal and dental tissues are remarkably sensitive to the environment; therefore, it is necessary the archaeology and anthropology cooperate together. Dena F. Dincauze, an author of the North American textbook of the environmental archaeology, suggests aims of palaeoenvironmental studies as following: historical or philosophical (concerning the natural environment and the human evolution). The most important representative in the history of the North American environmental archaeology is Karl W. Butzer, who laid the foundation for an interdisciplinary study, namely geoarchaeology. From the 1960s onward, he formed part of processual archaeology which understood human culture as a means of human adaption to changing environment. With the development of the landscape archaeology, a study of past ecosystems came to the fore (Larsen 1997; Beneš, Pokorný 2008).

Environmental research does not have a long tradition in Czech prehistory (with the exception of the Palaeolithic archaeology). At the beginning of the 20th century, many Czech archaeologists devoted to cultural-historical archaeology, migration and diffusion. These include, for example, Lubor Niederle, Karel Buchtela, Jaroslav Böhm, Jan Filip, Jiří Neustupný. The pre-war study under a lead of Jan Filip dealt with the vegetation and climate of Bohemia in prehistory; and from this period, there were many researchers. After World War II, the situation did not permit the continuation of research development into the natural environment in context with human history. In 1960s, Thomas Kuhn called the units, into which archaeologists grouped together – *paradigms* = certain patterns by which scientists gather their materials and evaluate them. It is a set of theoretical ideas reflecting what individual researchers have in common. At the beginning of the 1980s, Jan Rulf studied the relationship of the Neolithic and Eneolithic settlements with some natural environment parameters. Zdeněk Smrž interested in the natural environment in terms of microregions in north-west Bohemia. From the beginning of the 1990s, there is a rising interest in the natural environment. An increased interest in study of the narural environment and ecofacts occured due to better opportunities for specialist studies and the establishment of specialist environmental institutions within the framework of universities and archaeological institutes. Nowaday, the future of environmental archaeology in the Czech Republic is in hands of archaeologists, whose systematic interest can secure sufficient employment opportunities for a new generation of natural scientists (Neustupný 2010; Beneš, Pokorný 2008).

2.2 Definiton of human migration

A definition of human migration is a movement from one place or country to another one, where populations settled. In many countries, human migration meant huge benefits, such as an economic growth, population increase, cultural and religious changes etc. A human evolution is inseparably connected with a movement from one place to another one and subsequently with an adaptation to a new environment. It is related to a movement of early predecessors out of Africa (from Africa to Eurasia), as well as a movement of *Homo sapiens*, who followed the same routes, through them *Homo erectus* had sailed (King 2008; Fleagle *et al.* 2010).

A movement is an important factor determining the way of life of individuals. During migration problems can pass, for example, lack of food, a space for living, an environmental or climate change, enemy attacks, etc. And therefore, individuals frequently see as the best solution a moving out to a more suitable place (Cloudsley-Thompson 1988).

Hominins moved into a new feeding area and became part of the carnivore guild based on the ability to also exploit plant resources. As stated above, this affected many aspects of their ecology, including home range size and dispersal abilities, and also affected the ecology and survival within the diverse carnivore communities of the Pliocene and Early Pleistocene. A development of the culture represented by the manufacture and use of stone tools was one of the most significant factors enabling hominins to successfully expand into Eurasia (Fleagle *et al.* 2010).

As far as moving mechanism, Cloudsley-Thompson (1988, 15) wondered whether if travellers suddenly found themself in a completely different part of environment, would they able to find a way home without a compass and without any help. The answer could be yes. Not by some mysterious sense of direction, but by sight orientation, collective memory and sense of time. If they got northward from home and if they were in the northern hemisphere, then the sun in the sky was lower than at home. And if they got southward, the sun was higher. However, if travellers were moved eastward, the watch would show more hours; and likewise westward the watch would show fewer hours. On the other side of the equator they could think that the sun moves across the sky in the opposite direction. Before they would set out the journey home, they had to just long stay in the same place to figure out, which direction the sun moves. Individuals are capable to control their movement in the right direction just by using an instinctive use of these facts (Cloudsley-Thompson 1988).

The human migration can be divided according to several criteria – temporary and permanent, compulsory and voluntary, internal and international. The migration can be subdivided according to needs: subsistence migration (to ensure the subsistence as an existential necessity), betterment migration (to improve living conditions), and career migration (to achieve a professional qualification) (Bade 2005).

Understanding of human evolution must be based on an interpretation of human physical (bone) as well as cultural (artefacts, ecofacts) remains. Human remains predate the origins of our own species (*Homo sapiens*) (Cameron, Groves 2004). My Bachelor thesis is focused on isotopic studies of human bones and teeth.

2.3 Human migration in Quaternary and "Out of Africa" phenomenon

To introduce the history and migration of the first hominins, it is necessary to outline the evolution and resettlement of even their predecessors (anthropoids – apes and monkeys) and their natural environment.

At the Oligocene/Miocene a transition of warmer climatic conditions returned. From the earliest Miocene, the rainforest belt covering most of Africa broke up into a number of distinct ecological niches. There were ever-increasing patches of woodland and grassland interrupting the vast tracts of rainforest. The tropics were the natural environment of anthropoids. Apes and monkeys lived in tropical and subtropical forests and woodlands, where food resources were relatively effortless to find. Monkeys were inhabitating rather low latitude tropical and riparian forests and closed woodlands across Central Africa. Apes were more common, they inhabited limited areas of tropical forests and they were finding a food of a higher quality, especially fruits. The differential ditribution of the hominins came about; it can be explained by a change in worldwide climatic conditions during the middle Miocene. This change brought about a cooling that affected Africa, because it became drier and cooler (Cameron, Groves 2004; Fleagle *et al.* 2010).

The switch from the ape dominance and the diversity in the Late Miocene to the monkey dominance may be related to the climate and habitat changes during the Late Miocene of Africa and Europe. The morphology of the dentition of these early monkeys suggests that they had similar diets with a high proportion of seeds, they were more terrestrial than their modern counterparts; and they were able to adapt to the seasonality. The most prevalent genus of monkey in the Plio-Pleistocene was *Theropithecus*. Hominins were almost as widely geographically dispersed in the Pliocene and Early Pleistocene as the most widespred monkeys, altough they were less common. Eventually, *Theropithecus* began to disperse. In the Middle Miocene, hominoids were widespread in Eurasia in contrast to Africa, where tehy were very rare. They disappeared from Europe in the Late Miocene. Fossil hominins are abundant in eastern and southern Africa in the Pliocene; however, the first evidence of the hominin migration out of Africa is that of *Homo erectus* (Fleagle *et al.* 2010).

We can trace our prehistoric roots back to the African continent between 6 and 7 million years ago. It was the time when populations of proto-chimpanzes and proto-humans split from a common ancestor and each started its own evolutionary journey. In eastern African pastures these ancestors were living there throughout five milions years. These first migrants had to adapt to a new environment. At the earliest hominins we can see a form of bipedal locomotion, some reduction in male canine size, development of a bicuspid lower third premolar, and an increace in molar enamel thickness. Later, hominins developed a number of uniquely shared features not seen in other clades – an absolute increase in brain size, further increase in molar enamel thickness, further reduction in male canine size, reduced supraorbital torus, absolute reduction in postorbital constriction, development of a relatively high frontal, and a nonprognathic prexamilla. Afterwards, *Homo erectus* emerged and he spread out of Africa. Before an entrance of *Homo sapiens*, *Homo erectus* made exploratory routes throughout the Earth. Many years later, the above mentioned *Homo sapiens* evolved at the same place. About 125 000 years ago also *Homo sapiens* set out the journey from Africa to Eurasia and from there across the world (Cameron, Groves 2004).

Homo represents the first hominin to disperse out of Africa. The term *hominin* is used to describe those groups considered to be closely associated with the emergence of the human lineage (this does not necessary mean that they need to be ancestral to humans). Hominins were able to utilize and manufacture stone tools, which was the first adaption that enabled hominins to acquire a feeging strategy and compete with carnivores with an increasing success. Hominins migrated into habitats, from which other catarrhines were excluded, and mainly into latitudes far situated from the tropics (Cameron 2004; Fleagle *et al.* 2010).

The ability to combine plant and meat resources gave the Early Pleistocene hominins considerable dietary flexibility and the opportunity to exploit various food sorts in seasonal habitats. Subsequently, a shift to meat eating occured. Hominins came into a direct competition with carnivores sharing their habitats and they shared a long history of interactions. One can assume that carnivors migrated out of Africa at the same time as the earliest hominin dispersals (Fleagle *et al.* 2010).

Before hominins could disperse out of Africa, they had to disperse out of their habitats in sub-Saharan Africa to North Africa. In the Middle Pleistocene, the successful long term colonizations of North Africa by hominins were very rare and less successful than their colonizations of Eurasia. The hominin expansion into Eurasia in the Early Pleistocene was most probably along the western coast of the Red Sea. The ecological and climatic diversity within Africa influenced the hominin dispersal into Eurasia and colonization of northern continents (Fleagle *et al.* 2010).

The Last Glacial Maximum (26 500–19 000/20 000 years ago) was characterized by the disappearance of the Neanderthals, when the northern parts of Europe were covered by ice sheets, leaving humans to survive in poorly resourced environments. The northern European parts were either completely abandoned or sparsely populated. This period includes several interrelated material cultures varying in their geographic ranges and temporal durations. Humans (though highly adaptable to different environments) could not live on the vast glaciers that covered most of the northern Europe during the last glaciation. Northern Europe was gradually recolonized from refugia after the Last Glacial Maximum. The two major refugia were in southwestern France/Cantabria (Atlantic and Mediterranean zone) and Ukraine/Central Russian Plain (Periglacial zone); however, other minor refugia could exist in between. The recolonization profound effects on the genetic diversity of Europeans (Pinhasi *et al*. 2012; Torroni 2001).

The Pleistocene/Holocene transition was also marked by the recolonization of areas uninhabited during the pleniglacial. Three phases can be identified via the example of the British Isles. The first, which began around cal. 12 500 BC (towards the end of the Lateglacial Interstadial) was characterized by the rapid and widespread dispersal of human populations into lowlands. The climate amelioration came to pass as a consequence of a movement of the Polar Front in response to the waxing and waning of the polar ice cap. The mean temperature for the warmest month has been estimated to have reached around 17° C while that for the coldest month remained low at around 0° C. The landscapes of the earlier part of the Lateglacial Interstadial remained predominately open grasslands. The second, dating from cal. 10 999 to 9000 BC, was an episode of consolidation with little further spread of settlement. During this episode, the Polar Front was displaced as far south as the latitude of Galicia. The mean temperature for the warmest month dropped to 10° C while that for the coldest month were as low as minus 20° C. During the third phase, cal. 8999–7000 BC, a further rapid extension of settlement occured. One of the most significant developments during this period was the northward migration of the Polar Front from the latitude of Galicia to that of Iceland. This brought the warm and biologically productive waters of the North Atlantic drift to the shores of northern and western Britain. For instance, according to DNA studies, the Caucasus and North Africa, together with Arabia and Anatolia might have demarcated major migratory corridors in the human bidirectional dispersals between Eurasia and Africa during the Pleistocene and Holocene. The hostile environment created by the extensive Pleistocene glaciations certainly limited the dispersal opportunities, which might have resulted in population fragmentation because of the existence of nonrandom breeding groups. Thus, the long-term population fragmentation could promote isolation and local genetic microdifferentation by effect of genetic drift (Tolan-Smith 1998; Alfonso-Sánchez *et al*. 2008).

The fossil record enables us to propose a number of likely adaptive alterations within and between specific groups based on fossilised morphology and our understanding of functional anatomy and developmental processes. The strontium isotope study of skeletal remains adds a new dimension to the inquiry that offers a new insight (Cameron 2004; Price *et al*. 2001).

