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STRONTIUM ISOTOPES AND PREHISTORIC HUMAN MIGRATION: THE BELL BEAKER PERIOD IN CENTRAL EUROPE

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Abstract: Human skeletal remains from Bell Beaker graves in southern Germany, Austria, the Czech Republic, and Hungary were analyzed for information on human migration. Strontium isotope ratios were measured in bone and tooth enamel to determine if these individuals had changed 'geological' residence during their lifetimes. Strontium isotopes vary among different types of rock. They enter the body through diet and are deposited in the skeleton. Tooth enamel forms during early childhood and does not change. Bone changes continually through life. Difference in the strontium isotope ratio between bone and enamel in the same individual indicates change in residence. Results from the analysis of 81 Bell Beaker individuals indicated that 51 had moved during their lifetime. Information on the geology of south-central Europe, the application of strontium isotope analysis, and the relevant Bell Beaker sites is provided along with discussion of the results of the study.

Key words: archaeological chemistry, Bell Beaker, central Europe, migration, Neolithic, strontium isotopes

The movement of people in the past – via marriage, migration, conquest, colonization – is a topic of major interest in archaeology. The arrival of new groups has often been used to explain the appearance of innovative features in the archaeological record. Examples are numerous and include the arrival of modern humans, the spread of agriculture, the introduction of metals, and many, many

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others. Debates have raged in many areas about the nature and consequences of population movement in prehistory.

The Bell Beaker period in central and western Europe is a case in point. The Bell Beaker period falls at the transition between the Neolithic and Bronze Age, from c. 2500 to 2000 BC. Bell Beaker materials are distinctive and known primarily from graves, often containing robust males. Artifacts associated with these Bell Beaker graves include ceramic drinking vessels, jet and amber ornaments, gold and bronze objects, and archery equipment. The distribution of Bell Beaker materials is patchy across Europe, from Denmark to Sicily and from Slovakia to Ireland. The presence of new materials and artifacts and their irregular distribution have suggested to many that migration or colonization was responsible for the spread of this culture. Others, however, suggest that trade and exchange moved this distinctive material among indigenous elites.

A number of arguments revolve around the effects of migration versus diffusion on cultural change (e.g. Adams et al. 1978; Anthony 1990; 1997; Burmeister 2000; Champion 1992; Chapman and Hamerow 1997). Rebuttal, rather than resolution, continues in most cases because human movement and residential changes have been difficult to measure in the past. Evidence is generally circumstantial. Archaeologists have traditionally relied on indirect means, such as diagnostic artifacts, styles of pottery decoration, vessel form, architecture, or other presumed signals of identity, to examine questions of mobility (e.g. Rouse 1986). Such proxy information, however, is often suspect; materials may have moved through trade, exchange, theft, or other mechanisms without direct transport by the original producers.

In this study, a relatively new technique is used to examine prehistoric residential change directly using strontium isotope ratios in human bone and tooth enamel from Bell Beaker graves. Differences in values between the tooth and bone of the same skeleton indicate movement during the lifetime of the individual. An earlier investigation focused on Bell Beaker burials in Bavaria (Grupe et al. 1997, 2001; Price et al. 1994b, 1998). The present study reports on additional Bell Beaker graves from Austria, the Czech Republic, and Hungary and provides a more detailed discussion of the geological context of these cemeteries.

This report is organized as follows. Brief and general introductions to the Bell Beaker period and to strontium isotope analysis are presented initially. Information on the geography and geology of central Europe is followed by isotopic studies of specific Bell Beaker cemeteries in Bavaria, Austria, the Czech Republic and Hungary. The results of these studies suggest that both human mobility in the Bell Beaker period and the utility of strontium isotope analysis are high.

THE BELL BEAKER PERIOD

The Bell Beaker is one of the more intriguing and lesser-known periods in European prehistory. Discussions of this phenomenon occupy surprisingly little space in texts and on library shelves, yet the evidence is fascinating. The term Bell

Beaker is used for a type of pottery and a group of people, as well as the period of time (Lüning 1994; Sangmeister 1972; Shennan 1986; Sherratt 1994).

The Bell Beaker period is named after a distinctively shaped ceramic vessel, probably a drinking cup. This uniform pottery is found most commonly in graves that also contain other distinctive materials such as jet and amber ornaments, some of the first gold and bronze objects in Europe, archery equipment, and occasional equestrian gear. The Bell Beaker individuals found in these graves are frequently robust males with a distinctive 'short-headed' skull (e.g. Gerhardt 1976, 1978). Settlements from this period were almost unknown until the latter half of the twentieth century.

Bell Beaker materials are distributed irregularly from Scandinavia to the Mediterranean and from Ireland to eastern Europe (Fig. 1). Analysis of radiocarbon dates compiled from this period suggests an origin in the Rhine delta shortly before 2500 BC in a Corded Ware context (Lanting and van der Waals 1976). This early and expansive Bell Beaker phase is assumed to have split into three 'regional

Figure 1. *The distribution of Bell Beaker materials in Europe (after Harrison 1980:12).*

groups': the southern Bell Beaker with finds in Spain, Portugal, southern France and Italy; the western Bell Beaker with sites in central and northern France, Great Britain and Ireland, the Benelux countries, the Rhine region, and the north German lowlands; and finally the eastern group in Hungary, the Czech Republic and Slovakia, Austria, and southern Bavaria. In some regions such as the British Isles, the distribution of Bell Beaker materials is almost continuous, while in others the remains are very sparse. The date for the end of the Bell Beaker is variable in these areas, depending on the appearance of Bronze Age materials.

The exotic materials found in Bell Beaker graves, along with their patchy distribution, the equestrian emphasis, the absence of settlement and the distinctive human skeletal remains indicated to many archaeologists that this phenomenon was the result of human migration. In the larger context of European prehistory the appearance of Bell Beaker is thought to signal the breakdown of traditional social structures and the emergence of more mobile groups (Sherratt 1994).

In an attempt to explain Bell Beaker, Childe (e.g. 1950, 1957) used analogies with groups such as traders, merchants, prospectors, smiths, warriors, missionaries or a kind of gypsy folk. This interpretation has remained the conventional view of Bell Beaker. Others, however, including Harrison (1980:164) and Engelhardt (1991a), have suggested that increased social differentiation, not population movement, was responsible for the adoption and spread of Bell Beaker materials as symbols of wealth and status. One of the very few archaeometric studies of Bell Beaker materials involved the analysis of the chemical composition of both local and Bell Beaker ceramic vessels in Bohemia and Hungary (Rehman et al. 1992). The results of this study indicated that Beaker and local pottery were rather similar in composition so the obvious inference was made that it was all produced locally, disputing the notion of migration.

The question of human mobility in the Bell Beaker period remains unresolved. It has not been possible to determine if characteristic artifacts were brought by their owners or imported by local leaders. Strontium isotope analysis of Bell Beaker skeletons, however, offers a means to resolve this question.

STRONTIUM ISOTOPE ANALYSIS

The basic principles for the strontium isotope analysis of human skeletal remains are straightforward. Both the amount of elemental strontium and its isotopic ratios in rock, groundwater, soil, plants, and animals vary depending on local geology (Dasch 1969; Graustein 1989; Hurst and Davis 1981). The strontium isotope ratios in different rocks are a direct function of the age and composition of the material (Faure 1986; Faure and Powell 1972).

Because materials in nature have variable strontium contents, variations in absolute ^{87}Sr abundances are expressed as isotope ratios. Variations in strontium isotope compositions in natural materials are conventionally expressed as $^{87}Sr/^{86}Sr$ ratios (the abundance of ^{86}Sr is similar to that of ^{87}Sr). The stable isotope ^{87}Sr is formed over time by the radioactive decay of rubidium (^{87}Rb, $t_{1/2} \sim 4.7 \times 10^{10}$ years) and comprises approximately 7.04 percent of total strontium (Faure and Powell 1972). The other isotopes of strontium are nonradiogenic, and include ^{84}Sr (~ 0.56%), ^{86}Sr (~ 9.87%), and ^{88}Sr (~ 82.53%). Thus the total global ratio of $^{87}Sr/^{86}Sr$ is approximately 0.71327 (7.04/9.87).

Geologic units that are very old (> 100 million years) and had high original Rb/Sr ratios will have high $^{87}Sr/^{86}Sr$ ratios today, often above 0.720. Such units include clay-rich rocks such as shale or igneous rocks that have high potassium and silica contents such as granite (Faure 1986). In contrast, rocks that are geologically young (< 100 million years) and that have low Rb/Sr ratios, such as late-Cenozoic volcanic fields, generally have $^{87}Sr/^{86}Sr$ ratios less than 0.706 (e.g. Rogers and Hawkesworth 1989). Rocks that had very low initial Rb/Sr ratios, such as basalt, can have $^{87}Sr/^{86}Sr$ ratios less than 0.704.

