minerals

MDPI

Article

The First Data of Strontium Isotopic Composition of Osteological Material from Late Bronze to Early Iron Age Settlements in the Crimea Region

Marianna A. Kulkova [1,*], Maya T. Kashuba [1,2], Yulia V. Kozhukhovskaya [1,3], Vitaliy A. Tikhomirov [1,4] and Alexander M. Kulkov [1,5]

1 Department of Geology and Geoecology, Herzen State Pedagogical University, 191186 St. Petersburg, Russia; mirra-k@yandex.ru (M.T.K.); jv-k@mail.ru (Y.V.K.); tihomirov.va1985@gmail.com (V.A.T.); aguacrystals@yandex.ru (A.M.K.)
2 Institute for the History of Material Culture RAS, 191186 St. Petersburg, Russia
3 Theory of Language and Literature and Sociolinguistics Department, V.I. Vernadsky Crimean Federal University, Prospekt Vernadskogo 4, 295007 Simferopol, Republic of Crimea, Russia
4 Institute of Archaeology of Crimea RAS, Prospekt Vernadskogo 2, 295007 Simferopol, Republic of Crimea, Russia
5 RDMI Center, Institute of Earth Sciences, St. Petersburg State University, 191186 St. Petersburg, Russia
* Correspondence: kulkova@mail.ru; Tel.: +7921-9052303

Abstract: Comparison of the $^{87}Sr/^{86}Sr$ signatures of archaeological osteological material with features of geological provinces can be applied to determine the places of birth and living of individuals. Such reconstructions were conducted for both humans and domestic animals at the Late Bronze–Early Iron Age sites of the Crimea. The Crimean Peninsula is an interesting testing polygon for such research because it is characterized by a diverse geological situation within a relatively small area. The initial data allowed us to distinguish between three groups of mobility at the Bai-Kiyat I settlement and two groups at the Dolgii Bugor site. The Bai-Kiyat I site is located on the seacoast, so the proxy line for this area will correspond to the value of the ratio of strontium isotopes in seawater (0.7092). The inhabitants of this settlement, including a child from a burial on the settlement, are characterized by this value of strontium isotopes. Other groups include nonlocal people. The data obtained indicate that the steppe zone of the Northern Black Sea region was an ecumene, within which active mobility of groups of people was registered. This mobility is associated primarily with the pastoral type of economy in the period from the Chalcolithic to the Early Iron Age.

Keywords: $^{87}Sr/^{86}Sr$ signatures; geology of Crimea; mobility in Late Bronze Age; Early Iron Age; steppe zone; the Northern Black Sea region; Belozerka culture; Kizil-Koba culture

Citation: Kulkova, M.A.; Kashuba, M.T.; Kozhukhovskaya, Y.V.; Tikhomirov, V.A.; Kulkov, A.M. The First Data of Strontium Isotopic Composition of Osteological Material from Late Bronze to Early Iron Age Settlements in the Crimea Region. *Minerals* **2024**, *14*, 410. https://doi.org/10.3390/min14040410

Academic Editor: Pedro Álvarez-Lloret

Received: 18 February 2024
Revised: 3 April 2024
Accepted: 13 April 2024
Published: 16 April 2024

1. Introduction

In the recent past, the framework of interdisciplinary research, which integrates the humanities and natural sciences, has been expanding. In this connection, the application of geochemical methods to the study of archaeological finds, as well as their geological context, is a valuable tool in solving different tasks. One of the important problems of the social and economic processes of ancient populations is the assessment of their mobility, the emergence of both population groups and individuals in a given territory. Establishing places of birth and residence is important for both nomadic populations and settled communities. The cultural and historical processes that took place on the territory of the Crimea at the turn of the Late Bronze–Early Iron Ages were associated with migrations in the ecumene of the steppe belt of Eurasia. In this period, new communities appeared here, the material culture of which is closely connected with the cultures of the Late Bronze Age of the Northern Black Sea region and the Carpathian–Danube basin. The strontium isotope analysis for the determination of the mobility of ancient populations is a tool that may shed light on this problem. On the other hand, studying the movement of domestic animals in the internal area of the Crimean Peninsula is also important for the characteristics of the economic system associated with local pasture places and cattle camps. The Crimean Peninsula is an interesting testing polygon for such research because it is characterized by a diverse geological situation within a relatively small area.

The method of determining strontium isotopes in osteological materials is widely used to solve different archaeological questions. One of them is to develop models of people's habitation and migration based on the local geology of their residences and diet features [1,2]. Strontium isotopic signatures are transferred from eroded geological materials through soils and the food chain into human or animal skeletons. Strontium atoms replace calcium atoms in the hydroxyapatite of teeth and bones and enter the skeletal tissues of animals and humans. This functions as evidence of the diet of a person, as well as the geological region in which the person grew up [3]. Different minerals, even from the same rock, have differentiations in both $^{87}Sr/^{86}Sr$ ratios and Sr concentrations. Their uneven weathering will vary the formation of biologically available Sr. Sr isotopes in a natural reservoir can be estimated as a mixture of different sources of the material, including inputs from the atmosphere and weathering of bedrock, river and groundwater, and intermediate reservoirs including the biosphere and soil [2]. Therefore, local soils may have different $^{87}Sr/^{86}Sr$ ratios depending on the rate of mineral weathering and different sediment sources entering the soil. Strontium enters soils to a greater extent in the process of the weathering of volcanic and carbonate rocks than for continental silicate rocks, and it can also be removed in the process of soil erosion [4,5]. The geological diversity of a territory is a cause of local variability in the $^{87}Sr/^{86}Sr$ ratio in the soil, associated with different degrees of weathering of rocks. For example, for loess deposits within Northern Europe, a value range of $^{87}Sr/^{86}Sr$ is from 0.713 to 0.716 in Brittany and Normandy, and in Belgium, it is higher, up to 0.730 [6]. Coastal soils contain more than 50% marine strontium [5,7]. In the Outer Hebrides, it was found that, although the island consists of radiogenic granites and gneisses ($^{87}Sr/^{86}Sr$~0.715), in the biosphere the seawater strontium dominates. Therefore, the strontium ratio in the bones of people, herbivores, and other animals from Bronze Age sites falls below 0.7105 [8,9].

Changes in strontium isotopes ($^{87}Sr/^{86}Sr$) in the bones of individuals reflect the average intake of strontium from food and water over the last 7–10 years of the individuals' lives [10,11]. The strontium isotope analysis of archaeological bones has been used to reconstruct the transition from a sedentary to a pastoral style of life for sites of several prehistoric periods [12], as well as to study the adaptations of hunter-gatherers in ancient times [13]. Strontium isotopy has been applied to questions of marriage, migration, conquest, and colonization in prehistoric Europe [1–3,14–19]. Application of strontium isotope analysis in archaeology allowed the identification of migrants who moved between different geological provinces. It is possible to compare the $^{87}Sr/^{86}Sr$ ratio in adult tooth enamel, which forms before twelve years, with the ratio in bones, which forms throughout adult life [20]. Theoretically, if teeth and skeletal bones have different strontium ratios, then a person spent the last years of life in a different geochemical province than in his youth [21,22]. In the process of remodeling bone tissue, organisms uptake strontium with an isotopic ratio of the area in which the individual lives. The strontium isotopic ratio in the bones gradually approaches that of the new habitat. By comparing the $^{87}Sr/^{86}Sr$ signature of individuum bones with the composition of geological sediments, it is possible to determine the long-term residence in that region. Such research gives a possibility to reach a new level of reconstruction of both human and domestic animal habitation at the archaeological sites of the Crimea (Figure 1).