2.3.1 The emergence of Homo erectus

The period human quaternary evolution is classified on two human specieses. The first species *Homo erectus* was almost as high as we are, but much muscular. They were able to produce hand axes and flints from the stone and to communicate among themselves. But their facial features were strikingly different from faces of modern people; noses were flattened and nostrils were reversed upward, as for example, gorillas, and at the forehead a distinctive supraorbital arch outlined. The Plio-Pleistocene fauna of Africa (especially eastern Africa) was the probable source area for *Homo erectus*. *Homo erectus* came into existence in Africa about two millions years ago (100 000 years before a huge climate change: the Ice Age was ending), when the carnivore guild was disappearing and hominins were becoming increasingly dominant. A watter supply stored in glaciers melted and a warmer and damper climate occured. In consequence of this process, deserts became green and Sahara became pastures, in which ruminants and carnivores settled. It brought a significant change into individual's life. The food was more accessible and *Homo erectus* was indenpendent of local conditions. The result was that *Homo erectus* began to rapidly migrate (in groups and southward). During several generations the species reached the very southern tip of the African continent; fossil remains of *Homo erectus* were discovered in Swartkrans in South Africa. Next, they reached the African edge and travelled across the Sinai. Another reamins were found, for example, in China, Black Sea, Gruzia and Atapuerca. It is possible that *Homo erectus* reached also southern Europe. Scientists from the whole world discussed, whether modern people originate from *Homo erectus*. It is necessary to mention that while some hominins migrated to Eurasia, others remained in Africa. Those who migrated completely became extinct, and those who remained in their homeland did not go extinct (King 2008; Fleagle *et al*. 2010).

2.3.2 Homo sapiens and the birth of modern humans

The earliest representatives of the second species *Homo sapiens* appeared around 250 000–150 000 years ago in the same place as *Homo erectus*. The earliest evidence for the emergence of truly modern humans is from Africa, with the discoveries of *Homo sapiens* from Herto in the Middle Awash of Ethiopia (fossil specimens and stone artefacts were dated to between 160 000 and 154 000 years ago). The next earliest evidence for modern humans is from Singa in the Sudan. Other discoveries are, for example, from Dire-Dawa and Omo-Kibish in Ethiopia, Jebel Irhoud and Dar-Soltan in Marocco, Border Cave in Kwazulu-Natal, and Klasies River Mouth in the southern Cape. In Europe, the first discovery of truly modern people was made in 1868, when skeletons were excavated at the Cro-Magnon rocks shelter at Les Eyzies in France („the Cro-Magnon race“). Other European discoveries are following: in the former Czechoslovakia at Mladeč, Předmostí, and Brno; in France at Combe Capelle, Grimaldi, Chancelade, Aurignac, and many other sites; in Germany at Oberkassel; etc. In Asia, the discoveries are, for example, in China at Ziyang, Shanxi Province, Upper Cave at Zkoukoudian, Liujiang; Vietnam; Niah Cave in Borneo; the Wajak skulls from Java; Indonesia; and many others. There are also discoveries from Australia, e.g., Kow Swamp, Cohuna, Coobool, Cossack, Lake Mungo, Williandra Lakes, Sangiran, and on and on (Cameron, Groves 2004).

Homo sapiens, to which modern people belong, spreaded the whole world out. Individuals had big brains and they were able to produce complicated stone tools. Similarly to *Homo erectus*, also *Homo sapiens* stayed for a long time in his home country. Sahara became desert again. It was not possible to cross over this dry and bare wasteland, and therefore, humans remained for tens of thousands years imprisoned in the southern half of the African continent. And thereafter, approximately 125 000 years ago, the desert became green again and kept green for next thousands years. *Homo sapiens* commenced his journey northward, in footprints of *Homo erectus*. He moved along the Nile River and maybe he reached the Egyptian coastline. Afterwards, he left Africa and moved to Israel and Lebanon, situated in the eastern coastline of the Mediterranean Sea. As soon as he left the African continent, the trail, which he passed, was closed. Sahara became the desert again and the coastline of the Mediterranean Sea dryed out. The process took tens of thousands years; people were imprisoned, and to gain food and roof above a head was increasingly harder then before (Tattersall, Schwartz 2009; Cameron, Groves 2004).

About 90 000–85 000 years ago *Homo sapiens* had another chance to survive – he reached the southern tip of the Arabian Peninsula, Strait of Hormuz and Asia. Subsequently, he moved on along the Indian western coastline, after he turned northward and reached Burma, Thailand and Java. Nevertheless, 71 000 years ago the natural disaster passed and humans almost died out. The volcano Toba situated in Sumatra erupted and the eruption lasted six weeks; the eruptive volume was almost

3000 km^3. The ash spreaded out westward through Asia and shadowed the sun. As a consequence, plants and animals died out and the five-year-old volcanic winter happened; after that at minimum 1000 years the global cooling ensued (just as cool as the Ice Age). The population decreased to only 10 000 individuals. Fortunately, about 50 000–40 000 years ago *Homo sapiens* populated destructed plains again. The species reached Australia (including New Guinea and Tasmania), Himalayas, Near East, Siberia, Bosphorus Strait. North America was settled about 22 000 years ago; and later, people found a way across Mexico to South America. The last area: Scandinavia was colonized by *Homo sapiens* because of the global warming (at the end of the Ice Age). It happened 9 000–10 000 years ago, when glaciers melted and its watter nourished a grass, plants and animals. After a stabilization of climate, continents and oceans acquired its present shape. People lernt various customs and some left their home to find a different way of life (King 2008; Tattersall, Schwartz 2009; Cameron, Groves 2004).

2.4 Emergence of the Neolithic

The emergence of the Neolithic was significant due to its importance for transition from foraging to farming and the origins of domestication. The appearance was associated with the arrival of new people – colonists from the south-east. There are three hypotheses concerning the Neolithic process. The first one, the migration hypotheses, states that in Central Europe the Neolithic came from the first farmers from the Near East and south-eastern Europe. The second one, the acculturation hypotheses, argues that the local hunter-gatherers accepted the Neolithic way of life. And the last integrationist hypotheses talks about the interaction among the indigenous Mesolithic population and the neighbouring Neolithic societies (Bentley *et al*. 2003; Divišová 2012).

The Neolithisation process is described as the transition from hunting and gathering to farming. The process was connected with domestication of wild plants and animals, and the human society had changed. The transition from foraging to farming was the result of immigration of populations from the Near East. Population increased, families expanded, villages grew, and the agricultural way of life spread around the world. The Neolitisation process was not unified (Mesolithic populations played a key role). The process relates with the *Linearbandkeramik* (LBK) bringing a rapid spread of agriculture from southeastern Europe into Central Europe approximately 7500 years ago (Childe 1950; Bentley *et al*. 2003).

The Neolithic transition has been widely studied, and was traditionally considered as the major demographic process in Europe. It is assumed that during this process, local admixture between indigenous hunter-gatherers and the advancing wave of farmers was minimal. Consequently, the current European gene pool was interpreted as consisting mainly of genetic variation originating in Near Eastern Neolithic populations, with only a small contribution from pre-Neolithic Europeans. The archaeological record indicates that the Neolithic transition in Europe was not a single continuous dispersal process from the Near East into Europe, but instead involved a series of punctuated maritime and land movements along coastal routes and major river valleys. On the basis of genetic study of three Neolithic hunter-gatherers and a Neolithic farmer from Scandinavia, it is suggested that the Neolithic farmer was more closely related to modern southern Europeans, whereas the hunter-gatherers were more closely related to modern Northern Europeans (Pinhasi *et al*. 2012).

Table 1: Chronology, subsistence, and geographic distribution of the main archaeological cultures of western Eurasia

Culture	Subsistence	Period	Geography
Middle Paleolithic	Hunter-gatherers	300-30 uncal. ka BP	Western Eurasia
Upper Paleolithic	Hunter-gatherers	50-11,5 uncal. ka BP	Western Eurasia
Mesolithic	Hunter-gatherers	11,5-5,5 cal. ka BP	Western Eurasia
Epipaleolithic	Hunter-gatherers	20-11,5 cal. ka BP	Near East, Anatolia
Pre-Pottery Neolithic	Farmers	11,5-8,3 cal. ka BP	Near East, Anatolia
Pottery Neolithic	Farmers	8,3-7,8 cal. ka BP	Near East, Anatolia
Early Neolithic	Farmers	8,5-6 cal. ka BP	SE/Central Europe
Middle/Late Neolithic	Farmers	6,5-4,5 cal. ka BP	SE/Central Europe

Source: Pinhasi *et al*. 2012, 498

The first farmers of Central Europe originated in the Transdanubia and spread from the western Ukraine to the Rhine River in Germany. The earliest farming settlements in Europe are seen by 6500 BC in Greece, and very soon after in the western Mediterranean (in Central Europe, these settlements appeared around 5500 BC). The new economy (partly based on domestic plants and animals not native to Europe) was the result of an influx of new human population (Childe 1950; Divišová 2012).

During the past several millenia, human societies have undergone major transformations in their social orders. Ten thousand years ago, humans lived in small and mobile groups subsisted on wild plants and animals. Several hunting groups domesticated local plant and animal species to establish a faming way of life. The agriculture was accompanied by greater sedentism and population growth, and the expansion of the farming way of life into new territories through the migration and trade. After some time, these groups became larger and more complex social systems characterised by cities, political states and class inequalities emerged. The Linearbandkeramik brought other new features, including pottery, longhouses and ground-stone adzes. And again, the new way of life expanded throughout territories. With the origins within or near to the Starčevo-Körös culture of the Great Hungarian Plain (5700–5500 cal. BC), Serbia, and Romania, the western expansion of the Early LBK (5500–5375 cal. BC) paused near the Upper Rhine Valley. The Great Hungarian Plain extended in the southern and eastern part of Hungary, in some parts of Slovakia, Serbia, Ukraine, Romania and Croatia. During the Middle LBK (5300–5100 cal. BC), the expansion continued westward into Alsace and the Rhineland. (Bentley *et al*. 2003; Childe 1950; Price *et al*. 2001).

The Linearbandkeramik is regarded as the initial phase of the Neolithic of Central Europe and a classic example of prehistoric migration. The westward expansion of the LBK reached the Rhine and Neckar Valley about 5500 BC. The Upper Rhine Valey is part of large dith approximately 40 km wide, extending from Basel, Switzerland, to Mainz, Germany. The western part of the graben, the Vosges Mountains, is composed mainly of Palaeozoic granites and metamorphic rocks (Price *et al*. 2001).

2.5 Migrations in the Ancient world

2.5.1 Concept of Indo-European origins

There is an assumption that “*Indo-European*“ communities had to exist. *Indo-Europeans* colonized Europe from North India, where their language consecutively evolved in diverse languages as we know them today. Approximately at the same time skillful sailors sailed in the Pacific Ocean, but it is not clear why they set forth (King 2008).

The language can be thought as some kind of cultural DNA, because its roots can be trace back in history for generations (untill a discovery of family ties). For instance, English is related to German, because the English term “uncle“ sounds almost like the German “Onkel“. The relations between the two languages are well preserved in written records; and the whole theory is supported by many archaeological findings: in the early Middle Ages, germanic tribes invaded England, and over time, their language evolved to a form that was different from the German language spoken by people on the continent. Both Germanic dialects eventually became independent and they became different, but still related languages. However, the language tree goes much deeper into history than a few hundred years. After a research, we find out that the most basic concepts and ideas are common to many European languages, which leads to a conclusion that many European and some Indian languages come from the same source (Renfrew 1987; King 2008).

For archaeologists, language is the necessary item for understanding humans. The *Indo-European* languages are generally supposed to owe their affinity to some common descent; this conclusion derives from the idea of a family tree. It is suggested that the language evolution began about 5000 BC; nevertheless, the largest language expansion could take place in the years 4500–2000 BC (King 2008; Mallory 1989).