Rocks deriving from marine sediments also have known or inferable strontium isotope values. The strontium isotopic variation of seawater through time has been published in some detail. The ratios of seawater changed through time resulting in different isotopic signatures for marine sediments of different ages (Fig. 2). The strontium isotopic variation of marine sediments is quite small (0.707–0.7093) but a curve of $^{87}Sr/^{86}Sr$ in seawater from the middle Cambrian to the present has been calculated (e.g. Azmy et al. 1999; Burke et al. 1982; Gale et al. 1988; Korte 1999; Qing et al. 1998; Veizer and Compston 1974; Veizer et al. 1997, 1999). Because the strontium isotopic composition of seawater is global at any given time, isotopic ratios for marine sediments of specific ages can be used for our study area.

These differences in strontium isotope ratios may seem small, but they are exceptionally large from a geological standpoint, and far in excess of analytical error (± 0.00001 for $^{87}Sr/^{86}Sr$). Measurement of strontium isotope ratios, usually on thermal ionization mass spectrometers (TIMS), is normally reported to the fifth or sixth decimal place. The strontium isotope ratios reported in this study have been measured using instruments at the University of Wisconsin (UW), the University of Munich, and the University of North Carolina (UNC). Same sample

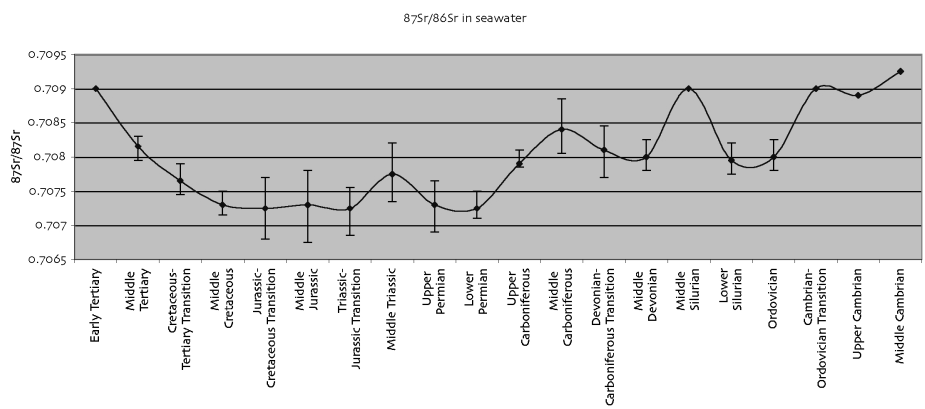


Figure 2. *The ratios of seawater changed through time resulting in different isotopic signatures for marine sediments of different ages (after Gale et al. 1988: Fig. 3).*

measurements on the instruments ensured that results are comparable. Details of preparation and procedure have been published elsewhere (Price et al. 1994a, 2002)

The strontium isotope ratio in human bones and teeth matches diet, which in turn reflects the strontium isotope composition of the local geology. Bone undergoes replacement or turnover of its inorganic phase (e.g. Jowsey and Gordon 1971; Parfitt 1983) so that measurements of bone strontium reflect the last decade or so in the life of the deceased individual. Bone turnover rates are not well documented but in general strontium isotope ratios in bone represent a mix of consumption over a minimum of 10 years, depending on the type of bone.

Tooth enamel, on the other hand, forms during infancy and undergoes relatively little change during life. Enamel has very few internal organic structures and is thus considered inert tissue and does not recrystallize or remodel after formation (Steele and Bramblett 1988). In human teeth and bones, then, strontium isotope ratios can serve as tracers of the geology of the areas where individuals grew up and where they died, respectively. Differences in strontium isotope ratios between bone and tooth of the same individual thus provide a signal of change in residence (Ericson 1985, 1989; Price et al. 1994a, 1998, 2002; Sealy et al. 1991).

The strontium isotope ratios in human bone and tooth enamel represent a composite of the diet. In enamel, that food initially comes from the mother during gestation and breast-feeding. Portions of the enamel that form after weaning contain strontium from the child's own dietary intake. Depending on the geological complexity of the place of residence, the sources of strontium isotopes may be singular or multiple. It is perhaps useful to think of a geographic dietary catchment as the source of strontium isotopes that appear in bone and tooth enamel. Residence in a geologically homogeneous region will mean that all components of the diet will have an identical strontium isotope ratio. In geologically heterogeneous regions, the diet will reflect a mixture of the strontium isotope ratios from local geological zones in proportion to the amount of food from each zone. Although there is substantial variation in the bioavailability of strontium in the environment, bone and tooth enamel, as slow-forming tissues, form over a long period of time and accumulate an average measure of bioavailable strontium (Price et al. 2002).

It is also essential to keep in mind the distinction between bone and enamel values. Fig. 3 provides a summary of the relationship between strontium isotope ratios and bone and tooth enamel. Bone values should be more representative of the place of residence during the last years of life. It is of course likely that some individuals may have moved more than once. In such cases bone strontium isotope values will reflect a combination of the original places of residence, length of stay, and number of years of residence prior to death.

Because there are several sources of variability in strontium isotope ratios, human bone and tooth enamel from a given locality exhibit a range of values and it is not always obvious how to distinguish migrants. In this article we use a cut-off point based on the isotope ratios in bone, which provide a conservative estimate for long-term residents of the area. For this cut-off value we use the mean value ±2

		Bone Isotope Ratio	
		Local	**Exotic**
Enamel Isotope Ratio	**Local**	Indigenous	Recent Returnee
	Exotic	Long-term Migrant	Short-term Migrant

Figure 3. *Possible outcomes of enamel/bone isotope analysis.*

standard deviations of the bone strontium isotope ratios in the sample from each site (Price et al. 2002).[1] By definition, 97.5 percent of the bone values at the site fall within this cut-off point. Given the fact that the bone values may include recent arrivals, the cut-off values are indeed conservative and some migrants may not be identified in this manner.

Post-depositional contamination of bone and tooth (diagenesis) is normally not a significant problem in strontium isotope studies. Certainly, bone and dentine is more susceptible to diagenesis than the denser dental enamel (Chiaradia et al. 2003; Kohn et al. 1999; Molleson 1988; Vernois et al. 1988). On the one hand, however, cleaning techniques have been developed which remove much of the diagenetic contamination from bone (Price et al. 1992; Sillen 1989). Sealy (1989) tested the acid-wash procedure of Sillen on the isotopic compositions of strontium in bone and was successful in recovering the known, biological values from bone that was initially contaminated with diagenetic strontium of a different isotopic ratio. Other researchers (e.g. Koch et al. 1992; Schmitz et al. 1991; Staudigel et al. 1985), using such acid-cleaning procedures, have had similar success obtaining $^{87}Sr/^{86}Sr$ measurements from fossils as old as the Paleozoic Era. On the other hand, diagenetic strontium that may remain in a bone sample is composed of local isotope ratios and should only mask the evidence for migration, not provide it.

Research on fossil and modern animals and humans has demonstrated the potential of using strontium isotope ratios for the study of questions concerning migration and movement away from an original local environment. Sealy and others examined the origins of recent and prehistoric residents of the Cape region of South Africa (Cox and Sealy 1997; Sealy et al. 1991, 1995). Price et al. (1994a) and Ezzo et al. (1997) investigated strontium isotopes at Grasshopper Pueblo (AD 1300) in north-central Arizona and found very high rates of migration in this population. Sillen and Sealy (1995) and Sillen et al. (1998) employed strontium isotopes to examine diet and ecozone use in early fossil hominids in South Africa. Price et al. (2000) demonstrated high rates of immigration at the Classic period Mexican city of Teotihuacan and identified migrant burials in foreign enclaves within the city. Price et al. (2001) and Bentley et al. (2002) documented different patterns of migration in the Linearbandkeramik culture, the first farmers of central Europe. Montgomery et al. (2000) report an investigation of Neolithic skeletal remains from the chalk of Cranborne Chase in Dorset, England.