One of the most significant sites of the Late Bronze Age in northwestern Crimea is the Bai-Kiyat I settlement (Figure 1), excavated in the 1990s by Vitaliy A. Kolotukhin [23]. The settlement is located on a high bank of 4–5 m height and is limited to the north by the shore of the Black Sea. In the 1990s Kolotukhin excavated about 14 houses having various functions which were surrounded by stone walls. The investigated part consists of 2100 sq.m, inside of which there were hearths, a household area, and ash pits. Vitaliy A. Kolotukhin attributed this settlement to the end of the Sabatinovka culture and the beginning of the Belozerka culture and dated it to the 12th–10th centuries BC [23]. According to archeozoological determinations based on materials from excavations in 1993–1994, cattle (more than 60%) and the bones of sheep and horses are presented in equal proportions (18.6% and 17.5%) in the collection. Pig bones were also found. The use of marine mollusks is noteworthy; for example, scallop shells were deposited in a stack (more than 100 pieces) in a small pit covered with stones [24]. A distinctive feature of this monument is the burials identified at the settlement, which is rare for monuments of this period. The anthropological collection includes three burials and about 20 fragments of skulls. A unique feature of this settlement is the burials identified inside the settlement, which is rare for sites of this period.

Another site is the Dolgii Bugor settlement (Figure 1), located in the foothills of the Crimea mountains. This site was excavated by Vitaly A. Tikhomirov [25], and he attributed it to a developed period of the Kizil-Koba culture dated to the 8th–6th centuries BC. Bones collected at this settlement are presented as kitchen remains from domestic animals. The Dolgii Bugor site is located in a longitudinal depression between the spurs of the Main Ridge and the cuesta massif of the Inner Ridge of the Crimean Mountains in the valley of the Alma River, on a small table hill adjacent to the western outskirts of the village. The archaeological site is situated near the Partizanskoe village of the Simferopol region of the Republic of Crimea. This hill is surrounded by steep slopes, near its foot flows the drying Sablynka River, which flows into the Alminskoe River basin.

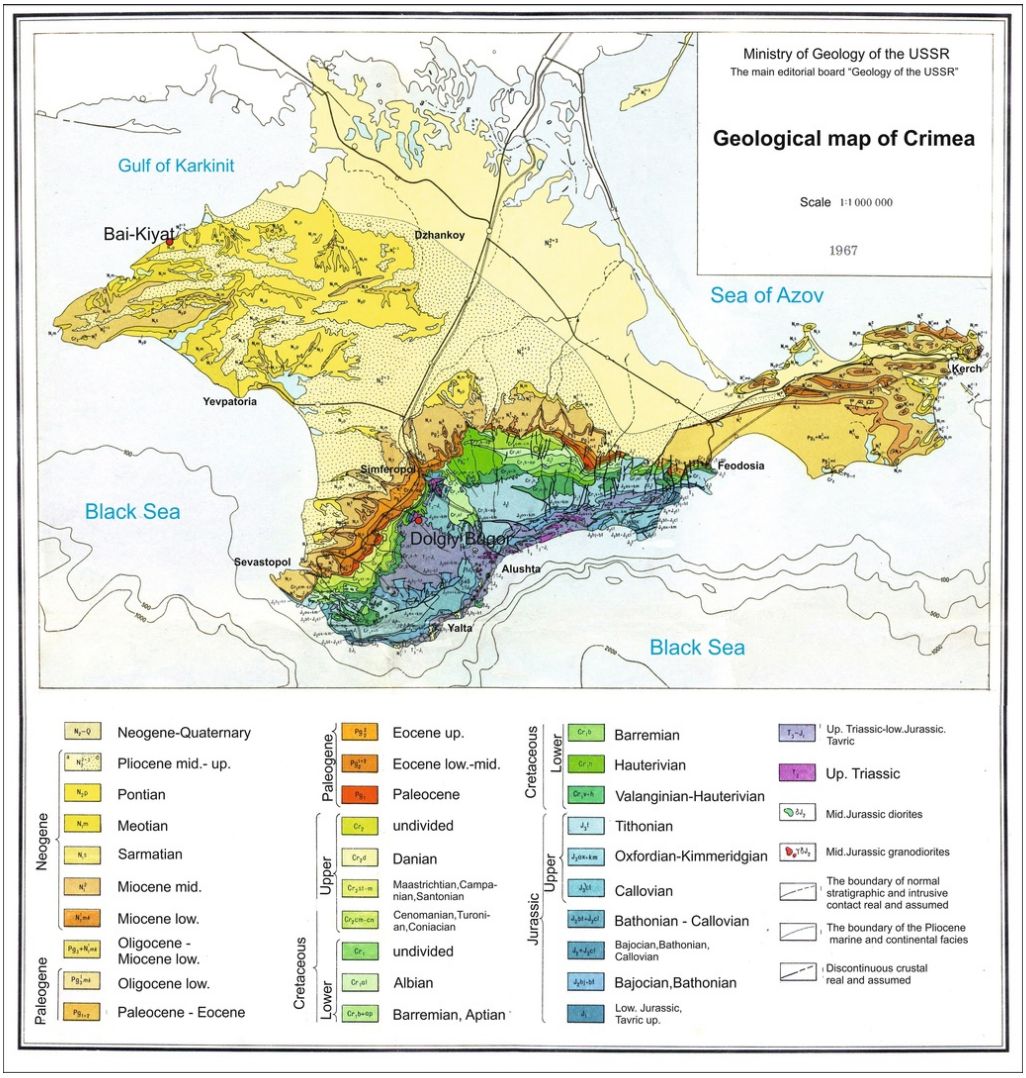

Figure 1. The geological map of the Crimean Peninsula (according to Yudin [26,27]) with location of archaeological sites under consideration.

2. Geological Background of the Crimea Peninsula

The Crimean Peninsula is located in the northern part of the East European Plain, with which it is connected by the Perekop Isthmus, which narrows to 8 km (Figure 1). The Black Sea surrounds the Peninsula in the north and south, and in the east, there is the Azov Sea. The area of the Peninsula is about 26.860 sq. km, of which 72% is plain, 20% is mountains, and 8% is lakes and other water bodies. The relief includes the North Crimean Plain with the Tarkhankut Upland up to 179 m, the Kerch Peninsula, and the Crimea mountains, with a length of 150 km. At the base of the Crimean plain, there is the Scythian platform, which consists of a shale–limestone folded foundation overlain by a thick sedimentary cover of loess-like loams, sandstones, limestones, marls, and clays [26]. The basement of the Scythian Plate is composed of strongly deformed Paleozoic rocks dominated by metamorphosed shales and carbonates. The main tectonic structures within the Crimean Plains are the Karkinitsky depression in the north, the Indolo-Kubansky depression in the east, the Simferopolsky uplift in the center, the Tarkhankut-Novoselovskiy uplift in the west, and the Alminskaya depression in the southwest. The thickness of the cover ranges from the first hundred meters on the Simferopol uplift to 1–2 km. In the Karkinitsky depression, it reaches 5 km, and in the east of the Indolo-Kuban depression, up to 8 km. In the sedimentary cover of the Scythian plate, three large complexes can be distinguished, separated by unconformities. They are different in their geological history: (1) Triassic–Jurassic complex; (2) Cretaceous–Paleogene and Lower Miocene complex (i.e., including the Maikop series), and (3) Neogene–Quaternary complex. Each of them forms an important structural floor in the cover structure of the Scythian plate. Deposits of the Paleogene, Neogene, and Quaternary (Anthropogene) systems are widespread within the Crimea Peninsula. In the eastern part, there is the North Kerch thrust zone. The Central Crimean Plain, the Tarkhankut Upland Plain, and the Northern Crimean Lowland were determined in the Scythian plate relief.