Many places have been regarded as a homeland of *Indo-European* language: from northern Germany up to western Turkey. Recent researches demonstrated that their origin may be in the northern coastline of the Black Sea and westward of the Caspian Sea, in the Balkan, or in Central Europe. However, it is known where *Indo-Europeans* settled after an arrival. About 5000 BC they could make for westward from their homeland. A majority went past the northern coastline of the Black Sea; however, a part went round the Black Sea from the south, which warrior nation called

Hittites later became. Afterwards, divers continued northward along the Volga River. *Germans* made for northern Europe and settled today's Denmark and Scandinavia. *Illyrians* went round the Black Sea and moved southward to the Balkan: Greece and Albania. *Celts* headed along the Danube River to Western Europe, Iberian Peninsula and British Isles. *Italics* populated the Italien peninsula. About 4000 BC *Indo-Aryans* set out southward around the Near East to India (King 2008; Mallory 1989).

Regarding the concept of *Indo-Europeans* by perspective of the Czech archaeology, Jiří and Evžen Neustupní connected *Indo-Europeans* with the Linear Pottery culture belonging to the Neolithic period. The Neolithic settlement was established by gradual colonization of farmers, who moved into unpopulated places. They tried to improve their social relationships. These first farmers were of *Indo-European* origin, because the continuity of settlement in the wider context of Central Europe lasted during this period (Neustupný, Neustupný 1960).

2.5.2 Lapita people and the western Pacific settlement

About 3300 BC, new people spoken by an Austronesian language set forth from the southern Chinese coastline to Taiwan. These colonists called "Lapita people" consecutively expanded to Philippines and New Guinea. Newcomers passed by the northern coastline and set out to the sea again. They established communities in the Bismarck Archipelago. Afterwards, they temporarily settled down in Melanesia and established there the Lapita culture. The mobility of Lapita has been observed based on pottery production (vessels decorated with geometric ornaments). Around 2800 BC Lapita people moved from the Bismarck Archipelago towards Samoe, Tonga, Vanuatu and New Caledonia (Shaw *et al*. 2009; King 2008).

2.5.3 Ancient Greek origins

As far as Ancient Greece, the ancient Greek culture had a big influence on western languages, philosophy, science, art and politics. The first important civilization of Ancient Greece did not came into being in the continent, but in the island Crete. Greeks were not inhibitants of Crete, but peaceful merchants Minoans did. They settled islands Rhodes and Thera. The Greek population decreased and new waves of migrations began. *Dorians*, one of the most important Greek civilizations, settled the southern Macedonia. It is evident that they moved southward up to Crete, Rhodos and southern Anatolia. *Ionians* originated in Euboea and Attica moved across the Aegean Sea to the western Anatolian coastline. Some settlements were vulnerable regarding attacks of neighbouring nations; therefore, settlers built up defensive walls, and within them the population increased. Thereby, new city states „*poleis*“ were created. Later, *poleis* set up settlements even outside their territories, and it brought the expansion of the Greek culture about. Dorian and Ionian migrations (invasions) are known from ancient Greek epic poet, Homer (Pomeroy 1999; King 2008; Freeman 1996).

2.5.4 Romans and their role in human migration

Romans were people settling Ancient Rome which was probably formed about 8000 BC. Their rule lasted till the 5th–6th centuries AD. The Rome consisted of kingdom, republic, even the empire. At the period of its greatest extent, the Roman Empire, Romans subjugated a large area under control at the time of its greatest expansion. Romans subjugated alien enemy tribes living on the borders of their territory in order to protect the territory. Subsequently, they settled the new conquered territories by loyal migrants from inland. A never-ending process of acquiring new territories developed from this system, because whenever Romans conquered some area and subjugated a local population, new enemies lurked in the borders. Nonetheless, the impuls of the Roman expansion was also a need of the military elite to conquere new territories and gain new victories, which helped to its members in a political career and personal wealth (King 2008).

In 510 BC, the Roman Republic was established, when the local population got rid of the Etruscan hegemony. In the conquered territories, Romans founded colonies and built roads to link Rome with other significant places. In the 3rd century, Romans extended their influence to the very southern tip of the Italian Peninsula. In this century, Romans owned colonies (especially military colonies) also out of Italy, when colonialists were tax-exempted and had a right to, if they wanted, return to Rome and settle there (Freeman 1996).

To see the importance of the Roman Empire, I quote a couple of conquered areas: Britain, Hispania, Gallia Narbonensis (Narbonensian Gaul), Gallia Cisalpina (Cisalpine Gaul), Italy, Dalmatia, Macedonia, Thrace, Achaea, Dacia, Mauritania, North

Africa, Cyrenaica, Arabia, Asia. The boom of the empire had lasted especially in the period 510 BC–117 AD, thus from the establishment of the Roman Republic to the end of Trajan's reign (King 2008, Freeman 1996).

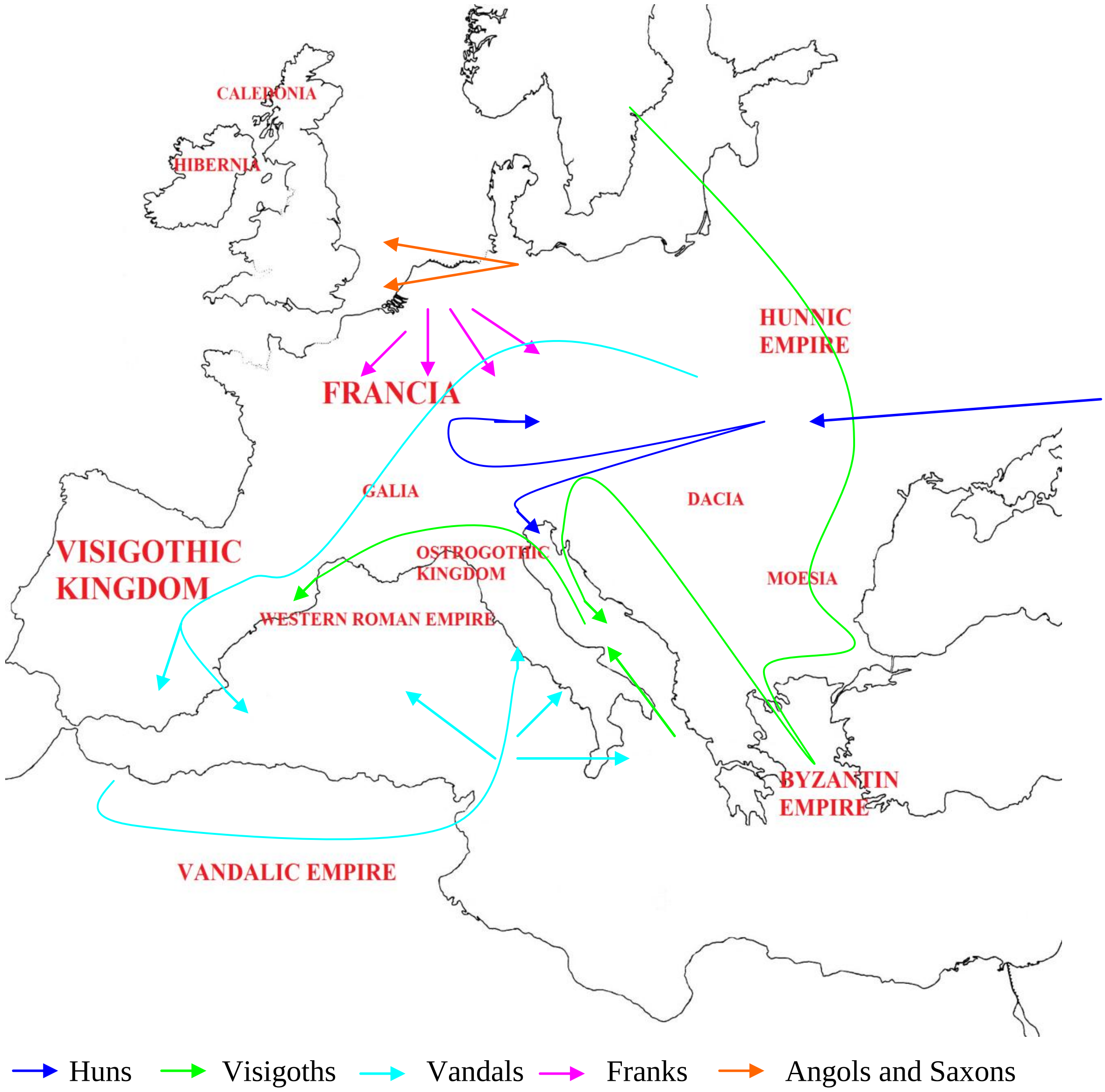
2.6 Migrations in the Middle Ages

The migrations in the medieval period were a consequence of unstability and violence after a fall of the Roman Empire. Most migrants were invaders, and wars caused mass transfers of populations. At the end of the 4th century, Asian and Germanic tribes began to force each other out; they moved through the eastern steppe westward and fetched the Roman imperium up. Consequently, by means of raids, settlement and diplomacy Islam began to expand. At the end of the 8th century, a new wave of migrants emerged: *Vikings*, who set to the high sea out and fetched North America up. In the east, Scandinavian navigators *Vikings* reached Kiev (later conquered by the last wave of Asian invaders "*Mongols*") and the Byzantine Empire (King 2008; Craughwell 1956).

2.6.1 Barbarian invasions in the Migration period

As stated above, about the 4th century Asian and Germanic tribes fetched the Roman imperium up. Its boundaries had not changed for 200 years. The empire was bounded: in the north by the Rhine and Danube rivers and Hadrian's Wall; in the east by the Persian Empire; in the south by the whole coastline of North Africa; and in the west by Galilee and Iberia (King 2008, Craughwell 1956).

The following map best shows the whole process of the Barbarian movement and expansion.



Map 1: The barbarian expansion in the migration period. Source: King 2008, 56-57

Huns, nomads from Asia, moved towards Central Asia, from there they continued westward. In the year 370, Huns defeated Ostrogoths and forced them to leave westward to the territory of Visigoths. They attacked Italy and moved to Francia. *Visigoths*, inhabitants of Hispania, moved from the Baltic Sea southward, crossed the Danube River, and settled in the Roman Empire. *Vandals*, East Germanic tribe, moved from Hunnic Empire westward to Francia and through Hispania they got to Vandalic Empire (Africa), where they established the city Carthage; and in the year 455, they penetrated to Rome. *Franks*, West Germanic tribe, originated in the North Sea gradually broadened their territory southward and eastward. *Angols and Saxons* moved from the North Sea to the southern and eastern parts of Great Britain, where they began to settle (from the year 450) (King 2008; Craughwell 1956).

2.6.2 Vikings and their invasion

At the late 8th century Vikings set forth to maraud coasts of foreign countries and cloisters (mainly British). Reasons could be following: a shortage of agricultural land, a European trade, social changes, etc. Scandinavia is considered as a Viking homeland. The expansion caused the establishment of Scandinavian settlements in northwestern Europe. In its western part, where nowadays Norway is situated, the coastline is jagged, and there was a homeland of Norwegian Vikings. The eastern part (today's Sweden) was a homeland of *Varangians*, the southern part of the Danish (King 2008; Craughwell 1956).

As it follows from King's (2008, 68-69) map, the Viking invasion could by divided into two directions: through Western Europe to the Mediterranean Sea and eastward, and across the Atlantic Ocean. The firt mentioned direction includes Rusia, British Isles, Jutland, Friesland, France, Spain, Italy, Byzantine Empire and Egypt. The second direction includes Dublin, Shetland, Faroe Islands, Iceland, Greenland, Markland (Canada) and Vinland (North America) (King 2008).