GEOLOGY OF CENTRAL EUROPE

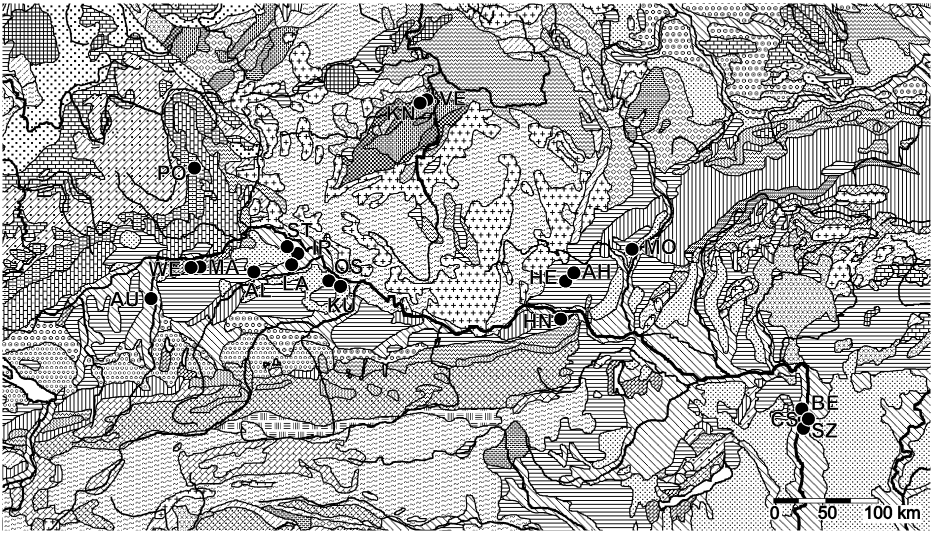
Samples for this study of strontium isotope ratios in human bone and tooth enamel come from Bell Beaker graves in Germany, Austria, the Czech Republic and Hungary. Some background on the geology of this region of south-central Europe is essential and an introduction is provided in the following paragraphs. Strontium isotope ratios for these geological formations are reported where possible. The archaeological sites and the specific Bell Beaker materials that we have analyzed are discussed in more detail in a subsequent section.

Geologically this area of south-central Europe is a complex mosaic of deposits (Dallmeyer et al. 1995), including many different units of old plutonic and metamorphic rocks as well as young volcanic ones and a large variety of marine and terrestrial sedimentary bedrock (Fig. 4). These rocks and sediments are characterized by distinctive strontium isotope ratios. Information on $^{87}Sr/^{86}Sr$ ratios for the old plutonic and metamorphic rocks have been published in the geochemical literature in connection with the Rb-Sr dating of those rocks. Research on strontium isotope variation in seawater over time provided data useful for marine sediments; terrestrial sediments are not very well known in terms of their isotopic composition.

The lowest strontium isotopic ratios in southern Germany have been recorded for young volcanic rocks that occur as relatively small outcrops across the landscape (Calvez and Lippolt 1980). Strontium isotopic values in these samples vary between 0.7036 and 0.7054. These values come from the Kaiserstuhl in the upper Rhine Graben, the Hegau south of the western Swabian Alb, as well as from the Vogelsberg and the smaller volcanic deposits in the Frankfurt area of Hessen. In Slovakia there are also large areas covered by andesites and their pyroclasts. Strontium isotope data are not available for this region but values for these volcanic features likely fall in this same range.

Old plutonic rocks like granite and metamorphic rocks like gneiss are highly variable in their strontium isotopic ratios. Gneiss and granites are present in the Black Forest and the Odenwald along the Rhine at the western edge of our study area and in the Bohemian Massif, which covers the eastern part of Bavaria and the western part of the Czech Republic. This region lies northeast of the Danube and is characterized by granitic and gneiss deposits with isotopic ratios greater than 0.710, ranging to 0.750 and higher (Grupe et al. 1997; Söllner pers. comm.). As the sample sizes for whole rock analyses are small, this variation depends greatly on which mineral is most common in the analyzed portion of the rock.

Figure 4. *Geology map of south-central Europe with major bedrock units. The legend provides basic information on the geological deposits in south-central Europe and some estimates of their strontium isotope ratios where available. Site locations are abbreviated as follows. AL = Altdorf; AU = Augsburg; IR = Irlbach; KÜ = Künzing-Bruck; LA = Landau; MA = Manching-Oberstimm; OS = Osterhofen-Altenmarkt; PO = Pommelsbrunn-Hartmannsdorf; ST = Straubing-Öberau; WE = Weichering; AH = Alicenhof; HE = Henzig; HN = Hetzmannsdorf; KN = Knezeves; MO = Moravská Nová Ves; VE = Velke Prilepy; BE = Budapest-Békásmegyer; CS = Csepel-Vízcsö II; SZ = Szigetszentmiklós-Üdülösor.*



- Fluviatile deposits (streams- and groundwater: 0.708 - 0.709)
- Bog/Peat
- Loess and aeolian sand (0.709 - 0.740)
- Younger moraines (Weichsel/Würm)
- Older moraines (Elster-Saale/ Günz-Mindel-Riß)
- Younger Tertiary (Upper Freshwater Molasse in Bavaria: 0.7221 - 0.7245; Upper Marine Molasse in Bavaria: 0.7085 - 0.7088)
- Older Tertiary
- Younger Cretaceous (Northern Bohemian depression: marine: 0.7072 - 0.7075)
- Older Cretaceous
- Cretaceous, undifferentiated
- Upper Jurassic (Malm) (0.7070 - 0.7071)
- Lower and Middle Jurassic (Lias, Dogger)
- Jurassic, undifferentiated (marine: 0.7070 - 0.7080)
- Upper Triassic (Keuper: 0.7100 - 0.7200)
- Middle Triassic (Muschelkalk: 0.7076 - 0.7082)
- Lower Triassic (Buntsandstein in Germany) 0.720 - 0.740 marine in Austria and Slowakia) 0.7075 - 0.7079)
- Triassic, undifferentiated (0.7070 - 0.7080)
- Permian
- Carboniferous
- Devonian
- Silurian/Ordivician/Cambrian
- Palaeozoic, undifferentiated
- Proterozoic
- Granite (mainly 0.71 - 0.8)
- Rhyolite
- Basalt and other young volcanites (0.7034 - 0.7054)
- Diabase
- Gneiss, Mica-schist, Phyllite, Marble (mainly 0.71 -0.77)

Table 1. Strontium isotope ratios for marine sediments in south-central Europe.

Sediment	Sr-Isotopic range	Source
Muschelkalk	0.7076–0.708	Korte (1999)
Upper Triassic Slovakia	0.7076–0.7079	Korte (1999)
Upper Triassic (Rhaet) Austria	0.7075–0.7079	Korte (1999)
Jurassic	0.707–0.7071	Horn et al. (1985), Todt (2001)
Jurassic generals range	0.7079 (early J.) 0.7068 (late J.)	Veizer et al. (1997)
Cretaceous	0.7074–0.7077	Veizer et al. (1997)
Upper marine molasse	0.7085–0.7088	Vennemann and Hegner (1998)
Tertiary general	0.7077–0.7095	Veizer et al. (1997)

To the northwest of the Danube lie the Franconian Alb, the Bavarian Highlands, and the Thuringian Forest. The highlands closer to the Danube are composed of Jurassic marine deposits. Further north there are upper Triassic 'Keuper', middle Triassic 'Muschelkalk' or shell limestone, and lower Triassic red sandstone deposits northwest of the Franconian Alb. The Keuper formation is the term for upper Triassic continental sediments in Germany. These horizons are dominated by sandstones and mudstones. Table 1 provides average measurements for the strontium isotope ratios of some marine deposits in south-central Europe.

Alpine erosion products of Tertiary to Holocene age characterize the Alpine Foreland south of the Danube. In the Tertiary period, mainly gravel was deposited under either marine ('Meeresmolasse') or fresh water conditions ('Süßwasser-molasse'). In the Pleistocene those clastic sediments were partly covered with glacial moraine in the south and loess deposits north of the Alpine Foreland. In the river valleys, gravel as well as finer materials continues to be deposited.

All these sediments originated in the Alps. But, as the Alps are composed of different kinds of rocks that weathered and contributed to the molasse basin at different times, there is some variability in the isotopic ratios of the locally available strontium in the prealpine lowlands.

The loess and marine carbonates should have strontium isotope ratios ranging between 0.708 and 0.710. These values were confirmed by the analysis of four soil samples from Bell Beaker cemeteries in this area with a strontium isotope ratio between 0.708965 and 0.709892 with a mean of 0.709377, essentially the same as Holocene seawater.

Surficial deposits on top of bedrock formations often provide the source for biologically available strontium isotopes. Large areas of older bedrock are covered with Quaternary loess or loess loam. Measurement of loess in the Rheinhessen region is reported at 0.72 and in the Pfalz region at 0.73 (Todt, Wine project; http://www.issi.unikl.de/pro/pro%5Fnr/pro%5F148%5Fii/kurzbe.htm; accessed 15 January 2002). The fluvial deposits of the Danube system are a mixture of the geologies of central Europe and exhibit a consistent $^{87}Sr/^{86}Sr$ ratio around 0.709.