Mountain Crimea is a fold-thrust region within the Alpine–Himalayan–Indonesian belt, extending across southern Europe and Asia (Alps, Carpathians, and Caucasus) and belongs to the young mobile Cenozoic folded zone. The mountains are heavily dissected by faults and rocks that were eroded. They are divided into three ridges: Main, Inner, and Outer. The maximum width is up to 50 km. The southern and highest Main Ridge rises above sea level to 1200–1500 m.

Cuestas of the Inner Range consists of the rocks of Upper Cretaceous, Paleocene, and Eocene carbonate strata. Neogene carbonates overlying Paleogene or Cretaceous strata are exposed in the cuestas of the Outer Range. The Neogene strata have differences in their thickness. On the Crimean Plain, the thickness reaches several hundred meters. The lower tectonostratigraphic floor in the Crimean Mountains is presented mainly with Triassic shale-dominated flysch deposits and Upper Jurassic and Lower Cretaceous limestones. There are olistoliths here which are composed of limestone arrays [27]. The upper tectonostratigraphic floor consists of alternating shales/marls and carbonate rocks of the Upper Cretaceous, Paleogene, and Neogene ages. They are deformed during the reactivation of the suture in Cenozoic times [28].The Paleogene system includes the Paleocene (Pg_1) (Inkerman and Kachen stages), represented by marls, limestones, and sandstones; the lower and middle Eocene (Pg_2^{1+2}) (Simferopol and Bakhchisarai stages)—Nummulitic limestones, clays, and marls; the Upper Eocene (Pg_2^3) (Bodrak and Alma stages)—clays, limestones, and marls; the Paleocene and Eocene ($Pg_{1\text{-}2}$)—clays, marls, and limestones; the Lower Oligocene (Pg_1^3mk) (lower part of the Maikop series)—clays; and the Paleogene and Neogene systems ($Pg_3 + N_1^1mk$) (Oligocene and Lower Miocene, Maikop series)—clays. The Neogene system includes the lower Miocene (N_1^1mk), the upper part of the Maikop series—clays; the Middle Miocene (N_1^2) (Tarkhan, Chokrak, Karagan, and Konk horizons)—clays, limestones, marls, sandstones, and sands; the Upper Miocene (N_1s) (Sarmatian stage)—clays, limestones, and sandstones; the Upper Miocene (N_1s) (Maeotic stage)—limestone-shell rocks, bryozoan reefs, marls, and clays; the Lower Pliocene (N_2p) (Pontic stage)—limestone-shell rocks, sands, and clays; and the middle and upper Pliocene ($N_2^{2\text{-}3}$) (Cimmerian and Kuyalnik stages): (a) marine clays with iron ores, sands, and limestones, and (b) continental pebbles, loams, and blocky limestone piles. The Neogene–Quaternary system (N_2-Q) exhibits deposits of mud volcanoes and hill breccias.

The Triassic–Jurassic system (T_3-J_1) (Tauride series) features sandy–clayey flysch and mudstones with siderite. The Kerch Peninsula is divided by the Parpach ridge on the southwestern part and the northeastern part. The southwestern part is a gently undulating plain with isolated hills (Konchek, Dyurmen, and Jau-Tepe mud volcano). The northeastern part is characterized by a hilly-ridge relief. In the basins, there are hills of mud volcanoes. Paleogene–Neogene deposits are exposed on the surface.

The Bai-Kiyat I site is geographically located within the Tarkhankut Upland. In the area of the site location, loess deposits from the Quaternary age are developed. They were formed on limestones of the Sarmatian and Pontic stages. The Dolgii Bugor site is located within the Mesozoic (Triassic–Jurassic) rocks developed in the foothills of the Crimean Mountains.

3. Materials and Methods

3.1. Osteological Material from Archaeological Sites

For analysis of the strontium isotope ratio, bone samples were taken from burials at the Bai-Kiyat I settlement and from household pits and the cultural layer at the Dolgii Bugor site. At the settlement of Bai-Kiyat I, the burials contain unique and rare anthropological material, including skull fragments. Animal bones have also been found in fragments. Therefore, to compare isotopic results for different samples, bone tissue was selected, not teeth.

At the Bai-Kiyat I settlement, 6 samples of human skull bones and 6 samples of animal bones were selected. The animal bones belong to small ruminants (sheep and goats) and one sample is from a large horned animal (*Bos taurus*).

Sample BK-94-A-1 is the fragmented skull of a man about 50 years old from burial 3, square 60. The buried person has preserved parietal and occipital bones, the right temporal bone and a fragment of the left temporal bone, a broken lower jaw with preserved first molars on both sides, second and third lower right molars, and a right first premolar.

Sample BK-94-A-2 is the skull of a 7–8-year-old child in fragments. There are preserved the frontal bone, broken into three parts, with an adjacent fragment of the nasal septum, the right parietal bone with the loss of the part adjacent to the temporal bone, the left parietal bone, broken into two parts, the left temporal bone, a fragment of the occipital bone, a fragment of the main and the lower jaw without branches, with preserved fragments of the first primary molars of the right and left sides, the second primary and first permanent molars and the second permanent molars with the roots formed on one-third.

Sample BK-94-A-3 includes two fragments of the right parietal bone of an adult over 35 years old. Sex cannot be determined.

Sample BK-94-A-4 includes fragments of the skull of a man over 50 years old including three fragments of the frontal and parietal bones with obliterated coronal and sagittal sutures, as well as the occipital bone.

Sample BK-92-b.1 from burial 1, square 27, includes the fragmented skull of an adult male, 35–40 years old. There is a fragmented frontal bone (4 fragments), 5 fragments of parietal bones, a damaged right temporal bone, two fragments of the lower jaw—the frontal part and the right half—both maxillary bones, with the adjacent left zygomatic bone, and a fragment of the base of the skull. On the right side, all the teeth of the upper jaw are preserved, as well as all the teeth of the lower jaw, except for the lateral incisor.

Sample BK-92-b.2 is the skull of a man over 40 but under 60 years of age. All sutures except the temporal ones and the area of the asterions are obliterated. The base bones are missing, the left zygomatic arch is damaged, and the bottom of the alveoli of the maxillary molars on the right side was posthumously destroyed. The skull was examined using computed microtomography [29]. Samples of sheep (*Ovis aries*) and goat (*Capra hircus*) bones were collected at the Dolgii Bugor site for analysis. Sample DB3888 was taken from utility pit 1. Sample DB3889 was taken from utility pit 2. Sample DB3887 was taken from utility pit 3.