The Vikings moved to many conquered areas during the Viking Age, i.e., they settled new territories. The Viking setllements (also burials) are known, for example, from Dublin in Ireland (Knudson et al. 2012), Sebbersund in Denmark (Price *et al*. 2012), Kaupand in Norway (Skre 2007), and many others.

2.7 Expanding world and discovery of the "New World"

In the 15th century, a dicrovery of America caused a new wave of migration, which went down in the American history. In 1492, an explorer Christopher Columbus set out on voyage from Spain westward across the Atlantic Ocean, where, as he hoped, find a free trade route to India. After 61 days spent on the sea Columbus landed in Bahamas. He was convinced that he reached the eastern Indian coast. Indeed, he discovered the American continent and many migrants imitiated his journey (Romanus 2001; Janáček 2003).

Explorers following in the footsteps of Columbus set out to the new lands in the West beacuse of the avarice, desire for adventure, trade, missions, etc. These explorers were mainly from Spain, Portugal, England, France, and also Vikings. Numerous of them departed for the North and South America in searching of gold, which was found in abundance there. But later, many people from the whole Europe, who realised that in the so called "New World", it was possible to find a better way of life (earn more money), incsreased. The most lucrative way was a trade with slaves lasting nearly 400 years, during which countless Africans were transported into North and South America and Caribbean. New colonies began to be established and they were under the British administration (King 2008; Janáček 2003).

2.8 The 18th and 19th centuries and the importance of industrialization

In the 18th and 19th century, at the time of industrialisation and colonialism, the mass population movements happened. New machines invented during the Industrial Revolution led to the outflow of labourers from the countryside and the rapid population growth in large and crowded cities. The urbanisation began in England in the end of the 18th century, soon after the entire world followed her. Further, a migration to the West with the aim to settle new American states took place. Trucks, the long march of Mormon pioneers and the influx into California within the period „Gold Rush" – these all have to do with imperial America. Meanwhile, in Europe, new empires created in other continents formed, and some Europeans decided to serve as colonial officials in Asia and Africa, where they lived in a voluntary exile. In Europe, a mass human movement occured at the end of World War II (Allen 2009; King 2008).

2.9 Migrations in modern world

The migration in the second half of the 20th century had its own specifics depend on the political development in the world. Within this period, huge displacement of people came to pass. After the end of the World War II, countless Soviet citizens, who were marked as the enemies of state and deported to gulags (work camps in Siberia and other parts of the Soviet Union), were arrested. Stalin introduced the practice of transfer of entire ethnic groups during the wartime; thereby he suppressed whichever nacionalist or anti-Soviet ideologies. Unfortunately, in the 40’s of the 20th century, the Jewish population ended up in the camps even more ferful than the Soviet ones. Millions of people died in Nazi concentration camps. For people who survived the origin of an independent state Israel in 1948 meant a fact that in the world exists a Jewish homeland, where it is possible to refuge. At the end of the 40’s of the 20th century, India and newly created Pakistan gained independence, and a large population exchange between these areas passed. In the last decades of the 20th century, much of the global migration was voluntary. Inexpensive travelling, open borders and economic equality among nations contributed to the fact, that the migration is nowadays easier and more desired than whenever before in the history of humans (King 2008; Krupp 2013; Filipec 1966).

3 Isotopic studies of human migrations

It is important to make a query: Which way of method tells us the most about the human migration? I focus on the stable isotope analysis, especially on the strontium signals in human bones, because strontium signal could be the credible indicator of migration. Nevertheless, as a student of archaeology I have to also mention another way of a detection of human migration – on the basis of the study of material culture.

“The whole subject of prehistoric archaeology depends upon the observation that there is patterning in the archaeological record of the past. To say this, of course, is to make the very simple observation that human communities at a specific time and place have their own way of life, which is related to the technological abilities available then. This way of life is reflected in the artefacts, the house remains, the monuments and all the other aspects of material culture which the archaeologist finds“ (Renfrew 1987, 23).

There was significant spatial patterning as well as temporal patterning; and at a given time different assemblages of equipment (e.g., different kinds of pottery) were consistently found in adjacent areas. However, one assemblage of equipment could be ascribed to settled farmers, another perhaps to mobile nomadic groups. The etnic groups are closely connected to the study of material culture; and, for example, the language, art style, and way of life is hanging together with the ethnic groups as well as the material culture. Earlier archaeologists saw that prehistory in terms of migrating tribes of people, whose movements would explain the changes in the material culture which may be observed in different areas (Renfrew 1987).

And now, the decription of the aforementioned method, stable isotope analysis, and subsequently the strontium isotope analysis reflecting the best the human migration closes in.

3.1 Stable isotopes

According to Cabicar (1983, 13-14), in 1910 Frederick Soddy pronounced that there are elements with identical chemical properties at different atomic weight and radioactive behavior; and he designated them “*isotopes*“. In 1912, Joseph John Thompson gave evidence of the existence of isotopes also at nonradioactive elements based the analysis of an ionic behavior in magnetic and electric fileds on. He measured a deflection of streams of neon ions, and he found different results out. Otto Hönigschmid detected a diversity of atomic weights of plumbum acquired from uranium and thorium ores. In subsequent years, Francis William Aston and Arthur Jeffrey Dempster proved an existence of stable isotopes at many other elements by means of a mass spectometer. Frederick Lindeman gave reasons for some physical-chemical differences in isotopic properties. The classical isotopic definition was patterned only on experiments with heavy metals, when the diversity is too low. However, the research of an isotopic behavior of light metals confirmed Lindeman’s conclusions (Cabicar 1983).

As for an isotopic definiton, “isotopes“ (a.k.a. “nuclides“) are atoms with the same number of protons and electrons but differing numbers of neutrons (Michener, Lajtha 2007).

Therefore, one element may concern a mixture of severel isotopes, ussualy in range 1-4. Isotopes of the identical element mutually differ by the relative atomic mass and affect a final relative mass of an element. In nature, there are roughly 329 isotopes, therefrom 273 stable isotopes and 58 radioactive isotopes. One element may comprise both stable isotopes and radioisotopes, at which a half-life is known. We are able to find out and measure small differences concerning an isotopic content occurring in nature. These differences depend on material origins, through them isotopes enter chemical reactions. Different conditions within these ractions may cause measurable changes in the isotopic composition of stable isotopes of elements; and consequnetly these changes bring favourable informations of many processes (Kovačiková, Brůžek 2008a; Cabicar 1983).

Regarding an isotopic cycle in nature, differences in an isotopic structure are influenced by global geochemical proccesses, such as nitrogen cycle, photosynthesis etc. The isotopic differences between various materials (e.g., leaves, minerals, seawater) are too small; and therefore, an isotopic composition is reported relative to an internationally accepted standard and expressed in parts per thousand deviations from that standard by:

- δ (‰) = $[(R_{sample}/R_{standard} - 1)] * 1000$
- Where R is the ratio of heavy-light isotope (Michener, Lajtha 2007).

The concentration of isotopes deposited during a life in human and animal bones and teeth shows further informations about the climate, as well as the organism position in food chains. An isotopic content adverts to credible datas about a former diet. An isotopic profile also shows informations about migration of humans and herds, lenght of nursing and demography (Kovačiková, Brůžek 2008a; Michener, Lajtha 2007).

3.1.1 Stable isotope analysis

As stated above, the stable isotope analysis brings credible informations about climate, former diet, migration, lenght of nursing, demography, etc. Stable isotopes get to organism through a diet (solid nourishment and liquids), and are consecutively incorporated into bone and tooth tissues. The most important applied isotopes are primarily: $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{87}Sr/^{86}Sr$, $^{18}O/^{16}O$, and $^{34}S/^{32}S$. Their natural sources are atmosphere, water and geological substrate, whence they enter plant and animal bodies, and partake in their tissue structure (Kovačiková, Brůžek 2008a; Michener, Lajtha 2007; Procházka 2006).

Isotopic methods are based on: differences in specific nuclear properties of stable isotopes and differences in their physical-chemical properties. Stable isotope analysis is applied in technics (e.g., nuclear technics), analytical chemistry, physics, physical chemistry, geology, cosmochemistry and biology. The application includes two fields of study: a field, where a given isotope serves as an initial material because of its specific characteristics; and a field of usage of stable isotopes in a tracer technique and its special modification, i.e., an isotope dilution analysis (Cabicar 1983; Michener, Lajtha 2007; Fry 2006).

3.1.2 How isotopes are measured

There are four required resources to use stable isotopes: labeled compounds, the protocol for isotope administration and sample recovery, the ability to prepare samples for isotopic analysis and the equipment for isotopic measurements (Klein *et al*. 1986).

Types of labeled compounds. Regarding metabolic studies, there are three categories of labeled compounds. First, use may be made of nutrients naturally enriched (e.g., sorghum, corn, sugarcane) or depleted (e.g., soybeans, wheat, temperate or cool-sea-son grass) in ^{13}C. However, these components must form a substantial portion of the diet, i.e., >50 %. Second, highly enriched nutrient precursors (>99 %), such as water, carbonate, nitrate, or ammonia can be incorporated directly into the diet. The third, an usage of specifically labeled substrates, such as $^{15}N_2$-urea, 1-^{13}C-propionic acid, $^{15}N_2$-lysine, or 6,6-^{2} H_2 glucose. These compounds are prepared by organic synthesis from the primary isotope forms (Klein *et al*. 1986).

Isotope administration and sample recovery. The particular circumstances of each study determine the best mode of introduction of labeled compounds. The choice must be made as to the interval at which sampling is necessary – minute, hourly, or daily. It is prefarable to collect more samples than less because of values (Klein *et al*. 1986).

Preparation of samples for measurement of isotopic content. Because stable isotopes do not emit externally detectable radiation, their measurement requires to be separated according to mass, by magnetic or electric field, and numbers of light, when heavy atoms or molecules must be determined. An isotope abundance and an increase above the natural ratio indicate the presence of added tracer. The separation process operates on charged gas moleculas moving within a high vacuum environment. Also preparation methods depend upon the isotopic species. At first, a preparatory phase occurs in laboratory. The sample is cleaned via abrasive needle with diamond surface, and subsequently adjusted in a subsequent of several days chemical phase (Klein *et al*. 1986; Kovačiková, Brůžek 2008a).

Stable isotopes ratios are mostly measured via a technique called "*Isotope mass spectrometry* (IRMS)", which was invented by Joseph John Thompson in 1910. A mass spectrometer is an instrument that separates charged atoms or molecules on the basis of their mass-to-charge-ratio. There are two basic types of IRMS. The first one is *dual-inlet* (DI-IRMS), where a precision for its use is higher. And the second one is *continuous flow* (CF-IRMS), which allows to introduce multiple component samples, such as soil, leaves and atmospheric air; and obtain isotopic datas for individual elements or compounds within the mixture. There are four components of isotope ration mass spectrometry: inlet system, ion source, mass analyzer, and ion detector. Semples are introduced to the mass spectometer via the inlet system as a gas, where capillary tubes are used to assure there is no isotope separation (fractionation) during introduction of gases into the mass spectrometer. In the ion source, electrons are released under high vacuum, where wire rhenium, tungsten or thoriated iridium is electrically heated.

The beam acquired from the ion source, enters the mass analyzer. Ionized masses are taken and separated on the basis of charge to mass ratios, and output to the detector, where they are detected and subsequently converted to a digital output. A quantity of studied isotope (δ) is expressed in per mille, and it is imporat to know its ratio in standard (see above). It is important because changes of isotope ratio are minimal, and their relative change is expressed. Because at the end of procedure the sample taken from collagen or hydroxyapatite from bones and teeth is irrecoverably lost, the stable isotope analysis is a destructive method (Kovačiková, Brůžek 2008a; Procházka 2006; Michener, Lajtha 2007; Cabicar 1983; Fry 2006; Košler *et al*. 1997).