The region in Austria where Bell Beaker sites are found is known as the Vienna basin, a faulted graben between the Alps and the Carpathians (Janoschek and Matura 1980). The rocks of the Alps underlie this basin as they continue into the Carpathian mountains. The most recent cycle of sedimentation filled the basin with limnic and lacustrine sediments that included Miocene limestones, sandstones, and clayey marls. Quaternary deposits from the Danube River on top of these beds are composed primarily of terraces built up from meltwater materials from the Alps. Loess materials were deposited in this area during the colder periods although often they have been reworked by river and lake activity.

The river continues along the Slovakian border in Cenozoic fluvial sediments before cutting between the Alps and the Carpathian mountains west of Vienna. The river flows largely in Cenozoic fluvial sediments from north to south through the Hungarian Basin, forced west by the highlands of the eastern Carpathians. The Hungarian Basin is part of the larger Pannonian Basin that lies between the Alps, the Carpathians, and the Dinaric Alps. This basin filled with molasse deposits (detritus shed from the rising Alpine mountains) beginning in the lower Miocene. Across this belt of molasse the Danube river carried sediments from the west, largely glacial in origin from the Alps. Loess deposits are also common in this region, often to substantial depth.

ARCHAEOLOGICAL SITES AND BURIALS

Bell Beaker sites in south-central Europe are found in this complex geological context. The majority of sites, however, are located in the lower-lying regions in areas of fluvial, molasse or loess deposits. The sites can be divided into four main regions: Bavaria in Southern Germany, north of Prague in the Czech Republic, north and northwest of Vienna, Austria, and the Budapest area in Hungary. The geographic locations of these sites are indicated in Fig. 4 by the two-letter abbreviations for the site name listed with their descriptions in the caption.

These archaeological sites are described below along with some information on their local geology. The results of the strontium isotope analyses of the human bone and enamel samples are presented in Table 2 and discussed later. These results are also shown as a bar graph of bone and enamel values at each site (Fig. 5). Some explanation of this graph is in order. Site names and country of location appear at the top of this graph. The samples from each site appear in the alternating shaded and unshaded portions of the graph. The individual bars on the graph represent individual samples; open bars are bone, black bars are tooth enamel. Adjacent bars indicate bone and enamel samples from the same individual.

Bavaria

More than 100 Bell Beaker sites have been excavated in Bavaria, with the majority found between the Danube and the Alps. Ceramics from sites in northern Bavaria are associated with the western group of the central European branch of the Bell Beaker tradition, while materials from the Danube River and south are affiliated

Table 2. Strontium isotope ratios for human bone and tooth samples from Bell Beaker sites in south-central Europe. M = Male, F = Female; U = Unknown; OBB = Older Bell Beaker, YBB = Younger Bell Beaker, BB = Bell Beaker; M = Migrant, L = Local. German samples analyzed in Madison and Munich (Grupe et al. 1997); non-German samples analyzed at UNC.

Site name	Country	Date	Grave no.	Age	Sex	Enamel 87Sr86	Bone 87Sr86	Migrant
Altdorf	Germany	OBB	180/3	A	M	0.70849	0.70962	M
Altdorf	Germany	OBB	177/2	J	M	0.71001	0.71009	L
Augsburg	Germany	OBB	2	A	M	0.70882	0.70806	M
Augsburg	Germany	OBB	3	A	M	0.70826	0.70806	L
Augsburg	Germany	BB	8	A	M	0.70838	0.70814	L
Augsburg	Germany	BB	9	J	F	0.71169	0.70818	M
Augsburg	Germany	BB	4	A	F	0.70861	0.70821	M
Augsburg	Germany	OBB	5	A	M	0.70866	0.70821	M
Augsburg	Germany	BB	14	A	M	0.70858	0.70822	M
Augsburg	Germany	BB	16	A	F	0.70832	0.70822	L
Augsburg	Germany	BB	10	A	M	0.71638	0.70825	M
Augsburg	Germany	BB	15	J	M	0.70842	0.70826	M
Augsburg	Germany	BB	17	A	F	0.70853	0.70831	M
Augsburg	Germany	OBB	20	J	M	0.70837	0.70833	L
Augsburg	Germany	OBB	1	A	M	0.70864	0.70837	M
Augsburg	Germany	OBB	22	A	F	0.70868	0.70858	M
Augsburg	Germany	BB	13	C	U	0.70840		M
Augsburg	Germany	BB	19	C	U	0.70846		M
Augsburg	Germany	BB	21	C	U	0.70975		M
Irlbach	Germany	BB	21	A	F	0.70991	0.70901	L
Irlbach	Germany	YBB	6	A	F		0.70913	L
Irlbach	Germany	YBB	14	A	M	0.70932	0.70914	L
Irlbach	Germany	YBB	20	A	M	0.70973	0.70922	L
Irlbach	Germany	YBB	22	A	F	0.70964	0.70929	L
Irlbach	Germany	YBB	9	A	F	0.70955	0.70932	L
Irlbach	Germany	BB	16	A	M	0.71150	0.70933	M
Irlbach	Germany	YBB	10	A	M	0.70931	0.70938	L
Irlbach	Germany	YBB	3	A	M	0.70955	0.70952	L
Irlbach	Germany	BB	1	A	F	0.71001	0.71092	M
Irlbach	Germany	YBB	4	C	F	0.70963		L
Irlbach	Germany	YBB	7	C	U	0.70956		L
Künzing-Bruck	Germany	YBB	372	J	F	0.70951	0.70866	M
Künzing-Bruck	Germany	OBB	332	A	F	0.70886	0.70879	L
Künzing-Bruck	Germany	OBB	335	A	M	0.70938	0.70902	M
Künzing-Bruck	Germany	YBB	349	A	M	0.70960	0.70905	M
Künzing-Bruck	Germany	OBB	338	A	M	0.70892	0.70925	L
Künzing-Bruck	Germany	OBB	278	A	M	0.70882	0.70928	L
Landau	Germany	YBB	7	A	F	0.70926	0.70884	L
Landau	Germany	YBB	4	A	F	0.71081	0.70897	M
Landau	Germany	OBB	9	A	F	0.70867	0.70912	M
Landau	Germany	YBB	5	A	F	0.71124	0.70957	M
Landau	Germany	BB	2	C	U	0.70949		M
Landau	Germany	YBB	3	C	U	0.70944		M
Manching	Germany	OBB	1	A	M	0.70923	0.70871	M
Manching	Germany	OBB	2	A	M	0.70846	0.70871	M

Manching	Germany	OBB	4	A	F	0.71122	0.70899	M
Osterhofen	Germany	OBB	25	A	M	0.70960	0.70903	M
Osterhofen	Germany	OBB	10	A	F	0.70915	0.70904	L
Osterhofen	Germany	YBB	28	A	F	0.71077	0.70904	M
Osterhofen	Germany	BB	21	A	M	0.70928	0.70911	L
Osterhofen	Germany	OBB	8	A	M	0.70986	0.70918	M
Osterhofen	Germany	BB	6	A	M	0.70924	0.70935	L
Osterhofen	Germany	YBB	30	A	M	0.71060	0.70938	M
Osterhofen	Germany	YBB	29	A	F	0.70893	0.70945	M
Pommelsbrunn	Germany	BB	1	A	M	0.71054	0.70998	M
Straubing-Öberau	Germany	BB	17	A	M	0.70919	0.71039	M
Weichering	Germany	OBB	17	A	M	0.70958	0.70857	M
Weichering	Germany	OBB	10	A	M	0.70886	0.70867	L
Weichering	Germany	OBB	3	A	M	0.70938	0.70870	M
Weichering	Germany	BB	5	J	M	0.70888	0.70870	L
Weichering	Germany	OBB	14	A	F	0.70868	0.70872	L
Weichering	Germany	OBB	18	A	M	0.70861	0.70905	L
Weichering	Germany	YBB	13	C	U	0.70910		M
Weichering	Germany	BB	12	C	U	0.70913		M
Weichering	Germany	BB	4	C	U	0.70917		M
Alicenhof	Austria	YBB	8	A	F	0.71011	0.71026	L
Alicenhof	Austria	YBB	16	A	M	0.70994	0.71055	M
Henzig	Austria	YBB	2	A	U	0.70946	0.70884	M
Henzig	Austria	YBB	3	A	U	0.70969	0.70912	M
Hetzmannsdorf	Austria	YBB	U	A	U	0.71261	0.70998	M
Knezeves	Czech Republic	BB	14	C	M	0.70934	0.70934	L
Knezeves	Czech Republic	BB	8	A	M	0.71024	0.71078	M
MoravskaNovaVes	Czech Republic	BB	39	A	U	0.71009	0.71038	L
VelkePrilepy	Czech Republic	BB	188	C	U	0.71286	0.71050	M
VelkePrilepy	Czech Republic	BB	185	A	M	0.71188	0.71063	M
VelkePrilepy	Czech Republic	BB	143	C	U	0.71292	0.71154	M
Budapest-Békásmegyer	Hungary	BB	445	U	U	0.70920	0.70925	M
Budapest-Békásmegyer	Hungary	BB	432a	U	U	0.70906	0.70960	M
Budapest-Békásmegyer	Hungary	BB	193	U	U	0.70952	0.70970	L
Csepel-Vizcsö II	Hungary	BB	3	U	U	0.71142	0.70941	M
Szigetszentmiklós-Üdülösor	Hungary	BB	1	U	U	0.71109	0.70943	M
Szigetszentmiklós-Üdülösor	Hungary	BB	13	U	U	0.71034	0.71002	M