3.2. Pretreatment Procedure and Measurement of Strontium Isotopes

One of the problems in strontium isotope determination in bone tissue is its high porosity and its contamination during burial. Strontium from groundwater penetrating bone after burial can replace strontium in the carbonate apatite of the mineral part of bone [2,30–36] Diagenetic Sr can fill pores since it is composed of secondary minerals and/or can be absorbed in microcracks or on the surface of the original hydroxyapatite crystals [34,37]. Postburial contamination of bone can be a problem in the determination of local $^{87}Sr/^{86}Sr$ changes. It can be unreliable based on the average $^{87}Sr/^{86}Sr$ values in human bone samples from a burial site [1,3,11]. However, the average value of strontium isotope ratio in archaeological bones may be a useful baseline, reflecting contamination from local groundwater [38]. Diagenetic strontium can be removed from skeletal samples via proper sample cleaning, such as with a weak acid [1,22,39,40]. The leaching of a bone sample with 5% acetic acid will dissolve the diagenetic strontium from the carbonate formed into the pore spaces, while the original strontium will be preserved because it is more tightly bound in the bone hydroxyapatite [41,42]. Sillen [42] suggested that diagenetic Sr can be easily removed because it concentrates in secondary mineral phases that are more soluble than biogenic hydroxyapatite. So, biogenic Sr can be isolated with the help of a series of sequential leaches in 0.1 N buffered acetic acid [43]. The Ca/P ratio was determined in archaeological bones which were pretreated with 5% acetic acid. The bones were soaked in 1 ml aliquots several times. In the first solution, the Ca/P ratio had a high value which reflects the relatively high Ca content and presence of diagenetic minerals, such as calcite. As a result of subsequent washes, Ca/P asymptotically approaches 2.1:1, reflecting the stoichiometry of biogenic hydroxyapatite: $[Ca_9(PO_4)_{4.5}(CO_3)_{1.5}(OH)]$ [44]. When the Ca/P ratio approached the biogenic value of 2.1, mostly biogenic calcium and strontium remained in the bone sample. The state of histomorphological preservation of bone and the degree of its diagenetic alteration was determined with the Sr/Ca and Ca/P rations [45]. Ca/P is an indicator of the extent of the mineralization of the osteological material. In a diagenetically unchanged bone or tooth, Ca/P should fall within the range of 1.8–2.7 [46].

Preparation and measurement of bone samples were carried out in cleanrooms with an ISO cleanliness of 6 and 7 under the direction of Dr. D.V. Kiseleva in the Institute of Geology and Geochemistry, Yekaterinburg (Russia). Ultrapure deionized MilliQ water (18.2 MOm·cm) was used at all stages of the analysis. Laboratory wares and materials in contact with reagents and samples were made of PFA (Savillex, Eden Prairie, MN, USA), PTFE, or polypropylene. All acids used were double purified below boiling point (Savillex, USA; Berghof, Germany). Bone tissue samples purified with acetic acid were dissolved openly in concentrated HNO_3 with the addition of H_2O_2 on a hotplate at 150 °C (by [47]). Chromatographic separation of strontium on SR resin (Triskem) was carried out according to a one-step scheme [48–52]. Strontium isotopic measurements were carried out on a Neptune Plus magneto-sector multi collector inductively coupled plasma mass spectrometer (MC-ICP-MS).

4. Results

The results of strontium signature measurements in archaeological bones are presented in Table 1. From the Bai-Kiayt I site, the strontium isotope ratio in the bones of a 7–8-year-old child (BK-94-A-2) from a burial at the settlement is 0.7092 (Table 1, Figure 2). The samples with values close to this includes samples of bones from burials (BK-94-A-3, BK-94-A-4, and BK-92-b.2), which belong to men aged 40 to 50 years. Also close to these values is a sample of cattle bones (BK-1993). Slightly higher values of the strontium isotope ratio are registered for the human bone sample BK-94-A-1 (0.709293) and the sheep bone samples BK-1993-342 and BK-94 (0.709268 and 0.709291).

Table 1. Results of measurements of $^{87}Sr/^{86}Sr$ in the archaeological bones from Bai-Kiyat I and Dolgii Bugor sites.

No.	Index	Site	Description	Bone of Human/Animal	$^{87}Sr/^{86}Sr$	SE, Abs
1	BK-94-A-1	Bai-Kiyat I	Burial 3	Male scull	0.709293	0.000007
2	BK-94-A-2	Bai-Kiyat I	Cultural level	Child scull	0.709214	0.000006
3	BK-94-A-3	Bai-Kiyat I	Cultural level	Adult scull	0.709199	0.000009
4	BK-94-A-4	Bai-Kiyat I	Construction (house) XI/XII	Male scull	0.709237	0.000016
5	BK-92-b.1	Bai-Kiyat I	Burial 1	Male scull	0.709577	0.000007
6	BK-92-b.2	Bai-Kiyat I	Burial 2	Male scull	0.709240	0.000007
7	BK-1993-342	Bai-Kiyat I	Cultural level	Sheep or goat	0.709268	0.000008
8	BK-1993	Bai-Kiyat I	Cultural level	Cattle	0.709195	0.000007
9	BK-94-198	Bai-Kiyat I	Cultural level	Sheep	0.709636	0.000010
10	BK-94-216	Bai-Kiyat I	Cultural level	Sheep	0.709578	0.000004
11	BK-94-464	Bai-Kiyat I	Cultural level	Sheep	0.709657	0.000009
12	BK-94-no number	Bai-Kiyat I	Cultural level	Sheep	0.709291	0.000012
13	DB3888	Dolgii Bugor	Household pit 1	Sheep or goat	0.710071	0.000009
14	DB3889	Dolgii Bugor	Household pit 2	Sheep or goat	0.709965	0.000015
15	DB3887	Dolgii Bugor	Household pit 3	Sheep or goat	0.708998	0.000012

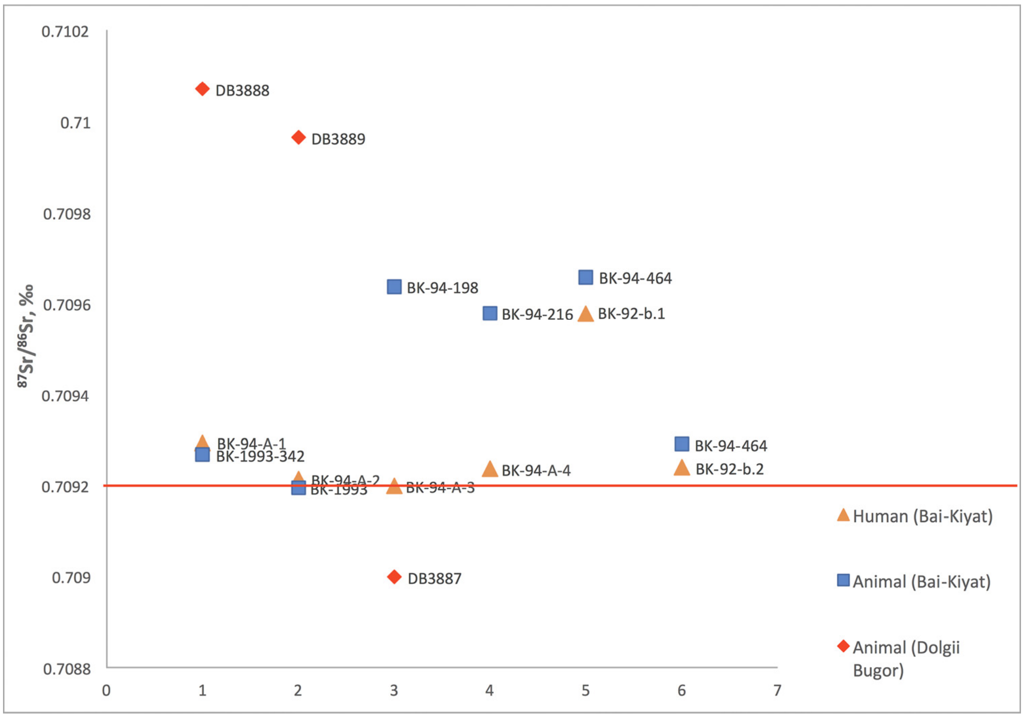

Figure 2. $^{87}Sr/^{86}Sr$ isotope ratios from the samples from Bai-Kiyat I and Dolgii Bugor sites.