3.1.3 Isotope fractionation

A different behavior of stable isotopes of the same element in different biochemical processes leads to enrichment or depletion of plant, animal and human tissues via a heavier isotope of a relevant element, which is more or less successfully used to access the origin of various organisms. For example, plants contain less ^{13}C than an atmospheric carbon dioxide because of heavier $^{13}CO_2$ behaves another way than lighter $^{12}CO_2$ during diffusion and enzymatic reactions. In terms of food chains, another enrichment or depletion occur, so called *isotope fractionation*, by the simple formula:

- $\delta X_t = \delta X_p + \Delta\delta_{pt}$
- Where *X* is the element that interests us, *t* studied tissue, *p* diet, and $\Delta\delta_{pt}$ factor of isotope fractionation between diet and studied tissue.

The isotope fractionation factor indicates how much the isotopic composition of a tissue differs from the isotopic composition of a diet. Within the framework of migration studies (as well diet studies), there are two basic principles of the application of stable isotope measurements. The first one: factors of isotope fractionation may be specific for a given tissue, and must be experimentally determined. And the second one: at metabolically active tissues (e.g., blood) the connection depends on the rate of a modification of a given tissue. The interpretation of the isotopic composition of tissues may be complicated by the fact that individual components of a diet (e.g., carbohydrates, proteins) incorporate into tissues via specific processes; and studied tissues can not reflect the isotopic composition as whole but nutritional components, from which they were synthesized (Procházka 2006, Gannes *et al*. 1997).

3.1.4 Selection of a suitable tissue

The right selection of tissues is of essential importance for an effective study of human migration. In the process of the selection of studied tissues, it is necessary to take into account: the isotope fractioanation in terms of a tissue providing informations about the isotopic composition of sources, the isotopic composition of sources, the rate of changes of isotope ratios in a given tissue, and the nondestructiveness of sampling. During the selection of tissues, it is possible to choose between metabolically active and metabolically inert tissues. When we choose several different tissues with a different period of an integration of geographic informations, we can get datas, from which it is possible to reconstruct the history of a movement of individuals throughout seasons. Metabolically active tissues carry flexible informations about their origin, and their reach into the past depends on the rate of transformation of a given tissue. At tissues with a rapid metabolism informations are short-term, because the half-exchange of elements is three days. Muscles and blood are characterized by a slower transformation. Now, I will discuss teeth and bones, where a bone collagen has a very slow rate of transformation and preserves informations for several years (Procházka 2006).

3.1.5 Chemical properties of bones, their preservation, and effects of diagenetic processes

The link between skeletal composition and place of residence is necessary in the studies of the human migration. The bones and teeth belong to the hardest tissues in the human body (Budd *et al*. 2004).

The bone consists of cells and extracellular matrix, when the bone contains two fractions – minearal (70 %) and organic (30 %). The compact bone tissue of adult humans consists of 55–60 % of tricalcium phosphate with the formula $Ca_{10}(PO_4)_6(OH)_2$. In mineral component, there are also trace elements, such as strontium (and many others). For instance, the bone mineral contains 99,1 % of strontium from its total quantity in the human body. As for an organic fraction, it is represented by collagen (protein insoluble in water and strongly bound to the mineral component of bone), proteins having a higher content of amino acids of proline and hydroxyproline, and fats and mucopolysaccharides. Bones completely transforms the organic components approximately every 6–10 years, thus it represents the last years of life of adult individuals. Growth is affected by various factors, such as genetic influences, growth hormone deficiencies and psychological stress (Kovačiková, Brůžek 2008a; Stloukal 1999; Larsen 1997).

The tooth is composed of three hard tissues – dental cement covering the surface of root and neck (the representation of inorganic substances in bone approximately corresponds to bones), dentine forming the main mass of teeth, and enamel covering the surface of crown. The enamel is not remodelled so that its composition is reliable indicator of childhood exposure. Although most of the permanent dentition is formed in childhood from three to four months after birth until about twelve or more years of age. The strontium isotopic content obtained during the growth and formation of dentition remains in dental tissued preserved throughout individual's life. Therefore, teeth are particularly advantagenous for study of the human migration (Budd *et al*. 2004; Stloukal 1999).

Effects of diagenetic processes play a key role in determining the human migration. It bears on physical, chemical and biological factors on bone during its storage in the soil. Both the organic and inorganic components of bones are affected by these processes, when the chemical composition may change. The diagenetic processes include, for example, the chemical reactivity of bone tissues, environmental conditions, pH, composition of surrounding soil, pressure, temperature, humidity, geographical location and on and on. The postmortem changes of the bone chemical composition cause also internal factors – spontaneous recrystallization and proteine hydrolyzate. In conclusion, the teeth are generally better preserved than the bones, and skeletons of adults better than children ones (Stloukal 1999; Price *et al*. 2004).

3.2 Application of stable isotopes in migrational studies

As far as the determination of a diet via stable isotope analysis, the first use dates back to the 70th and 80th of 20th century. Their usage to determine migration and residential mobility is about ten years younger; first publications have been occured not before recently in the Czech Republic. The pioneer of the study of the chemical composition of skeletal remains in the Czech Republic is Václav Smrčka from Medical Faculty of Charles University in Prague. He was for several decades devote himself to surgery, relationship of content of trace elements in skeletal remains, and nutrition of historical populations (Kovačiková, Brůžek 2008a).

Archaeologists and anthropologists use the chemical analyses of stable isotopes from skeletal remains, and these analyses are focused on the mineral component of teeth and bones. However, during diagenesis of bone tissue its mineral component is subjected to the environment, in which bones are saved. Afterwards, a bone contamination by trace elements from the environment occurs, and thus analysis results are unreliable and predictive value is insufficient. Stable isotopes studied in the organic bone component (collagen) are more resistant to post-depositional transformations, and therefore, they are preferred (Smrčka 2005).

Concerning the migration itself, each geographic area has its own specific geochemical characteristics corresponding with the stable isotope content of various elements incorporated in rocks. They get into soil and water via weathering; and afterwards, they get into plant food at typical ratio of a specific area. The migration study is based on the fact that tooth and dental tissues differ in terms of remodeling. A dental mineralization occurs in early stages of ontogenesis, i.e., within first years of human life. The stable isotope content acquired during growth and formation of dentition is observed in dental tissues throughout life. In comparison with teeth, a skeleton preserves an isotopic profile corresponding to the last years of life. If there is some difference in stable isotope ratio between area, where individuals were born, and area, where they died, it is possible to speculate about migration (Kovačiková, Brůžek 2008a; Price *et al*. 2002).

The main goal of most migration studies based on stable isotopes is to find out, which way populations were moving, and where they settled down. The most relevant is to: choose a suitable tissue, determine the isotopic composition of researched tissue from a representative sample of populations, and deduce the geographic origin of populations on the basis of similarities in the isotopic composition with populations of known origin. It is supposed that all individuals in given site have similar ratios of stable isotopes. However, this thesis is not always truthful. The great variability between individuals can be expected in cases, where individuals differ in a diet composition, places of gathering of food, or metabolism. And then, it is necessary to know metabolic processes associated with the growth of studied tissues, and differences in the isotopic composition of individual tissues even between parts of the same tissue and between individuals (Procházka 2006).

Geographical and year-on-year variability of climatic conditions may complicate the interpretation of results of isotopic studies. While we are relatively well informed about a distribution of average values $\delta^{18}O$ and δD in precipitation, differences are insufficiently known in areas or periods with the minimum of precipitation. Likewise, differences in a composition of parent material and soil heterogeneity may affect values $\delta^{15}N$ and $\delta^{87}Sr$ (Procházka 2006).

It is possible to divide stable isotopes used in migation studies, according to their atomic weight, into two groups: isotopes of light elements (e.g., carbon, hydrogen, nitrogen, oxygen, sulfur) and isotopes of heavy elements (e.g., plumbum, strontium). In nature, a distribution of stable isotopes of light elements is affected by both biochemical (e.g., nitrogen fixation in plants) and biogeochemical processes; while ratios of isotopes of heavy elements are affected mainly by biogeochemical processes. Ratios of stable isotopes of some elements are conditioned locally (biome, climate), other by a geological bedrock or by a distribution of precipitation in a continental scale. Unfortunately, the human activity may influence the natural occurrence of stable isotopes, such as nitrogenous fertilizers, exhaust gas, etc. (Kovačiková, Brůžek 2008a; Procházka 2006).

The research of migrations of historical populations is closely connected with the study of their food resources. Human migrations can be investigated on the basis of changes of food sources revealed via the isotopic analysis of carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), oxygen ($\delta^{18}O$), and sulfur ($\delta^{34}S$). The use of the element strontium is the most suitable for the study of the human migration, because strontium is not almost subject to diagenesis (Smrčka 2005).

In following subchapters, I cite above mentioned stable isotopes concerning migration studies. I quote strontium isotopes in separate chapter, because as I wrote above, the importance of strontium isotopes for determination of the human migration is immense.

3.2.1 Carbon isotopes

The first stable isotope connected to migration studies is carbon. The isotope ^{13}C content can be determined from collagen (a soft protein tissue found in human bones) and bioapatite (a calcium phosphate, the major component of the mineralised part in mammalian bones). $\delta^{13}C$ values are frequently negative numbers in the range from -

30 to -10 ‰. Values depend not only on the position of organisms in the food chain, but ecological factors (Kovačiková, Brůžek 2008a).

Concerning the photosynthesis, plants contain less ^{13}C than the atmospheric CO_2. Therefore, they are depleted of ^{13}C relative to the atmosphere; it is caused by physical and enzymatic processes, which discriminate against ^{13}C in favor of ^{12}C. Discrimination varies among plants using different photosynthetic pathways: C3 (Calvine cycle), C4 (Hatch-Slack cycle), and CAM (Crassulacean acid metabolism). The C3 pathway begins by the diffusion of CO_2 from the atmosphere into air-filled spaces within the leaf. That occurs through the still air occupying stomatal pores. C3 photosynthesis is catalyzed by a carboxylating enzyme rubilose bisphophate carboxylase/oxygenase (rubisco). $\delta^{13}C$ values for C3 plants reach the average from -23 to -34 ‰. C3 plants include most trees and shrubs, some cereals, grasses, etc., i.e., most of plants of the temperate zone. The C4 pathway is the same (the diffusion of CO_2 from the atmosphere into the leaf via stomata); however, C4 photosynthesis is catalyzed by a different enzyme: phosphoeonolpyruvate carboxylase (PEP) having a different discrimination. $\delta^{13}C$ values for C4 plants range from -9 to -17 ‰. The advantage of C4 plants is that they are able to multiply involve CO_2 arising during metabolism in photosynthetic reaction. They include plants of in the long term drier environment, e.g., maize, millet, sorghum, pineapple, sugarcane. CAM photosynthetic pathway is based on the same carboxylating enzymes as C4 plants. Nevertheless, they segregate enzyme activities between night and day. Because they are desert plants, the stomata in leaves remain shut during the day, but open at night to collect CO_2. Their $\delta^{13}C$ values range around -11 ‰ (Michener, Lajtha 2007; Ehleringer, Osmond 1989).

Marine plants contain more ^{13}C than land plants. When animals and humans eat plants, or other animals, their ratio of ^{12}C to ^{13}C is altered after the material is taken up by different kinds of tissues. The carbon isotopic content of collagen can indicate whether (in the course of a lifetime) an individual was in a food chain based mainly on C3 or C4 plants, or on land or marine foods, or a combination of these (Bahn 2002).