with the eastern group (Gerhardt 1953). The archaeological and anthropological evidence suggests that the closest sources for these Bell Beaker materials lay to the east and south, likely in the Czech Republic, Hungary, or Austria, and spread northwest into Bavaria along the Danube and other rivers which provided water, food, and transport.

There are a large number of excavated burials from graves and cemeteries of the Bell Beaker period in Bavaria (e.g. Gerhardt 1953). These sites have been excavated over the last 100 years with several the result of rescue from construction (e.g.

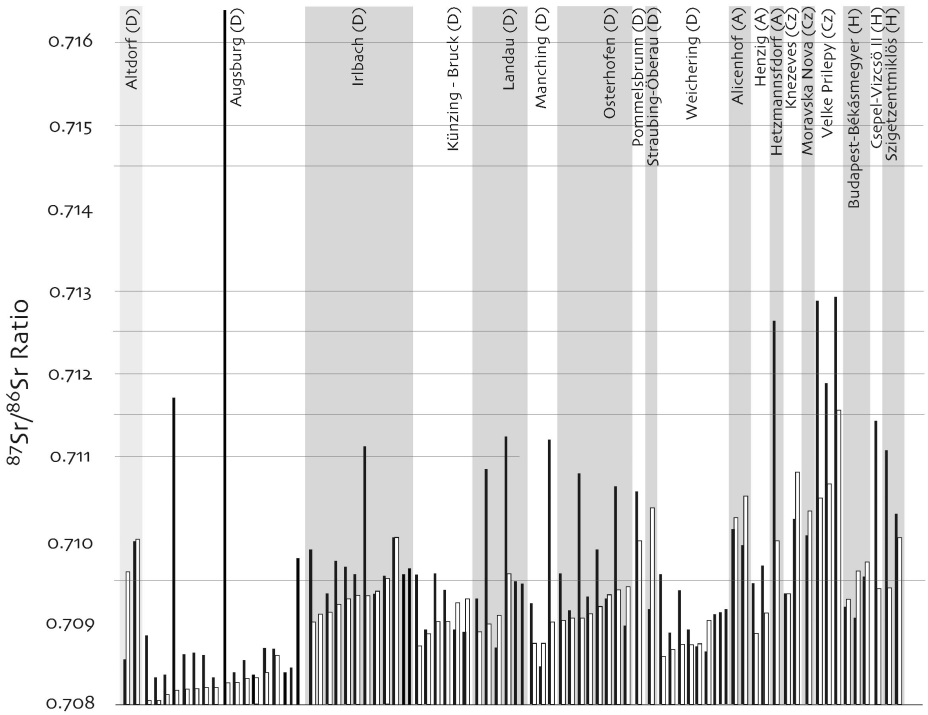


Figure 5. *Bar graph of strontium isotope ratios for Bell Beaker graves in Central Europe. Black bars are tooth enamel. Open bars are bone. Paired bone and tooth bars are from the same individual. Values are grouped by location of burial and ordered by strontium isotope ratio in bone. See Table 2 for original data. (D) Bavaria, (A) Austria, (Cz) Czech Republic, (H) Hungary.*

Kociumaka and Dietrich 1992; Weinig 1992). The sites can be dated to the earlier or later phase of the Bell Beaker period, based on diagnostic ceramics. The earlier phase begins around 2500 cal. BC and the later phase dates from 2300 until 2150 cal. BC. These burial sites occur primarily along the Danube River, but there are also examples north and south away from the river. Most of the Bavarian sites involved in this study, with the exception of Pommelsbrunn, are situated in the Alpine Foreland south of the Danube.

We have measured bone and enamel samples from 11 of these Bell Beaker burial sites in Bavaria (Fig. 6), in collaboration with Dr Gisela Grupe and Dr Peter Schrörter of the State Collection of Anthropology and Paleoanatomy, Munich, Germany (Grupe et al. 1997, 1999, 2001; Price et al. 1994b, 1998). The list of sites and the number of samples from each is shown in Table 3. Enamel from the first permanent molar and compact cortical bone from the femur was collected from skeletons where both tissues were preserved. Paired samples of bone and tooth enamel were obtained from a total of 71 Bell Beaker individuals and prepared for analysis. In addition, there are 10 individuals, largely children, for whom only

Table 3. Number of samples and number of migrants by site.

Site	Samples	Migrants
Altdorf	2	1
Augsburg	17	13
Ihrlbach	12	2
Künzing-Bruck	6	3
Landau	6	5
Manching	3	3
Osterhofen	8	5
Pommelsbrunn	1	0
Straubing-Öberau	1	1
Weichering	9	5
Alicenhof	2	1
Henzig	2	2
Hetzmannsdorf	1	1
Knezeves	2	1
Moravska Nova	1	0
Velike Prilepy	3	3
Budapest-Békásmegyer	3	2
Csepel-Vizcsö	1	1
Szigetzentmiklös	2	2
Total	82	51

enamel was available and one sample of bone only, for a total of 82 individuals. The results from the 11 individual sites are discussed later in alphabetical order.

Altdorf, Landkreis Ldkr. Landshut, Niederbayern (AL)

The site of Altdorf was discovered during highway construction northwest of Landshut in southern Bavaria (Christlein 1980). The cemetery is located on Pleistocene gravel in the Isar river valley. To the north and south of the site, gravel and conglomerates of the Tertiary sediments of the upper freshwater molasse are partially covered with loess. The site dates to the older phase of the Bell Beaker period.

Bone and tooth enamel were sampled from two burials from Altdorf, one juvenile and one adult, both male. The strontium isotope ratios in the bone were similar, between 0.7101 and 0.7096. Enamel values, however, were 0.7100 and 0.7085, respectively, and indicate that one of the two individuals was a migrant to this area, originating in a region with a lower strontium isotope signal, similar to the values at Augsburg.

Augsburg, Ldkr. Augsburg, Schwaben (AU)

The Augsburg site in southern Bavaria is located south of the town center, between Augsburg and Haunstetten, close to the sport facilities of the university. The cemetery is situated on the gravel of the lower terrace of the Lech River (Bakker 1986; Kociumaka and Dietrich 1992:67). Various sediments occur in the vicinity of the site, including Holocene fluviatile sediments in the valleys of the rivers

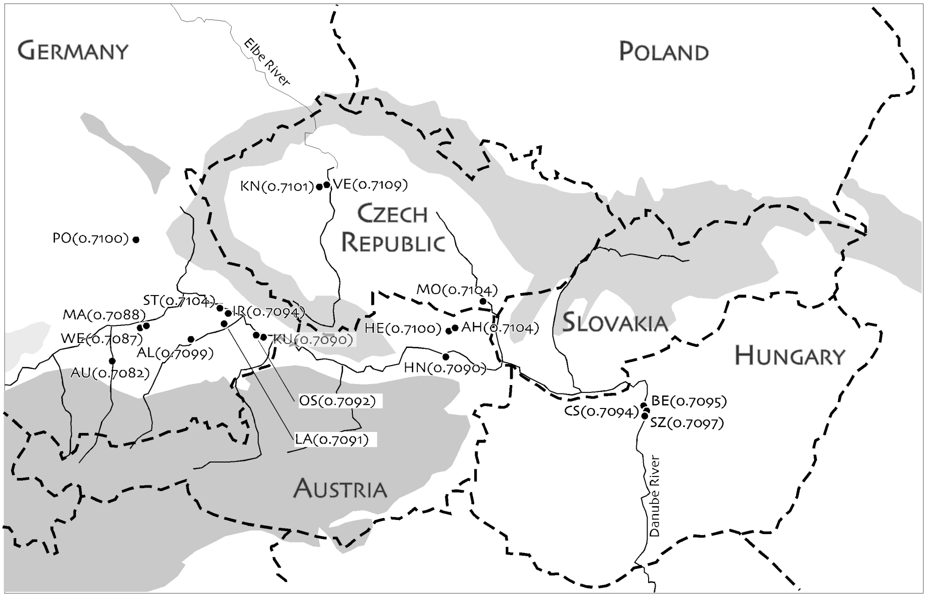


Figure 6. *Location of Bavarian Bell Beaker sites mentioned in this study and the average bone strontium isotope ratio at each site.*

Werlach and Lech as well as Holocene and Pleistocene gravel, loess, and sediments of the upper marine molasse at some distance to the site. A number of the burials can be dated to the older phase of the Bell Beaker period.