The next group of samples includes a 35–40-year-old male bone sample from burial 1 (BK-92-b.1) with a value of 0.709577. The ratios of strontium isotopes in sheep bones BK-94-198, BK-94-216, and BK-94-464 are close to this value, respectively, 0.709636, 0.709578, and 0.709657.

At the Dolgii Bugor site, based on strontium signatures, one can distinguish a group of sheep/goat bone samples with high values (DB3888, DB3889) of 0.710071 and 0.709965. One sample (DB3887) differs from all other samples studied and is characterized by a reduced value (0.708998).

5. Discussion

Comparison of the obtained data makes it possible to identify differences between the studied individuals at the local level (Figure 2). The settlement of Bai-Kiyat I is located on the sea coast, so the proxy line for this area will correspond to the value of the ratio of strontium isotopes in seawater (0.7092) [5,53,54]. In coastal marine areas in soils, the ratio of strontium isotopes corresponds to the values in seawater (0.7092), because sea salts accumulate in soils. They are accumulated in human organisms in the process of their life. The presence of mollusks found on the site is evidence also of the people using marine products. It can be argued that the child BK-94-A-2 was born and raised in this area, at the settlement of Bai-Kiyat I. The individuals BK-94-A-3, BK-94-A-4, and BK-92-b.2 were also residents of the Bai-Kiyat I settlement and grew up in this region. The results obtained for cattle bones (BK-1993) indicate the low mobility of cattle within the area of settlement.

The data on the human (BK-94-A-1) and sheep (BK-1993-342, BK-94) most likely indicate that this group (2) lived away from the coastal part of the peninsula. Possibly, they permanently inhabited the area of seasonal pastures or cattle pens but had a close connection with the settlement area.

The results obtained for man BK-92-b.1 and sheep BK-94-198, BK-94-216, and BK-94-464 included in group 3 indicate that this individuum and the animals spent most of their lives in another geochemical province, differing in strontium signature from the sea coast and near area.

So, there are clear differences between the $^{87}Sr/^{86}Sr$ in human and animal bones from the Bai-Kiyat I and Dolgii Bugor sites. These data were compared to $^{87}Sr/^{86}Sr$ data on the geological provinces of the Crimean Peninsula and adjacent territories, as well as data on strontium signatures in archaeological bones from the Bronze Age–Early Iron Age, Antiquity, and Medieval Age sites of the Northern Black Sea region (Table 2). The closest values of strontium isotopes to the samples under consideration are observed with the areas of development of Cenozoic carbonate rocks (0.7090–0.7110), which are widely developed within the Tarkhankut upland plain, as well as within the Kerch-Taman region. The Dolgii Bugor monument is located in the area of Upper Triassic–Lower Jurassic deposits. The strontium signature for the Mesozoic complex deposits is 0.7085, which is close to the values of the bone sample DB3887 from this site. The other two bone samples belonging to sheep have higher values (0.7099–0.7100). From the medieval tomb in Gorzuvity, located in the mountainous part, the values of the strontium signature were obtained from the soils (0.7141) and for the bones of the buried humans (0.7099–0.7100) [55]. The comparison to bones from the Dolgii Bugor site allows us to assume that sheep constantly grazed on pastures in the higher mountain regions of the southern coast of Crimea.

In the plain part of Crimea, the $^{87}Sr/^{86}Sr$ ratio is >0.7090. In this region, loess deposits associated with Cenozoic carbonates and aluminosilicate material of clayey rocks of different ages are widespread [56]. It should be noted that Quaternary deposits, represented by loess formed in flat areas, have similar strontium isotopic ratios. Thus, values for lowland loess in Central Europe are in the range from 0.7080 to 0.7100 based on the data of previous studies [16]. A similar level of values is also observed for the loess deposits of the Great Hungarian Plain and in the steppe zone of the Northern Black Sea region (Table 2). Skeleton remains from archaeological sites located in this territory are also characterized by similar $^{87}Sr/^{86}Sr$ ratios. The samples of group 3 from the Bai-Kiyat I site have $^{87}Sr/^{86}Sr$ ratios that are close to the archaeological bones from sites located in the steppe zone of the territory of Ukraine (Table 2): Eneolithic, Yamnaya, and Catacomb cultures from the Peshtchanka site (0.7104) and from the Vinogradnoe site (0.7098); Iron Age/Scythian culture from the Alexandropol site (0.7099), the Babina Mogila site (0.7097), and the Drana Kokhta site (0.7103); and from the Zolotaya Balka site (0.7099) [57], as well as from the Abony 36 (0.70909–0.70953) and Vésztö-Bikeri (0.70934–0.71026) sites on the Great Hungarian Plain [58]. The animals and the person from Burial 1 (BK-92-b.1) that belonged to group 3 probably lived for a long time in the inner steppe part of Crimea or even beyond it (Figure 3).