3.2.2 Nitrogen isotopes

Another important element for identification human migration is nitrogen. The $\delta^{15}N$ ratio depends primarily on its origin. There are different values; for example, some values differ during nitrogen uptake from soil nitrates arising by an oxidation of ammonium nitrogen (degradation of proteins), other differ when a symbiotic bacteria is involved. According to $\delta^{15}N$ values, it is possible to clearly identify the trophic level of organisms, as in the body of each living organism nitrogen is bound in proteins and amino acids (98 %), nucleic acids and urea. And so it is possible to determine its position in the food chain, where in general, $\delta^{15}N$ values increase by 2–3 ‰ in each stage of the food pyramid. If plants contain about 3 ‰ of ^{15}N, herbivores eating these plants reach 6 ‰ and carnivores 9–10 ‰. Higher $\delta^{15}N$ values can indicate costumers, whose protein source became freshwater or saltwater fishes; then $\delta^{15}N$ values range between 15–20 ‰. For example, the breast milk has a higher $\delta^{15}N$ content; thereby, it is possible to determine the age of a weaning and the transition on a different diet. It is demonstrated by a decline of $\delta^{15}N$ values (Kovačiková, Brůžek 2008a; Bahn 2002).

Subsequently, we can discover, whether juveniles were nourished by the breast milk, and for how long. Furthermore, the $\delta^{13}C/\delta^{15}N$ ratio shows informations about a position of individuals in the trophic chain and their diet, a planting and breeding production, a self-sufficiency to get food sources etc. (Kovačiková, Brůžek 2008a; Michener, Lajtha 2007).

3.2.3 Oxygen isotopes

Oxygen is another siutable element in determining human migration. Oxygen occurs in three isotopes: ^{16}O, ^{17}O, and ^{18}O, when ^{18}O is mostly used to monitor physiological changes of living organisms. Oxygen isotopes included in water, atmosphere and diet, are incorporated through the water in the body into the bone or tooth mineral on the basis of carbonate (CO_3^{-2}) and phosphate (PO_4^{-3}) ions during their formation. There are climatic and geographic differences causing dissimilarities of $\delta^{18}O$ values (influenced mainly by an amount of local precipitations and fluctuation of annual temperature). ^{18}O isotopes can reflect the way of farming and its abnormalities, such as uncharacteristic pastoral food sources. The highest $\delta^{18}O$ values occur in warmer months, the lowest in colder months. Bioapatite of tooth enamel reliably records seasonal changes by the moment of ending of a molar growth (Kovačiková, Brůžek 2008a).

3.2.4 Sulfur isotopes

Sulfur content brings informations about migrations of historical populations. In nature, sulfur occurs in four isotopes: ^{32}S (95 %), ^{33}S (0,76 %), ^{34}S (4,22 %) and ^{36}S (0,014 %). Sulfur is a complemetary analysis that determines carbon and nitrogen ratio obtained from collagen. Sulfur also brings informations about diet based on terrestrial, freshwater and marine sources. However, stable isotopes of sulfur are more suitable to obtain informations about animal diet and movement than those of human (Kovačiková, Brůžek 2008a).

3.3 Strontium studies in bioarchaeology

And now let's introduce another suitable element for pursuing the human migration: strontium. From my point of view, strontium is the most applicable element to determine the human (also animal) migration because of ability to analyze human migration based on local or regional concept; and this is the reason, why I focuse on strontium isotopes.

3.3.1 Chemical properties and occurence of strontium isotopes

Strontium belongs to alkaline soils and has a conciderable affinity to calcium engaged in many mineral specieses, e.g., plagioclases, apatite, carbonates etc. Strontium is formed by four natural isotopes: ^{84}Sr (0,56 %), ^{86}Sr (9,86 %), ^{87}Sr (7,0 %) and ^{88}Sr (82,58 %). Strontium isotope ratios are variable in time, which is influenced by the formation of radiogenic ^{87}Sr at the expanse of radioactive ^{87}Rb (its half-life is circa $4,7 \times 10^{10}$ years). Therefore, the strontium composition is dependent on the Rb/Sr ratio in geological material and on the time. The rubidium content, even as the Rb/Sr ratio varies in diverse minerals containing Rb; consequently, the ^{87}Sr amount is variable, too (Košler *et al*. 1997).

Table 2: Atomic weight and natural abundance of strontium stable isotopes

Isotopes	Atomic weight	Natural abundance
^{84}Sr	83,91325	0,56
^{86}Sr	85,90935	9,86
^{87}Sr	86,90899	7,02
^{88}Sr	87,90601	82,56

Source: Cabicar 1983, 272

Because isotopic ratios can be measured more accurately and easily than the absolute amount of individual isotopes, stable isotope ^{86}Sr is frequently used to the normalisation of other strontium isotopes, such as ^{87}Sr. Accordingly, variations of the strontium isotope content in natural materials are expressed by $^{87}Sr/^{86}Sr$ ratio corresponding approximately to the geological age of the substrate. This ratio is mostly in the range from 0.700 to 0.750. In rocks, the ^{87}Sr content depends on how much ^{87}Rb there was originally engaged, and on the rock age. Older rocks with high initial Rb/Sr ratios (e.g., continental granites) have the highest $^{87}Sr/^{86}Sr$ ratios – around 0.710; whereas younger rocks or rocks with low Rb concentrations (e.g., limestones, basalts) have lower ratios – about 0.704. Soil $^{87}Sr/^{86}Sr$ ratios are controlled by bedrock and by atmospheric deposition of strontium, such as dust and precipitation. Plants have $^{87}Sr/^{86}Sr$ ratios correspondent those of the soluble or available strontium in soils. Because of differences in the rooting depth, and the isotopic composition within soil weathering profiles; different plants within an ecosystem may have different $^{87}Sr/^{86}Sr$ ratios. Strontium concentrations are much lower in freshwater than in seawater, so $^{87}Sr/^{86}Sr$ ratios of estuarine waters are quickly dominated by marine inputs (Košler *et al*. 1997; Kovačiková, Brůžek 2008a; Michener, Lajtha 2007).

Regarding the strontium incorporation, strontium moves from substrate to water resources, and subsequently, is incorporated into plants, animals and living organisms. It is possible to pronounce, that if there is a difference of strontium isotope content between the area, where individuals were living at the time of teeth mineralization, and the area, where they died, there may be a change of place, migration, movement, or relocation in geographical term (Kovačiková, Brůžek 2008a).

The monitoring of the $^{87}Sr/^{86}Sr$ ratio is complicated by recent anthropogenic interventions into the environment and ignorance of the local isotopic signal. The local isotopic signature can be determined by analyzing of the local fauna skeletal samples of the same age. However, if the gradient of the $^{87}Sr/^{86}Sr$ ratio is missing, the mobility cannot be observed. The movement can be pursued only between areas with different isotopic signature (Kovačiková, Brůžek 2008a).

3.3.2 Application of strontium isotopes

Strontium is the most credible indicator of the human mobility gained from bone mineral and tooth enamel. Strontium isotope data can be used to study mobility as well as marine vs. terrestrial vs. freshwater foraging, and diet if there are persistent strontium isotope differences among local plant types. Strontium isotopes can be also used to characterize hydrothermal fluid sources, and to distinguish between phosphorite and carbonatite origin of phosphate fertilizers. Several studies have shown significant differences between the stroncium isotopic composition of natural groundwater and human inputs (Michener, Lajtha 2007; Žák, Dobeš 1991).

As stated earlier, the bone mineral contents 99,1 % of strontium from its total quantity in the human body. Strontium, just as calcium, incoroporates into organism particularly during growth. In prenatal period, children have the same bone composition as their mothers (adults weighing 70 kg have approximately 0,32 g of strontium). Natural strontium does not represent fundamental problem to humans; however, the problem arises after an occurence of ^{90}Sr in nature. The strontium analysis can determine the representation of plant food; animal food is composed of very low amount of strontium, because strontium accumulates in skeletals. Therefrom results, that higher strontium values reflect a higher intake of plant food, and lower values reflect a higher intake of animal food (the strontium content in bones of hunters and gatherers was lower than in bones of agricultural populations). There are two cautions regarding the strontium content: (1) the strontium content varies in the age of individuals – newborns have lower strontium values, adults higher; (2) kind of a diet is important – for example, sea shellfish increases strontium values (Smrčka 2005).

3.4 The most favorable areas for studying migration and results from strontium isotopic studies

Geological conditions are especially suitable to study residential and other mobility in some areas. These areas may include, for example, Rhine valley in Western Europe, Yucatán peninsula in southeastern Mexico, South America, Bavaria, and the Nile Valley in Egypt. The geographic map of strontium for the Czech Republic is probably absent; and because of the absence local standards from archaeozoological material must be determined. Nevertheless, Vedrovice LBK cemetery in southern Moravia may be considered as a single proof of the migration in the Czech Republic (Smrčka *et al*. 2008; Kovačiková, Brůžek 2008b).

In my thesis, I use several strontium isotopic studies to describe their relevancy in question of prehistoric and historical human migrations. I focuse on studies from Africa, Asia, Western Pacific, America, Southern and Southestern Europe, Western Europe, and Northern Europe. However, my point of interest is Central Europe, where strontium studies are particularly remarkable.

3.4.1 Results from strontium isotopic studies from Africa, Asia, Western Pacific and America

The migration in the Nile valley in Ancient Egypt is probably the most researched migration of historical populations. Migrations of humans and relations among Egypt and Nubia were confirmed, and they were long-term and full of mutual interaction, for example, trade, diplomacy, and military (Kovačiková, Brůžek 2008b).

Mobility chronologically from Late Acacus to Garamantian phase (9000 BC–first centuries AD) was investigated in the prehistoric Sahara, where the strontium isotope analysis of Holocene human skeletons from prehistoric burials of the Fezzan (Acacus Mts., Southwestern Libya) was used. The analysis of Sr isotopes in dental enamel of human skeletons was investigated with the aim to find out how mobility patterns changed with the emergence of the desert. A total of 35 individuals from 7 sites could be sampled for dental enamel. Among them, seven adults were selected for bone (usually a rib). Of the 35 individuals sampled for enamel, 27 gave results, while all of the 7 individuals sampled for bone gave successful readings. Data of the regional enamel samples showed distinct $^{87}Sr/^{86}Sr$ signatures from individuals at the different locations. $^{87}Sr/^{86}Sr$ in human tooth samples ranged between 0.70975 to 0.71206, in human bones between 0.71094 and 0.71184. Earlier (Late Acacus) and later (Garamantian) phase showed heterogenous signal, while Pastoral contexts revealed a more restricted range of $^{87}Sr/^{86}Sr$ values. For the earlier phases, the relatively high variation in $^{87}Sr/^{86}Sr$ probably reflected the residential mobility of hunting-gathering groups. For pastoral populations, the restricted range of $^{87}Sr/^{86}Sr$ values could indicate a localized settlement; the range could also reflect returning of populations to the same areas repeatedly (seasonal movements). Late Pastoral herders appeared to rely on intense mobility, widening, and diversifying their relationship with surrounding environment (Tafuri *et al*. 2006).

Strontium isotopes for identifying migration were used within Lapita populations in Southeastern Asia. Lapita people (ca. 3300–2200 BC) were intial colonists of the island groups to the east to Solomon Islands, spreading from Papua New Guinea to Tonga and Samoa. Mobility was signifiant due to maintaining cultural solidarity between Lapita communities. Two Lapita sites, Kamgot and Balbalankin, from the Anir Islands in the Bismarck Archipelago within the Early (ca. 3300–3000/2900 BC) and Middle (ca. 3000/2900–2700 BC) Lapita periods were investigated. 5 human teeth from about 5 individuals were analyzed - four from Kamgot, one from Balbalankin. All samples had strontium isotope signatures higher than those from the underlying basalt of the Anir Islands which averaged 0.7039. $^{87}Sr/^{86}Sr$ values ranged between 0.704997 and 0.708525. The strontium signature pointed out the human migration (Shaw *et al*. 2009).