Seventeen individuals were sampled from the cemetery at Augsburg (Fig. 5). Both bone and enamel were sampled for 14 individuals; three burials of children had no bone available and only enamel was analyzed. Nine of the juvenile and adult individuals were male and five were female. The strontium isotope values in bone range between 0.7081 and 0.7086; enamel values show much greater variation between 0.7083 and 0.7164. Of the 17 individuals at Augsburg, 13 were identified as migrants. Several of the enamel values, including one of the children, are greatly different from the range of bone values at Augsburg.

Irlbach, Ldkr. Straubing-Bogen, Niederbayern (IR)

The site of Irlbach is located in the Danube valley in eastern Bavaria, adjacent to the Bohemian Forest. The cemetery was found northwest of the castle of Irlbach on the lower terrace of the Danube, composed of Pleistocene gravels of Würm age (Böhm and Heyd 1991; Kreiner 1991). Adjacent deposits include the fluviatile sediments of the river valley. South of the site lie extended loess deposits and to the north, across the Danube, are the granite and gneiss of the Bavarian Forest, part of the Bohemian Massif.

Irlbach belongs to the younger phase of the Bell Beaker period. Twelve individuals were sampled from this cemetery, including six females and five males.

Two of the 12 individuals were children. Bone in two cases and enamel in one case were not available from the burials. The strontium isotope ratio in the bone samples was higher at Irlbach, falling in a range between 0.7090 and 0.7109, and also shows a very wide range. This wide range may reflect a diverse local geology or recent migrants to the site. The individual with the bone value of 0.7109 stands out from the rest and may well be a very recent immigrant to the site. Enamel values range from 0.7093 and 0.7115; two individuals can be identified as migrants.

Künzing-Bruck, Ldkr. Deggendorf, Niederbayern (KÜ)

The site is located on the southwestern edge of the village of Künzing-Bruck on the Danube in eastern Bavaria (Christlein 1977; Kreiner 1991). The materials lie on the fluviatile deposits of the Danube in close vicinity to Pleistocene gravel and an extended loess area to the south. Across the Danube are the granite and gneiss formations of the Bavarian Forest.

Six samples of bone and enamel were taken from burials at the site. These individuals included four males and two females, five adults and one juvenile female. Four of the burials are from the older phase of the Bell Beaker and two come from the younger phase. The values for bone are generally similar to those from nearby Irlbach and Osterhofen, ranging from 0.7087 to 0.7093. Enamel values are more varied, ranging from 0.7088 to 0.7096. Again there are a number of discrepancies between bone and enamel values suggesting that three of the individuals were migrants. Two soil samples from Künzing-Bruck were also analyzed and produced the same value of 0.7090, in the middle of the range of bone values.

Landau, Ldkr. Dingolfing-Landau, Niederbayern (LA)

The site of Landau is located on Tertiary sediments along the Isar River in eastern Bavaria, south of the Danube (Christlein 1981; Engelhardt 1991a; Husty 1992). South of the site, Tertiary sediments of the upper fresh water molasse are partly covered with loess. North of the site, the valley of the river Isar is filled with Holocene sediments on top of Pleistocene gravel, peat deposits and an extended loess belt.

Six Bell Beaker individuals were sampled from this cemetery, including two children and four adults. Bone samples were not available from the two child burials. Four of the burials from the cemetery are from the younger phase of the Bell Beaker. The four adult individuals were female. Bone isotope ratios vary from 0.7088 to 0.7096; enamel values range from 0.7087 to 0.7112. Five of the individuals at Landau have enamel values outside ± 2 SD for the bone values.

Manching-Oberstimm, Ldkr. Pfaffenhofen a.d. Ilm, Oberbayern (MA)

The sites at Manching-Oberstimm consist of two small cemeteries south of the town of Ingolstadt and west of Manching on the south side of the Danube valley in central Bavaria. Oberstimm-East contained four graves and two graves were reported from Oberstimm-West (Rieder 1982, 1986). The sites are situated on gravel of the Danube River that was deposited during the upper Pleistocene. In the vicinity of the sites to the south are Holocene peats and bogs; north of the sites are fluviatile deposits of the Danube and beyond Pleistocene gravel and scattered deposits of the upper freshwater molasse that covers an upper Jurassic limestone (Malm).

There are three burials from Manching-Oberstimm-East and include two adult male and one adult female, belonging to the older phase of the Bell Beaker period. Isotope values in bone range from 0.7087 to 0.7090 while enamel values are much more variable, from 0.7085 to 0.7112. All three individuals were probable migrants to the site.

Osterhofen-Altenmarkt, Ldkr. Deggendorf, Niederbayern (OS)
This site is located south of the monastery of Altenmarkt at the confluence of the Danube and the Isar in eastern Bavaria. The cemetery is located on loess deposits that also extend to the south of the site (Schmotz 1989, 1991). North of the site are deposits of Pleistocene gravel and fluviatile deposits of the Danube. Across the Danube lie the granite and gneiss bedrock of the Bavarian Forest.

Eight individuals from this cemetery were sampled, five males and three females, all adults. Osterhofen contains burials from both phases of the Bell Beaker. Bone values range from 0.7090 to 0.7094 and enamel from 0.7089 to 0.7108. At least five of the individuals have sufficient discrepancies between bone and enamel to suggest they are migrants to this site. A soil sample from Osterhofen was analyzed and produced a value of 0.7099, significantly different from the local bone values. This discrepancy documents the reported difference between strontium isotope ratios in local geology and the biologically available level (Price et al. 2002).

Pommelsbrunn-Hartmannsdorf, Ldkr. Nürnberger Land, Mittelfranken (PO)
Pommelsbrunn is a small cemetery in the village of Hartmannsdorf, located in northern Bavaria (Koch 1988). The site is located on marine sediments (marl, limestone or dolomite) of the upper Jurassic (Malm). In the near vicinity of the site sediments (sandstones, clay, marls and limestones) of the middle Jurassic (Dogger) and upper Cretaceous also occur. Only a single burial, an adult male, was sampled from the site. The strontium isotope ratio for bone was 0.7010 and enamel was 0.7105. This difference between the two tissues is difficult to interpret and the individual may not be a migrant.

Straubing-Öberau, Ldkr. Straubing-Bogen, Niederbayern (ST)
Straubing-Öberau is a small cemetery on the south side of the Danube valley in eastern Bavaria (Engelhardt 1989, 1991b; Kreiner 1991). The site is located on fluviatile gravel deposited by the Laaber River. Nearby are the Holocene sediments of the river valley and Pleistocene gravels. Loess deposits lie to the south of the site and to the north, across the Danube, are the granite and gneiss deposits of the Bavarian Forest.

A single adult male skeleton was sampled from this site. The enamel value (0.7092) was substantially lower than the bone value (0.7104) from this individual. A soil sample analyzed from Straubing-Öberau produced a value of 0.7097.

Weichering, Ldkr. Neuburg-Schrobenhausen, Oberbayern (WE)

This site is one of the larger cemeteries from central Bavaria, located on the south side of the Danube valley, to the east of the village of Weichering in the fields known as 'Toter Mann'. The local geology closely resembles the situation at Manching-Oberstimm with the addition of some older Holocene gravels north of the site on the other side of the Danube.

Nine individuals were analyzed from this site, including five adult males, one juvenile male, one adult female, and three children. Bone samples were not available from the children. Five of these individuals date to the older phase of the Bell Beaker period (Weinig 1992). Bone values are generally low and similar, ranging from 0.7086 to 0.7091 while enamel values vary from 0.7086 to 0.7096. At least five of the individuals at this site may be migrants.

Austria

Samples from Austria came from the Naturhistorsches Museum Wien, with the kind assistance of Professor Maria Teschler-Nicola and Dr Karin Wiltschke. Three sites were sampled, Alicenhof (Zwingendorf), Henzig, and Hetzmannsdorf. The location of these sites is shown in Figure 6. All three sites belong to the later Bell Beaker period, dating to around 2000 BC. The sites are located in the Vienna Basin, characterized by a mixture of Tertiary sediments, Pleistocene and Holocene gravel and other fluviatile deposits. In many places the older sediments are covered with Quaternary loess.