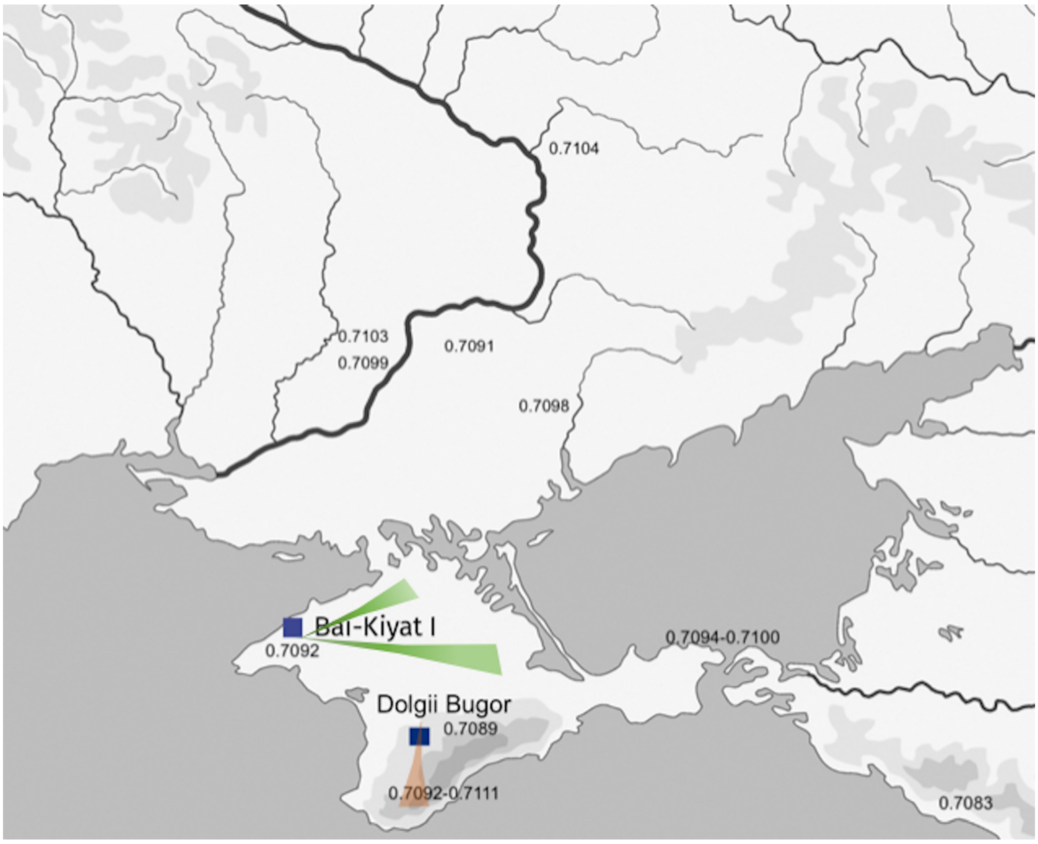

Figure 3. Mobility of inhabitants of the Bai-Kiyat I and Dolgii Bugor settlements in the Crimean Peninsula region.

Data of the strontium isotopes obtained for archaeological bones from the Late Bronze Age sites located in the Caucasus [59] (Table 1) have significant differences from a studied complex of bone samples. Therefore, this geochemical province can be excluded from consideration for the assessment of the studied samples.

Table 2. The $^{87}Sr/^{86}Sr$ data on the geological provinces of the Crimean Peninsula and adjacent territories, and data on strontium signatures in archaeological bones from the sites of the Northern Black Sea region.

Region	$^{87}Sr/^{86}Sr$	Reference
GEOLOGICAL BACKGROUND		
The Northern Black Sea region		
Cenozoic substrates (bulk rock)	0.7090–0.7110	[57]
Precambrian substrates (crystalline and metamorphic rocks)	0.7120–0.7800	[57]
Mesozoic substrates (bulk rock)	0.7070–0.7090	[57]

Table 2. *Cont.*

Region	$^{87}Sr/^{86}Sr$	Reference
Paleozoic substrates (bulk rock)	0.711–0.713	[55]
Cretaceous sedimentary carbonates (Kerch-Taman region), bulk rock	0.707	[56]
Cenozoic carbonates (Taman region), bulk rock	>0.709	[56]
Upper Jurassic limestones (bulk rock)	0.70701–0.70710	[60]
The Caucasus region		
Sediments of the Late Neopleistocene (Khvalinian)	0.70832–0.70859	[61]
Limestones–Sarmatian stage–Neogene	0.708542 ± 0.00001	[61]
Transcaucasia (sedimentary rocks of the Eopleistocene and Neopleistocene–Holocene)	0.70727–0.70766	[61]
The Caucasian foothill zone at ca. 500–800 m asl with sediments of the Eocene and the Oligocene	0.70792–0.70873	[59]
The foothills of the Mt. Elbrus massive at the boundary of Devonian bedrock and a Pleistocene lava-field	0.70829–0.70921	[59]
The Carpathian-Danube region		
The Great Hungarian Plain	0.70866–0.71147	[62]
N Transcarpathian Basin	0.70881–0.70910	[58]
Danube and Tisza Rivers (water)	0.70890–0.70960	[58]
ARCHAEOLOGICAL MATERIALS FROM SITES		
Vinogradnoe site (Ukraine), Eneolithic, Yamnaya, and Catacomb cultures	0.7098 ± 0.0003	[57]
Peshtchanka site (Ukraine), Eneolithic, Yamnaya, and Catacomb cultures	0.7104 ± 0.0008	[57]
Alexandropol site (Ukraine), Iron Age/Scythian culture	0.7099 ± 0.0006	[57]
Babina Mogila site (Ukraine), Iron Age/Scythian culture	0.7097 ± 0.0010	[57]
Drana Kokhta site (Ukraine), Iron Age/Scythian culture	0.7103 ± 0.0020	[57]
Mamai-Gora site (Ukraine), Iron Age/Scythian culture	0.7091–0.7113	[57]
Zolotaya Balka site (Ukraine), Iron Age/Scythian culture	0.7099 ± 0.0005	[57]
Tomb in Gurzufiti, Middle Ages (Crimea)	0.7092–0.7111	[55]
"Temple near the village Veseloe" (eastern part of the Imereti Lowland), Middle Ages	0.708295 ± 0.0014	[63]
Phanagoria (Taman), 3rd cent. BC–5th cent. AD	0.709453–0.71002	[64]
Ransyrt-1 (the North Caucasus), early Late Bronze Age ritual site	0.70786–0.70889	[59]
Gumbashi-1 (the North Caucasus), Late Bronze Age 2	0.70849–0.70979	[59]
Vésztö-Bikeri (Great Hungarian Plain)	0.70934–0.71026	[58]
Abony 36 (Great Hungarian Plain)	0.70909–0.70953	[58]
Ampoiţa-Doştior, Ampoiţa-Peret, Meteş-La Meteşel, Livezile (Transylvanian Basin), and Early Bronze Age	0.7091–0.7105	[65]
Padina, Lepenski Vir, Vlasac, Hajdučka, Vodenica, Icoana (the Danube Gorges), and Mesolithic–Neolithic	0.7091–0.7095	[66]
Alicenhof–Zwingendorf (Austria), Bell Beaker period	0.7103–0.7106	[67]

The data on the herd have similarities with data in the settlements of Belozerka culture located in the Northwestern Black Sea region: at the settlement of Voronovka II, the horse (27.4%) took second place [68], and at the Taraclia-Gaidabul settlement, the horse (20%) was in third place after cattle (51%) and sheep/goats (25%) [69]. Probably, the horse could be used not only as meat in the diet of the people, but shepherds could use it for riding to pastures which were away from the settlement. The fact of using a horse for riding is confirmed here by two cheek bone pieces at the settlement of Bai-Kiyat I, as well as cheek and horn bone pieces at other Late Bronze Age sites in Crimea (Fontany, Chuyuncha, and Druzhnoe 2) [23]. It is worth noting that in Bai-Kiyat I there are no obvious premises for keeping livestock, but on the Tarkhankut Peninsula, more than 50 archaeological sites are already known where the stone walls of cattle pens were recorded [70]. The radiocarbon dates obtained for some of these cattle pens show that they are synchronous with the Bai-Kiyat I site. For example, the Tarkhankut-H8 site of the Belozerka culture dated to ca. 1125–941 calBC [70]. It is possible that the cattle pens were used by inhabitants of several settlements in the region.