Strontium isotope analysis was utilized to test the hypothesis that emergence of interregional exchange networks and the occurence of exotic grave goods in local tombs would correspond with a highly mobile population and a considerable immigrant presence during the Umm an-Nar (2700–2000 BC) period in Southeastern Arabia (United Arab Emirates). A total of 100 individuals from six monumental Umm an-Nar tombs were sampled. $^{87}Sr/^{86}Sr$ values from Mowaihat 0.708863 ± 0.000014 (n = 12), Tell Abraq 0.708873 ± 0.000020 (n = 27), Umm an-Nar Island 0.708902 ± 0.000079 (n = 33), and Unar 1 0.708805 ± 0.000065 (n = 25) all displayed little isotopic variability indicative that a population was not highly mobile. Nevertheless, two immigrants from Tell Abraq and one immigrant from Mowaihat indicated an interregional interaction (Gregoricka 2013).

Archeaological research in the Midwestern United States highlited the role of population movement in affecting interregional cultural change. Strontium isotope values in bone and tooth enamel were used to identify non-local individuals. In the Midwest, researchers identified potential population movements beginning about 10 000 BC. About 200 AD movements are thought to have occured on a pan-regional scale with populations entering the area from as far away as the mid-south, the upper Ohio River Valley, and the eastern Plains. After 200 AD, migrations occured at a more intraregional level within the Midwest. Archaeological evidence of human movement is clear in the post-1000 AD period. During this time, large Mississippian center of Cahokia arose, regional conflict increased, and climatic shifts occured. The late prehistoric era (post-1400 AD) was characterized by large-scale shifts of population. The scale of population movement was sufficiently great. 47 enamel samples, 28 samples of bone, and four dentine samples from about 79 individuals were analyzed. There were two distinct groups, those with $^{87}Sr/^{86}Sr$ values 0.7096 ± 0.0005, and those with $^{87}Sr/^{86}Sr$ values 0.7119 ± 0.0005. These two groups were significantly different from one another (Hedman *et al*. 2009).

Immigration in the ancient Maya city of Tikal, Guatemala (Mesoamerica) was investigated via strontium (and oxygen) isotopic meauserements on archaeological human teeth. The analysis concerned the period from the Early Classic period (250 BC–550 AD) till the Late Classic period (550–850 AD). 97 tooth enamel from about 97 individuals were sampled, when the $^{87}Sr/^{86}Sr$ values ranged between 0.70406 and 0.71626. Strontium isotopes provided some measure of the immigration to and within the Maya area, confirming that a significant number of Early and Late Classic burials at Tikal contained the remains of individuals born some distance from where they came to be buried. Data indicated that approximately 11-16 % of the sampled skeletons spent their childhood at distant sites. Several royal burials demostrated long distance movement of both males and females (Wright 2012).

The nature of Tiwanaku (South Central Andes) influence during the Middle horizon (500–1100 AD) was attributed to imperial expansion or economic and/or religion relationships. Strontium isotope data from human remains from Tiwanaku sites identified first-generation immigrants from the Lake Titicaca basin outsider of the Tiwanaku heartland at the Peruvian site of Chen Chen. At 62 individuals, enamel strontium signatures showed the values ranging between 0.706562 and 0.719211. Sr ratios demonstrated movement within the Lake Titicaca basin. There were variable relationships between Tiwanaku heartland and peripheral sites during the Middle horizon. At Chen Chen, there was clear evidence that migrants from the southern Lake Titicaca basin lived and were buried at the site. The oasis of San Pedro de Atacama did not include direct colonization. Results from the southern Lake Titicaca basin demostrated a higher than expected degree of residential mobility at smaller Tiwanaku-affiliated sites (Knudson 2008).

3.4.2 Results from strontium isotopic studies from Southern and Southeastern Europe

Strontium isotope data from tooth enamel from human burial remains from the Danube Gorges in the North-Central Balkans (between present-day Serbia and Romania) showed a significant increase in non-local individuals from about 6200 cal. BC with several waves of migrants into this region. The Danube Gorges was characterized by rich burial record spanning the Mesolithic-Neolithic transition. 153 individuals were analyzed and $^{87}Sr/^{86}Sr$ values ranged between 0.708795 and 0.709893. Data provided an evidence of a period of coexistence between indigenous groups and early farmers before farming communities absorbed the foragers completely in the first half of the 6th millennium BC (Borić, Price 2013).

Strontium isotopes were used to identify biological markers of mobility in late prehistoric Portugal. The study utilized strontium isotopes in dental enamel from burial populations related to the fortified Chalcolithic settlement site of Zambujal (ca. 2800–1800 BC) in the Estremadura region to distinguish the presence of non-local individuals. Zambujal has long been considered a central location of population aggregation, trade, and craft production during a time of increasing political centralization and social stratification. Human remains were selected from 6 collective burial sites located within 25 km of Zambujal near the city of Torres Vedras. These sites were diverse in terms of their funerary context (differences in social status by burial type). A total of 55 human dental remains from about 55 individuals were selected from the sites. The local $^{87}Sr/^{86}Sr$ composition was defined as 0.7090–0.7115, and the $^{87}Sr/^{86}Sr$ isotope ratios for the entire human samples ranged around 0.710115. The results found that only 9 % (5 out of 55) of the total surveyed individuals could be classified as non-local, when the majority came from one burial site, Cova da Moura. It is possible that some of these non-locals came from the Alentejo region of the

Portuguese interior, corresponding with known exchange patterns (Waterman *et al*. 2014).

Strontium isotope analysis of human remains from San Martín de Dulantzi (Alegría-Dulantzi, Álava, Spain) graveyard was used to investigate mobility patterns during the Early Middle Ages. Some archaeological human remains had “Germanic“ grave goods; therefore, the role of Germanic migrations during the disintegration of the Roman Empire and the transformtion of Roman society during the Early Medieval period was observed. Studied samples corresponded to 33 individuals – 10 men, 16 women, and 7 undetermined, including 22 long bone samples and 11 dental samples. All of them were mature/senile individuals, with the exception of one child. Some individuals were buried with weapons, personal ornaments, and other items. $^{87}Sr/^{86}Sr$ isotope ratio of human long bones ranged from 0.707793 to 0.708019, dentine samples from 0.70789 to 0.708199, and dental enamel samples from 0.707925 to 0.709196. Human bone remains had similar $^{87}Sr/^{86}Sr$ isotope ratios, and were similar to the local isotope signature with the average values of $^{87}Sr/^{86}Sr$ = 0.70788. Within tooth sample $^{87}Sr/^{86}Sr$ isotope ratios, notable differences between dental enamel and dentine fractions could be observed; and the resulting $^{87}Sr/^{86}Sr$ enamel values indicated non-local provenance. Within foreign individuals, two distinct isotope compositional groups were distinguished. These two groups indicated two foreign populations with provenance from different geological settings. The Dulantzi population constituted mainly a local society with many immigrants. Migration cycles occured during Phases 4 and 5 at the site (6th–9th centuries) involving a movement of a very limited number of adults and youth of both genders (Ortega *et al*. 2013).

3.4.3 Results from strontium isotopic study from Wales

There was an evidence of early medieval trade and mainly migration between Wales and Mediterranean Sea region. In Wales, Mediterranean pottery from the 5th till 7th centuries was discovered. Despite the collapse of the Roman Empire in the early 5th century, archaeological evidence suggested that trade with the Mediterranean continued into the mid-7th century. It is suggested that people as well as pottery continued travel to Wales from Byzantium, and that they subsequently settled amongst the local communities. Strontium (and oxygen) isotope analysis was undertaken from human remains from four early medieval cemeteries from Wales. Three cemeteries were located near the Pembrokeshire coast – Brownslade, West Angle Bay and Porthclew, whilst the fourth cemetery, Llandough, was located in southeast Wales. All four cemeteries were situated close to the settlement, where the Mediterranean pottery was found. In total, 33 individuals (including adult males, females and non-adults) were sampled. The strontium isotope values ranged from 0.7092 to 0.7134; whilst the local range was expected as 0.7092–0.7110. Five individuals had strontium values indicative of a more radiogenic geology suggesting a place of origin from elsewhere in Wales or Egland. Reasons of mobility could be following: fosterage, the need for employment and religious motivations. The presence of more than one person of possible Mediterranean origin from burials indicated that the long-distance movement of people to Wales was not just an isolated event, and that migrants could live in south Wales during the early medieval period (Hemer *et al*. 2013).

3.4.4 Results from strontium isotopic study from Sebbersund

Strontium isotopes were used to observe mobility in an 11th–12th centuries AD Danish churchyard in the important Viking Age and early Medieval site of Sebbersund in Northern Jutland. Sebbersund was considered as an important trading place in Northern Denmark with overland contact to the rest of country and overseas contact to Norway, Sweden, England and the European continent. Sebbersund could be also an entry point for Christianity coming from England or continental Europe into Scandinavia. 19 human tooth enamel samples from about 19 individuals were measured. The local range was suggested as 0.7078–0.7108; however the measured values ranged from 0.70897 to 0.71329. It is suggested that three individuals with $^{87}Sr/^{86}Sr$ values above 0.711 were non-local – graves 74, 101 and 225. The individual from Grave 101 with a value of 0.713 came from older geological terrain than Denmark, such as known from Norway, Central and northern Sweden and the northernmost part of the British Isles. Individuals from Graves 74 and 225 came from an older terrain, likely in areas similar to Grave 101 (Price *et al*. 2012).

3.4.5 Results from strontium isotopic studies from Central Europe

According to Price's (*et al*. 2004) study, the most samples of strontium isotope ratios in human bone and tooth enamel come from Bell Beaker graves in Germany, Austria, the Czech Republic and Hungary. This area is composed of different units of old plutonic and metamorphic rocks as well as young volcanic rocks and marine and terrestrial sedimentary bedrock, which all are characterized by distinctive strontium isotope ratios. Young volcanic rocks have $^{87}Sr/^{86}Sr$ values in the range between 0.7036 and 0.7054, old plutonic rocks 0.710–0.750 and higher, marine carbonates 0.708–0.710, surficial deposits around 0.709. The application of strontium analysis to human skeletal remains from the Bell Beaker period provided strong evidence that the migration was substantial in this period. The exotic materials found in Bell Beaker graves, the equestrian emphasis, absence of settlement and distinctive human skeletal remains indicate to many archaeologists the human migration. The Bell Beaker is considered as the breakdown of traditional social structures and the emergence of more mobile groups (Price *et al*. 2004).

The Bell Beaker people, along with pottery, spread over large parts of Europe – from Portugal and Ireland to Hungary and from Scotland to Sicily and North Africa. Bell Beaker materials are known primarily from graves, and artifacts associated with them include ceramic drinking vessels, jet and amber ornaments, gold and bronze objects, and archery equipment (Grupe *et al*. 1997; Price *et al*. 2004).

During the early part of the period, there is an absence of common house types, utilitarian pottery, or burial customs. The early expansive Bell Beaker phase appeared along the Lower Rhine River followed by a split into three regional groups: the southern Bell Beaker with finds from Italy, southern France, Spain, and Portugal; the western in central and northern France, Great Britain and Ireland, the Benelux countries, the Rhine region, and the north German lowlands; and the eastern group with sites in Hungary, the Czech Republic and Slovakia, Austria, and southern Bavaria. Human skeletal materials associated with Bell Beaker artifacts are morphologically distinct from those of the indigenous people of the earlier Neolithic. However, there are insufficient informations about settlement sites or house structures from the period. The materials were not spread continuously across Europe but rather in patchy, island-like concentrations, such as, for instance, in Bavaria, where the strontium isotope analysis of 69 individuals from Bell Beaker graves suggested that 17,5–25 % of all individuals were non-local. And thus, the Bell Beaker people were considered as elite in a society, in which a social strata crystallized as the culmination of regional differentiation in the earlier Neolithic. On the basis of the strontium isotope analysis, the direction of migration for the Bell Beaker population is from north-east to south-west (Grupe et al. 1997; Mallory 1997; Case 1993).