Alicenhof – Zwingendorf (AH)

The site is located southwest of the village of Zwingendorf on fluviatile sands (Kern 1984, in prep.; Teschler-Nicola 1992:58–59). North of the site are Pliocene marine sediments and loess at some distance. South of the site are Pliocene marine sediments and Pleistocene gravels.

The two samples from Alicenhof came from an adult male (grave 16) and young adult female (grave 8). Bone values ranged from 0.7103 to 0.7106; the enamel values were lower at 0.7099 and 0.7101 respectively. The lower enamel value indicates that one of the individuals originated in another region.

Henzig (HE)

The site of Henzig is located on fluviatile gravels of the Große Tulln River (Friesinger 1976; Jungwirth 1976). South, east, and west of the site are loess and Pliocene marine deposits; Pleistocene gravels dominate north of the site.

There are two samples from the site (graves 2 and 3) of adult individuals, sex unknown. The enamel samples range between 0.7095 and 0.7097 and the bone samples from 0.7088 to 0.7091. If the bone is representative of the local strontium isotope ratio, then both individuals may well have been migrants.

Hetzmannsdorf (HN)

The site of Hetzmannsdorf is located just east of the village of the same name in eastern Austria (Hasenhündl 1990). The site lies in loess deposits; to the east are Pliocene marine sediments and Pleistocene gravel. A single adult individual was sampled from the site. There is a pronounced difference between bone (0.7010) and enamel values (0.7126) indicating that this individual was a migrant.

Czech Republic

There are several hundred sites with Bell Beaker burials in the Czech Republic. The sites we have sampled are Knezeves, Moravska Nova Ves, and Velke Prilepy. These samples and the strontium isotope results are listed in Table 2.

The Czech sites are situated in an area with variable geological conditions. The area is dominated by Cretaceous sandstone and claystones and older Algonkian (Proterozoic) and Carboniferous sandy to clayey sediments that may be slightly metamorphic. In many places in the investigated area these older sediments are covered with Quaternary loess.

Knezeves (KN)

This site lies on the widely distributed loess in this region. The loess sits atop Cretaceous sediments, mostly sandstones; to the north and northeast of the site lie Algonkian (Proterozoic) sediments (pelites, psammites, phyllites, that is, clay or sandstones that can be slightly metamorphic).

Graves at Knezeves were found during rescue excavations in 1953–1954 at a village northwest of Prague in Bohemia (Kytlicová 1956a, 1956b). The two samples came from grave 8 (male, age 14–adult) and grave 14 (male, age 7–19) at Knezeves. The enamel sample values range from 0.7093 to 0.7107. These two individuals clearly originated in different geological areas and one is likely a migrant.

Moravská Nová Ves (MO)

This is a multi-component site recovered in rescue excavations in south Moravia in 1991–1992 (Dobisíková and Velemínsky 1996). Moravská Nová Ves is located on or near Quaternary deposits of loess, fluviatile sediments and Cretaceous deposits. Three Bell Beaker graves were uncovered at the site. There is a single sample from this site in this study (grave 39, adult) with generally similar values in bone and enamel suggesting a locally born individual.

Velke Prilepy (VE)

This is a multi-component site at the village of the same name in Bohemia, uncovered during rescue excavations in 1994–1996 (Smejtek and Vojtechovská 1997, 1999). The materials sit on Quaternary deposits of loess. To the south are clay and sand residual deposits formed on a variety of old rocks. Older deposits include Proterozoic sediments and sandstones that are widely distributed around the site. Southwest of the site are Cretaceous sandstone and claystones.

There were a total of eight Bell Beaker graves at the site of which three have been sampled. Grave 143 contained a child about 10 years of age; grave 185 held a mature male 40–50 years old; grave 188 was a child (13–14 years of age). Bone values range from 0.7105 to 0.7115, while enamel values range from 0.7119 to 0.7129. All these individuals appear to be migrants and both the local area and especially the place of origin have high strontium isotope ratios. These values are among the highest we have recorded in the Bell Beaker study for both bone and enamel.

Hungary

Samples were obtained from three sites in the Budapest area, Budapest-Békásmegyer, Csepel-Vízcsö II, and Szigetszentmiklós-Üdülösor.

These sites are all in the floodplain of the Danube within a few kilometers of the city of Budapest (Kalicz-Schreiber and Kalicz 1998). All of the Hungarian samples were obtained through the courtesy and assistance of Dr Anna Enrödi and the late Dr Rózsa Kalicz-Schreiber. These samples and the strontium isotope results are listed in Table 2.

Budapest-Békásmegyer (BE)

This site is located in the southern part of the city of Budapest on Oligocene foraminiferous clay and silt. Around the site lie different Tertiary clastic sediments. Three individuals were sampled from graves 193, 432a and 445. Bone and enamel values are generally similar, ranging from 0.7093 to 0.7097 for bone and 0.7091 to 0.7095 for enamel. Two of these individuals appear to be migrants.

Csepel-Vízcsö II (CS)

Csepel-Vízcsö II lies on the northern end of Czepel Island in the city of Budapest (Kalicz-Schreiber 1997; Kalicz-Schreiber and Kalicz 1998). South and east of the site are Holocene fluviatile sediments, Pleistocene eolian sand and loess; north and west of the island across the Danube lie different Tertiary clastic sediments across the Danube. The sampled individual from grave 3 is clearly a migrant given a bone value of 0.7094 and an enamel value of 0.7114.

Szigetszentmiklós-Üdülösor (SZ)

Szigetszentmiklós-Üdülösor lies in the northeast part of the Csepel Island in the south of Budapest (Enrödi 1992). It is situated on fluviatile Holocene silt and brick earth in the Rackevai (Soroksari) Danube valley. West and north of the site lie Holocene silt and brick earth and Holocene eolian sand; there is loess across the Danube. North of the site, on the other side of the Danube, lie Holocene silts and brick earth and different Tertiary clastic sediments.

Two samples come from this site, one from the settlement (grave 1) and one from the cemetery area (grave 13). The bone and tooth enamel from grave 1 show a pronounced disparity and also the enamel value from grave 13 lies outside the ± 2 SD of the bone ratios from the same site. This indicates that the two individuals must have been migrants into the area.

OBSERVATIONS

The samples from Bavaria were the basis for the initial phase of this study (Grupe et al. 1997, 1999, 2001; Price et al. 1994b, 1998). The analyses from sites in Austria, the Czech Republic, and Hungary are complementary to the original Bavarian investigation and are presented here for the first time. These areas have been suggested as the original homeland of the Bavarian Bell Beaker (Gerhardt 1953).

Strontium isotope analysis of Bell Beaker burials in south-central Europe has produced a number of observations that provide insights on this important time period. The results of the analysis are shown in Figure 5.

It is clear from the graph that there is substantial variation in the strontium isotope ratios among the samples. This general pattern alone suggests a rather high degree of movement by Bell Beaker individuals. To put this observation in more objective terms we can use various methods to determine the proportion of migrants. In this study a cut-off based on ± 2 SD of the strontium isotope ratios in bone samples from the individual sites (shown in Fig. 5) has been used. With this method, 51 of the 81 individuals examined (61.7%) were determined to be of non-local origin.

Two other methods were used to identify migrants in the original study of Bavarian Bell Beaker burials. A rather arbitrary value of 0.001 or greater in the difference between bone and enamel values in the same individual was used to identify migrants. Using this method in this study still results in a high proportion of migrants (17/71, or 23.9%, with both bone and enamel measurements). A second method involved using the combined bone strontium isotope ratios from all the samples to calculate a single value for ± 2 standard deviations for the cut-off for immigrants. This was an extremely cautious approach and ignored the variation between individual sites. With this method, the proportion of migrants in the original Bavarian study was estimated to be approximately 17.5 percent. More elaborate statistical methods are unwarranted in this study because of the small sample sizes at the individual sites.

In considering the meaning of these percentages, it is important to recall that strontium isotope ratios in tooth enamel can only identify migrant individuals in the first generation. Cemeteries are likely to contain several generations and thus only a proportion of the graves can be expected to be possible migrants. The fact that between 17.5 percent and 61.7 percent can be identified using different methods for defining immigrants suggests that migration in the Bell Beaker period was very high indeed.