An analysis of the available data on the strontium isotopes of the geological provinces of the steppe zone of Crimea and adjacent territories, as well as for the remains of people and animals from the archaeological sites of the Northern Black Sea region, shows similar values that are typical for this entire territory. These data indicate that the steppe zone was an ecumene, within which active mobility of groups of people was registered. This mobility is associated primarily with the pastoral type of economy in the period from the Chalcolithic to the Early Iron Age [19,57,58]. An anthropological analysis of human skulls was carried out by Alisa V. Zubova (MAE RAS, Kunstkamera Museum, St. Petersburg). This analysis from a craniological point of view showed that people buried in the Bai-Kiyat I settlement are characterized by an average massiveness of the skull, mesocrania, possibly with a tendency towards brachycrania, sharp profiling of the facial skeleton, and medium-high protrusion of nasal bones. The morphological characteristics of skulls and the dental system are typical for the population of the steppe zone of the East European Plain during the Bronze Age (populations of Yamnaya and Catacomb culture). The investigation demonstrates the absence of eastern features, and the presence of some markers that are typical for southern European orientation (extreme gracilization of the lower third molar and convexity of the upper incisors). These data also indicate close interaction between the populations of the steppe zone of the Northern Black Sea region over several millennia.

6. Conclusions

The results obtained regarding strontium isotopes in human and animal bones from the Bai-Kiyat I and Dolgiy Bugor sites give information about the local mobility of people and domestic animals from these settlements. At Bai-Kiyat settlement I, three groups, including people and domestic animals living in different geological provinces, were distinguished.

Group 1—"local" residents. They include a 7–8-year-old who was born and grew up at the settlement, as well as three men aged 40–50 years old. This group also includes a cow that grazed within the settlement;

Group 2—sheep and a person that lived at some distance from the Bai-Kiyat I settlement. Probably, these animals and humans permanently lived in the area of pastures for livestock and cattle pens, not in the shore zone;

Group 3—"migrants" from the interior of the flat part of the Peninsula or the mainland. This group includes the a 35–40-year-old man and sheep.

At the Dolgii Bugor site, two groups of sheep and goats were differed:

Group 1—sheep that grazed near the settlement;

Group 2—sheep and goats, pastured in the mountainous part of the Southern Coast of Crimea.

This information can be used as a model of explanation for nonpermanent residents of this settlement (people and sheep of groups 2 and 3). The differentiation of geological rocks of the Crimean Peninsula allowed for the reconstruction of the local mobility of people and animals inside the region with the help of strontium isotopy. On the other hand, strontium signatures in archaeological bones can be applied as a marker of cultural and social transformations in space and time. In this context, inhabitants of the steppe zone of the East European Plain during the Bronze Age could move long distances and their strontium signatures did not change at all.

The results obtained present the first investigations of the people and domestic animal mobility on the Crimean Peninsula in the Late Bronze–Early Iron Age based on isotope geochemical markers. Further work in the determination of strontium signatures in zoological and anthropological remains at sites of this period, as well as in modern samples of soil, water, and plants will expand these data.

Author Contributions: Conceptualization, M.A.K. and M.T.K.; Data curation, M.A.K., M.T.K., Y.V.K. and V.A.T.; Formal analysis and Investigation, M.A.K., A.M.K. and M.T.K.; Methodology, M.A.K., M.T.K. and A.M.K.; Project administration, M.A.K.; Visualization, M.A.K., M.T.K. and A.M.K.; Writing—original draft, M.A.K.; Writing—review and editing, M.A.K. and M.T.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Russian Science Foundation (RSF), grant number 22-18-00065, "Cultural and historical processes and paleoenvironment in the Late Bronze-Early Iron Age of the North-Western Black Sea region: interdisciplinary approach" https://rscf.ru/project/22-18-00065/, accessed on 16 April 2024.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Acknowledgments: The authors wish to thank D.V. Kiseleva for analysis of strontium isotopes.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of this study; interpretation of the data; or in the writing of the manuscript.

References

1. Price, T.D.; Johnson, C.M.; Ezzo, J.A.; Burton, J.H.; Ericson, J.A. Residential mobility in the prehistoric Southwest United States. A preliminary study using strontium isotope analysis. *J. Arch. Sci.* **1994**, *24*, 315–330. [CrossRef]
2. Bentley, R.A. Strontium Isotopes from the Earth to the Archaeological Skeleton: A Review. *J. Archaeol. Method Theory* **2006**, *13*, 135–187. [CrossRef]
3. Grupe, G.; Price, T.D.; Schröter, P.; Söllner, F.; Johnson, C.M.; Beard, B.L. Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: A study of southern Bavarian skeletal remains. *Appl. Geochem.* **1997**, *12*, 517–525. [CrossRef]
4. Borg, L.E.; Banner, J.L. Neodymium and strontium isotopic constraints on soil sources in Barbados, West Indies. *Geochim. Cosmochim. Acta* **1996**, *60*, 4193–4206. [CrossRef]
5. Chadwick, O.A.; Derry, L.A.; Vitousek, P.M.; Huebert, B.J.; Hedin, L.O. Changing sources of nutrients during four million years of ecosystem development. *Nature* **1999**, *397*, 491–497. [CrossRef]
6. Gallet, S.; Jahn, B.M.; Lanoe, B.V.; Dia, A.; Rossello, E. Loess geochemistry and its implications for particle origin and composition of the upper continental crust. *Earth Planet. Sci. Lett.* **1998**, *156*, 157–172. [CrossRef]
7. Whipkey, C.E.; Capo, R.C.; Chadwick, O.A.; Stewart, B.W. The importance of sea spray to the cation budget of a coastal Hawaiian soil: A strontium isotope approach. *Chem. Geol.* **2000**, *168*, 37–48. [CrossRef]
8. Montgomery, J.; Evans, J.A.; Roberts, C.A. The mineralization, preservation and sampling of teeth: Strategies to optimise comparative study and minimise age-related change for lead and strontium analysis. *Am. J. Phys. Anthropol. Suppl.* **2003**, *36*, 153.
9. Montgomery, J.; Evans, J.A. Immigrants on the Isle of Lewis—Combining traditional funerary and modern isotope evidence to investigate social differentiation, migration and dietary change in the Outer Hebrides of Scotland. In *The Social Archaeology of Funerary Remains*; Gowland, R., Knüsel, C., Eds.; Oxbow: Oxford, UK, 2006; pp. 122–142. ISBN 1842172115.
10. Jowsey, J. Age changes in human bone. *Clin. Orthop.* **1961**, *17*, 210–218.
11. Price, T.D.; Burton, J.H.; Bentley, R.A. The characterisation of biologically-available strontium isotope ratios for investigation of prehistoric migration. *Archaeometry* **2002**, *44*, 117–135. [CrossRef]
12. Tafuri, M.A.; Bentley, R.A.; Manzi, G.; di Lernia, S. Mobility and kinship in the prehistoric Sahara: Strontium isotope analysis of Holocene human skeletons from the Acacus Mts. (southwestern Libya). *J. Anthropol. Archaeol.* **2006**, *25*, 390–402. [CrossRef]
13. Haverkort, C.M.; Weber, A.; Katzenberg, M.A.; Goriunova, O.I.; Simonetti, A.; Creaser, R.A. Hunter-gatherer mobility strategies and resource use based on strontium isotope ($^{87}Sr/^{86}Sr$) analysis: A case study from Middle Holocene Lake Baikal, Siberia. *J. Arch. Sci.* **2008**, *35*, 1265–1280. [CrossRef]
14. Bentley, R.A.; Knipper, C. Geographic patterns in biologically-available strontium, carbon and oxygen isotopes signatures in prehistoric SW Germany. *Archaeometry* **2005**, *47*, 629–644. [CrossRef]
15. Bentley, R.A. Human Migration in Early Neolithic Europe: A Study by Strontium and Lead Isotope Analysis of Archaeological Skeletons. Ph.D. Thesis, Department of Anthropology, University of Wisconsin, Madison, WI, USA, 2001.
16. Bentley, R.A. Characterising human mobility by strontium isotope analysis of the skeletons. In *Khok Phanom Di: Summary and Conclusions*; Higham, C.F.W., Thosarat, R., Eds.; Oxbow Books: Oxford, UK, 2004; pp. 159–166. ISBN 0-85432-282-X.
17. Chiaradia, M.; Gallay, A.; Todt, W. Differential lead and strontium contamination styles of prehistoric human teeth at a Swiss necropolis (Sion, Valais). *Appl. Geochem.* **2003**, *18*, 353–370. [CrossRef]