The use of strontium isotope analysis of a human skeletal population from LBK cemetery of Vedrovice (Southern Moravia in the southeastern part of the Czech Republic) to reconstruct the human migration was realized. The study was regarded as a multi-disciplinary approach to reconstructing biological and social life at Vedrovice connected with the transition to agriculture in Central Europe. Vedrovice has been represented site complex, compirsing several key components including the Early Neolithic settlement and its cemetery – “Široká u Lesa“. The site has been regarded as one of the largest collections of Neolithic human remains in Central Europe. Vedrovice could serve as a local focal point of far-flung contact network that facilitated the exchange of informations and goods (Northern Bohemia, Southern Poland, Western Hungary, and coastal Southeastern Europe), and as a founder community for the early LBK settlements. Dental microwear studies; study of ancient DNA; study of material culture; analysis of nitrogen, sulphur and carbon; and mainly analysis were undertaken in the project. Strontium isotopes extracted from teeth were analyzed for 22 individuals. The majority of values were local in origin, but 5 individuals spent their at least part of their childhood away from Vedrovice. These non-locals probably grew up in the upland areas to the northwest and to the southeast of the settlement. One or two individuals were born away and lived most of their life out of Vedrovice. There was a relative absence in the cemetery of females aged 15–20 and males in their twenties, and it could indicate that these people left Vedrovice and moved elsewhere (Zvelebil, Pettitt 2013; Smrčka *et al*. 2004; Smrčka *et al*. 2008).

The strontium isotope analysis of human skeletons was carried out, for example, in the LBK village of Vaihingen (cal. 5500–5400 BC to 5000–4900 BC) in the Neckar Valley near Stuttgart, which is an excellent site for investigating potential interaction between farmers, foragers and/or other groups during the Mesolithic/Neolithic transition. The 6–8 ha site contains more than 100 LBK longhouses and 130 LBK graves, where 40 skeleton remains were well preserved because the heavy and clayey loess. The $^{87}Sr/^{86}Sr$ values in the 25 human bone samples were normally distributed, with an average of 0.709591 ± 0.000224; when the local range corresponds to 0.70914–0.71004. The tooth $^{87}Sr/^{86}Sr$ values were found more significantly outside the local range from those burials in the ditch than from those within the settlement at Vaihingen (Bentley *et al*. 2003).

Another example of Linearbandkeramik (late LBK) from the Neckar Valley is the site of Talheim (located about 30 km of Vaihingen), where the strontium (also oxygen and carbon) isotope signatures from human bones and teeth showed up three groups correlated with hereditary traits. Talheim represents a group of people who lived at the same time and were then killed in a single event (possibly, a massacre occured there). 34 individuals were analyzed – 18 adults and 16 children. In the local group, there were many local children but no adult women, suggesting they were taken alive at the time of massacre. Another group included two men who may have been closely related. A third group had a composition suggestive of a nuclear family. The local $^{87}Sr/^{86}Sr$ range is estimated as 0.70895–0.70921 (Bentley *et al*. 2008).

Samples for the strontium isotope analysis from the LBK were gained from Flomborn and Schwetzingen in the Upper Rhine Valley. The local Sr isotope signature at both cemeteries should be close to waters of the Rhine River. The signature ranged between 0.708 and 0.709. At Flomborn, samples included 5 bones and 11 teeth from 11 individuals (7 females and 5 males) ranging in age from child to mature. At Schwetzingen, there were analyzed 6 bones and 21 teeth from about 21 individuals, also from a range of ages. The mean bone $^{87}Sr/^{86}Sr$ value at Schwetzingen is 0.70941 ± 0.00036, while at Flomborn the value is higher – 0.70995 ± 0.00019. The tooth $^{87}Sr/^{86}Sr$ value differs again – at Swetzingen 0.7868–0.71013, at Flomborn 0.70957–0.71033. There were identified 7 migrants among the 11 individuals from Flomborn (64%), and 7 migrants out of 21 from Schwetzingen (33 %). With the exception of one value, all these immigrants had $^{87}Sr/^{86}Sr$ values above the local range (Price *et al*. 2001).

Afterwards, the Copper Age (Chalcolithic) came to pass. Study of human migration during the Late Neolithic and Copper Age (ca. 5000–4500 cal. BC) was investigated in the Great Hungarian Plain. There were changes in settlements, subsistence, cultural assemblages, mortuary customs, and trade networks. These changes indicated a shift from sedentary farming villages to a more mobile, agropastoral society. Ten human tooth samples (first upper or lower molar) and five human bone samples (ribs and long bones) from about 15 individuals were analyzed for their strontium isotope composition from six archaeological sites – Hódmezővásárhely-Gorzsa, Kisköre-Gát, Polgár-Csőszhalom, Tiszapolgár-Basatanya, Hajdúböszörmény-Ficsori-tó and Magyarhomorog. These sites represented the Late Neolithic period, Early Copper Age and Middle Copper Age. The $^{87}Sr/^{86}Sr$ values for bone ranged from 0.70963 to 0.71057 with a mean value of 0.70997 ± 0.00026. Values for tooth ranged from 0.70936 to 0.71067 with a mean value of 0.70987 ± 0.00027. There was an increase in variability of the strontium isotope ratio between the Late Neolithic and the Middle Copper Age. Therefore, there was an evidence for increased social interaction during the Copper Age (Giblin *et al*. 2013).

3.4.6 Conclusions from strontium studies

In several studies, the strontium signature differs, in comparison with other studies, where the strontium signature is too fractional. I focused on the successful ones, where the human migration was attested. Strontium isotope data from aforementioned studies indicated several conclusions. I can say that migrations in Africa and Asia took place largely and for a long time. In America, because its later discovery, migrations took place mainly in the Middle Ages, and the migration studies were successful there. Regarding Southern and Southeastern Europe, migrations were confirmed largely in Danube Gorges in Balkans and San Martín de Dulantzi in Spain; however, out of all individuals, only 9 % were indicated as non-locals in Zambujal in Potrugal. Strontium studies from Western and Northern Europe were focused on the Middle Ages period, and there was only a pausity of non-locals. As I focused on migration studies of strontium signatures from Central Europe, from which I got more results. Studies related mainly to migrations during the Linearbandkeramik period (LBK), and the human migrations were largely successful in almost all studies.

If I should evaluate the strontium analysis, I hold the view that the strontium signature from human bones and teeth very well indicates the human mobility. By means of strontium isotope analysis, it is possible to investigate the place of birth and death of human populations. Furthermore, it is possible to find out, whether individuals were moving because of trade, environmetal changes, social reasons, religion, etc. These factors make a significant contribution to understanding about human migrations.

Nevertheless, there are limits of strontium isotope analysis. Firstly, $^{87}Sr/^{86}Sr$ ratios may not always provide reliable data. For instance, the strontium signature from human skeletal remains can be too fractional at some places, or only a small number of non-local individuals can be found. Secondly, diagenesis processes can affect the strontium signal in human bones, because strontium isotopes and bone and tooth tissues are affected in different ways. And thirdly, contamination must be taken into account. These three points can lead to misinterpretations of the human prehistoric and historical migrations. When I summarize the results of the aforementioned strontium studies, I get the resulting table:

Table 3: Summary of aforementioned strontium studies

Region	Site	Period	Number of individuals	$^{87}Sr/^{86}Sr$ values	Relevancy of analysis
Africa	Fezzan (Sahara)	Late Acacus (9000 BC) – Garamantian phase (first centuries AD)	35	0.70975–0.71206	Migration confirmed
Asia	Western Pacific	Early (ca. 3300–3000/2900 BC) – Middle Lapita period (ca. 3000/2900–2700 BC)	About 5	0.704997–0.708525	Migration confirmed
	Southeastern Arabia	Umm an-Nar (2700–2000 BC)	100	0.708849–0.708981	2 non-locals
America	Midwestern United States	10 000 BC–1400 AD	About 79	0.7091–0.7124	Migration confirmed
	Tikal (Guatemala)	Early Classic (250 BC–550 AD) – Late Classic period (550–850 AD)	About 97	0.70406–0.71626	11–16 % of non-locals
	Tiwanaku (Andes)	Middle horizon (500–1100 AD)	62	0.706562–0.719211	Migration confirmed
Southern and Southeastern Europe	Danube Gorges (Balkans)	Ca. 6200 cal. BC	153	0.708795–0.709893	Migration confirmed
	Zambujal (Portugal)	Copper Age (ca. 2800–1800 BC)	About 55 individuals	about 0.710115	9 % of non-locals
	San Martín de Dulantzi (Spain)	Early Middle Ages	33	0.707793–0.708199	Migration confirmed
Western Europe	Wales	Early 5th – mid-7th centuries	33	0.7092–0.7134	5 non-locals
Northern Europe	Sebbersund (Denmark)	The Viking Age (11th–12th centuries AD)	About 19	0.70897–0.71329	3 non-locals

Central Europe	Vedrovice (Czech Republic)	LBK	22	–	Migration confirmed
	Bavaria (Germany)	LBK	69	–	17,5–25 % non-locals
	Vaihingen (Germany)	LBK	About 25	0.709591 ± 0.000224	Migration confirmed
	Talheim (Germany)	LBK	34	0.70895–0.70921	Migration confirmed
	Flomborn (Germany)	LBK	11	0.70957–0.71033	Low migration
	Schwetzingen (Germany)	LBK	About 21	0.7868–0.71013	Low migration
	Great Hungarian Plain	Late Neolithic – Copper Age (ca. 5000–4500 cal. BC)	About 15	0.70936–0.71067	Migration confirmed

4 Conclusion

In conclusion, I have used bioarcheological data, especially strontium isotope signature, to investigate paleomobility in archaeological human remains. Strontium isotopes are powerful tools with which to understand sources of materials in the environment, such as examining human migrations across large areas. The analysis provides a huge means for examining questions regarding human mobility and place of origin in the individual human past.

The role of population movement is affected by interregional cultural changes, evolutionary history, environmental changes, or population pressures. Migrations can be, for example, temporary or permanent, compulsory or voluntary, internal or international. Then, it is subdivided also according to severel criteria. And these effects are reflected in the development of human mobility.

The movement of people in the past is a topic of major interest in archaeology. The arrival of new groups has often been used to explaine the appearance of innovative features in archaeological record. The human movements have been occured because of, for instance, migration, colonization, marriage, conquest, subsistence, environmental change and many others.

Strontium isotope values ($^{87}Sr/^{86}Sr$) in bone and tooth enamel have been used increasingly to identify non-local individuals within prehistoric human populations worldwide. The strontium isotope ratio varies among different kinds of rocks (sediments reflect the ratio of their parent material), and is influenced by diagenetic processes. Using strontium isotopes of archaeological human remains, we explore the degree of variability in strontium ratios across regions.

If we find a difference in the strontium signature, it is necessary to take into account how high or low ranges resulted from the analysis. As it can be seen throughout the Bachaelor thesis, some areas are more suitable for the research of the human migration, whereas others are less suitable.

It is also important to distinguish human evolutionary migrations from those human migrations documented by strontium analysis. As far as human evolutionary migrations, for example, if we talk about the „Out of Africa” phenomenon, migrations can be proved on the basis of sporadic findings mainly of paleoanthropological character, with the exception of findings of small human populations of *Homo erectus* (e.g., Dmanisi in Georgia). This means that it is about an expected penetration of species outside the native territory for a very long time (many generations). In contrast, strontium isotope analysis provides a factual evidence of the human migrations concerning already younger prehistoric periods. Because as it can be seen in the thesis, strontium isotope analyzes relate predominantly to magration studies of human populations from prehistoric times, and then also from the Middle Ages.

5 Literature

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6 List of tables and maps

Tables

Maps