There is substantial variation in strontium isotope ratios both within and between the various sites investigated in this study. If we focus initially on the bone strontium values as more likely representative of the local signal, the three sites in Hungary appear to be generally similar. The Czech and Austrian sites, on the other hand, show considerable variation. The Czech burials have the highest strontium isotope ratios, reflecting the generally higher and more diverse values of the geology in that region. Although the number of samples is small, the Austrian values are also highly variable. Only the value at the site of Henzig falls between 0.708 and 0.709, as expected for the fluviatile deposits of the Danube Basin.

In terms of the mean bone strontium isotope ratio at each site, there is relatively little change in these values from east to west in the study area (Fig. 6). Sites in western Bavaria are somewhat lower, below 0.709, while sites in eastern Bavaria, and Hungary are between 0.709 and 0.710. The sites in the Vienna Basin are more variable, showing a wider range of values. Only the Czech sites to the north show somewhat higher average values.

Variation among the Bavarian sites is also substantial. The samples from Augsburg exhibit the lowest values. Samples from Altdorf, Pommelsbrunn, and Straubing-Öberau have higher values. Although many of the Bavarian sites lie in or near the floodplain of the Danube and its tributaries, local geological conditions produce substantial variation among these sites.

The strontium isotope data also provide details on other aspects of migration in the Bell Beaker period. Bell Beaker skeletal material in Bavaria has been found either in small cemetery sites (10–30 individuals: Augsburg, Irlbach, Künzing-Bruck, Landau, Osterhofen, and Weichering) or as single or very small groups of burials (no more than five individuals: Altdorf, Landau, Manching, Pommelsbrunn, and Straubing-Öberau). There do not appear to be substantial differences in migration rates between larger and smaller burial areas. Nor do there appear to be differences in migration rates between the older and younger sites. Comparison of the mean difference between bone and enamel strontium isotope ratios at the older (n = 24, mean = 0.00048) and younger (n = 19, mean = 0.00078) Bell Beaker sites is not significant.

Age and sex of the individuals sampled for this study is provided in Table 2 and summarized in Tables 4 and 5. In general there seems to be little difference in the mobility of males and females. Some 60 of the skeletons could be sexed either anthropologically or archaeologically; 38 were males and 22 were females. Out of these, 20 of the males (52.6%) and 12 of the females (60%) were migrants. Proportionately females are slightly more mobile but additional analyses are needed to determine the significance of this difference.

Age categories used in this study were: adult, juvenile, and child. The

Table 4. Distribution of migrant individuals by age group.

Age group	Number	Migrants	%
Adult	52	30	57.7
Juvenile	6	3	50
Child	13	8	61.5

Table 5. Distribution of migrant individuals by sex.

Sex	Number	Migrants	%
Male	38	20	52.6
Female	22	12	60

distribution of migrants in these age groups was similar (Table 4). It would appear that individuals of all ages were migratory, suggesting that family or larger groups may have been mobile units.

The variation in the strontium isotope ratios for tooth enamel in Figure 5 suggests that migrants came from a number of different areas. Values above 0.710 are exceptional in all areas except the Czech Republic. There is one extraordinary value above 0.716 from the cemetery at Augsburg. The original home of this individual may have been in metamorphic or sandstone geologies to the north of the Danube or perhaps the freshwater molasse to the east of the site. There are also three individuals from Austria and the Czech Republic with values above 0.712 that likely reflect the older metamorphic highlands of the Czech highlands. The generally higher values for both bone and enamel from the Czech region and Alicenhof site in Austria may be a reflection of the proximity of such deposits.

The fact that the majority of the values for bone fall between 0.710 and 0.708 reflects site location in or near the Danube valley. Although the distance from sites in the Budapest region to western Bavaria is more than 500 km, the strontium isotope ratios are generally similar, around 0.709. Thus it is unlikely that individuals moving from one place to another in the Danube valley would be distinguished in this analysis. For this reason, it is likely that individuals with higher, or lower, strontium isotope enamel ratios originated outside the Danube valley itself.

While it is possible to identify migrants, it is difficult to determine the specific homeland of these individuals because of the complex geology of south-central Europe and our lack of knowledge about surficial deposits at the site locations and how they are reflected in local biologically available strontium isotope. At present it is not possible to provide more detail with regard to place of origin. Within south-central Europe there are multiple localities where any given strontium isotope ratio might occur.

CONCLUSION

The application of this technique to human skeletal material from the Bell Beaker period has provided strong evidence that migration was substantial in this period, at least in south-central Europe. It is important to emphasize the use of direct, rather than proxy, measures of human mobility in the past. Materials and information can be carried or transmitted. Beakers and daggers do not provide direct evidence of human mobility. The analysis of human skeletal material provides a direct link to the individual. The strontium isotope evidence in this study indicates substantial mobility in the Bell Beaker period. It has been possible to determine the approximate incidence of migration in this region and to observe some differences among the sites. Differences with regard to individual age and sex or to the early as opposed to the late phase of the Bell Beaker period were not observed. Some suggestions regarding the origins of individual migrants can also be made but are as yet unconfirmed. In sum, the analysis of strontium isotopes in human skeletal remains provides new information on human migration and the significance of this behavior in the spread of Bell Beaker folk in prehistoric Europe.

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NOTE

1. In earlier reports on Bell Beaker burials from Bavaria (Grupe et al. 1997; Price et al. 1998), a single cut-off value was used for all enamel samples based on the mean and standard deviation of all the bone samples from all the sites combined. In this report we calculate a separate standard deviation for each site with more than one sample. This method should more accurately reflect local bioavailable strontium isotope ratios.

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ABSTRACTS

Isotopes de strontium et migration des hommes préhistoriques: la période des gobelets campaniformes en Europe centrale
T. Douglas Price, Corina Knipper, Gisela Gruppe et Václav Smrcka

Des restes de squelettes humains provenant de tombes de la civilisation des gobelets campaniformes d'Allemagne du sud, d'Autriche, de la République Tchèque et de la Hongrie ont été analysés afin d'avoir des informations sur la migration humaine. Les proportions d'isotopes de strontium furent mesurées dans les os et dans l'émail dentaire pour déterminer si ces individus avaient, au courant de leur vie, changé de résidence «géologique». Les isotopes de strontium, qui varient parmi les différents genres de roches, entrent dans le corps avec la nourriture et sont déposés dans le squelette. L'émail dentaire se forme pendant l'enfance et ne changera plus, tandis que les os évoluent pendant toute la vie. La différence entre les proportions d'isotopes de strontium contenues dans les os et dans l'émail dentaire d'une même personne indique un changement de résidence. D'après les résultats des analyses de 81 individus de la civilisation des gobelets campaniformes, 51 d'entre eux s'étaient déplacés durant leur vie. Des informations sur la géologie d'Europe centrale méridionale, l'application des analyses d'isotopes de strontium et les sites de la civilisation des gobelets campaniformes en question sont présentés ensemble avec l'évaluation des résultats de cette étude.

Mot-clés: chimie archéologique, Europe centrale, gobelets campaniformes, isotopes de strontium, migration, néolithique

Strontium-Isotopen und prähistorische Migration: Die Glockenbecherperiode in Mitteleuropa
T. Douglas Price, Corinna Knipper, Gisela Grupe und Václav Smrcka

Menschliche Skelettreste aus Gräbern der Glockenbecher-Kultur in Süddeutschland, Österreich, der Tschechischen Republik und Ungarn wurden auf Hinweise von Migrationsbewegungen untersucht. Um festzustellen, ob die betreffenden Individuen ihren „geologischen" Lebensraum während ihrer Lebenszeit geändert haben, wurde der Gehalt von Strontium-Isotopen in Knochen und Zahnschmelz gemessen. Strontium-Isotopen variieren durch verschiedene Typen des lokal anstehenden Gesteins. Sie werden durch die Nahrung in den Körper aufgenommen und im Skelett eingelagert. Zahnschmelz wird in der frühen Kindheit ausgebildet und ist unveränderlich; Knochen hingegen sind im Laufe des Lebens kontinuierlich Veränderungen unterworfen. Somit deuten Unterschiede im Strontiumgehalt von Zahnschmelz und Knochen desselben Individuums auf einen Wechsel des Lebensraumes. Die Untersuchungsergebnisse von 81 Glockenbecher-Individuen zeigten, dass 51 von ihnen im Laufe ihres Lebens umgesiedelt sind. Zusammen mit der Diskussion der Resultate dieser Studie werden Informationen zur Geologie des südlichen Mitteleuropa, zur Anwendung der Strontium-Isotopenanalyse sowie zu relevanten Fundplätzen der Glockenbecher-Kultur gegeben.

Schlüsselbegriffe: Archäo-Chemie, Glockenbecher-Kultur, Migration, Mitteleuropa, Neolithikum, Strontium-Isotopen