18. Kaiser, E.; Tuboltsev, O.; Benecke, N.; Evershed, R.P.; Hochmuth, M.; Mileto, S.; Riesenberg, M. Der Fundplatz Generalka 2 der Jamnaja-Kultur in der Südukraine. Archäologische Und Naturwissenschaftliche Untersuchungen. *Praehist. Z.* **2020**, *95*, 376–421. [CrossRef]
19. Gerling, C.; Eger, J.; Gak, E.; Kaiser, E. Isotopic perspectives on pastoral practices in the Eastern European forest-steppe during the Middle Bronze Age. *J. Arch. Sci. Rep.* **2024**, *54*, 104392. [CrossRef]
20. Ericson, J.E. Strontium isotope characterization in the study of prehistoric human ecology. *J. Hum. Evol.* **1985**, *14*, 503–514. [CrossRef]
21. Ericson, J.E. Some problems and potentials for strontium isotope analysis for human and animal ecology. In *Stable Isotopes in Ecological Research*; Rundel, P.W., Ehleringer, J.R., Nagy, K.A., Eds.; Springer: New York, NY, USA, 1989; pp. 252–259.
22. Sealy, J.C.; Sillen, A. Sr and Sr/Ca in marine and terrestrial foodwebs in the southwestern Cape, South-Africa. *J. Arch. Sci.* **1988**, *15*, 425–438. [CrossRef]
23. Kolotukhin, V.A. *Pozgniy Bronzovyi vek Kryma [Late Bronze Age of Crimea]*; Stilos Publ.: Kiev, Ukraine, 2003. (In Russian)
24. Kashuba, M.T.; Malyutina, A.A.; Kulkov, A.M.; Kozhukhovskaya, Y.V.; Kulkova, M.A. O funktsional'noy sposobnosti ispol'zovaniya nizhney chelyusti zhivotnykh v khozyaystvakh pozdnego bronzovogo veka (po nakhodkam iz poseleniy Bay-Kiyat I, poluostrov Tarkhankut) [About the functionality of the animal lower jaw in the economy of the Late Bronze Age (from finds of Bay-Kiyat I settlement, Tarkhankut peninsula)]. *Samara J. Sci.* **2023**, *12*, 140–149. (In Russian) [CrossRef]
25. Tikhomirov, V.A.; Kropotov, V.V. Issledovaniye goroda Dolgiy Bugor v 2020 godu [Research of the Dolgii Bugor fortified settlement in 2020]. *Hist. Archaeol. Crimea* **2021**, *15*, 145–151. (In Russian)
26. Yudin, V.V. Geologiya i geodinamika Tarkhankutskogo poluostrova [Geology and geodynamics of the Tarkhankut Peninsula]. In *Azov-Black Sea Testing Ground for Studying Geodynamics and Fluid Dynamics of the Formation of Oil and Gas Fields, Proceedings of XI International Conference "Crimea-2013", Simferopol, Crimean Peninsula*; Crimean Academy of Sciences: Simferopol, Ukraine, 2013; pp. 107–121. (In Russian)
27. Yudin, V.V. *Geodinamika Kryma [Geodynamics of Crimea]*; DIP: Simferopol, Crimean Peninsula, 2011. (In Russian)
28. Dublyansky, Y.V.; Klimchouk, A.B.; Tokarev, S.V.; Amelichev, G.N.; Spötl, C. Geology and hydrogeology of Crimea. Supplemental materials to: Groundwater of the Crimean peninsula: A first systematic study using stable isotopes. *Isot. Environ. Health Stud.* **2019**, *12*, 419–437. [CrossRef]
29. Zubova, A.V.; Kulkov, A.M.; Kulkova, M.A.; Moiseyev, V.G.; Kashuba, M.T.; Potrakhov, N.N.; Bessonov, V.B.; Kozhukhovskaya, Y.V. *Chronic Maxillary Sinusitis in Ancient Populations: X-ray Computed Microtomography Data*; Springer: Cham, Switzerland, 2023; pp. 141–152. [CrossRef]
30. Collins, M.J.; Riley, M.S. Amino acid racemization in biominerals, the impact of protein degradation and loss. In *Perspectives in Amino Acid and Protein Geochemistry*; Goodfriend, G.A., Collins, M.J., Fogel, M., Macko, S., Wehmiller, J.F., Eds.; Oxford University Press: Oxford, UK, 2000; pp. 120–142.
31. Hedges, R.E.M. Bone diagenesis: An overview of processes. *Archaeometry* **2002**, *44*, 319–328. [CrossRef]
32. Hoppe, K.A.; Koch, P.L.; Furutani, T.T. Assessing the preservation of biogenic strontium in fossil bones and tooth enamel. *Int. J. Osteoarchaeol.* **2003**, *13*, 20–28. [CrossRef]
33. Lee-Thorp, J.A. Two decades of progress towards understanding fossilization processes and isotopic signals in calcified tissue minerals. *Archaeometry* **2002**, *44*, 435–446. [CrossRef]
34. Nelson, B.K.; DeNiro, M.J.; Schoeninger, M.J.; DePaolo, D.J.; Hare, P.E. Effects of diagenesis on strontium, carbon, nitrogen, and oxygen concentration and isotopic composition of bone. *Geochim. Cosmogeochimica Acta* **1986**, *50*, 1941–1949. [CrossRef]
35. Nielsen-Marsh, C.M.; Hedges, R.E.M. Patterns of diagenesis in bone I: The effects of site environments. *J. Archaeol. Sci.* **2000**, *27*, 1139–1150. [CrossRef]
36. Tuross, N.; Behrensmeyer, A.K.; Eanes, E.D. Strontium increases and crystallinity changes in taphonomic and archaeological bone. *J. Arch. Sci.* **1989**, *16*, 661–672. [CrossRef]
37. Robinson, S.; Nicholson, R.A.; Pollard, A.M.; O'Connor, T.P. An evaluation of nitrogen porosimetry as a technique for predicting taphonomic durability in animal bone. *J. Arch. Sci.* **2003**, *30*, 391–403. [CrossRef]
38. Horn, P.; Müller-Söhnius, D. Comment on 'Mobility of Bell Beaker people revealed by Sr isotope ratios of tooth and bone: A study of southern Bell Beaker skeletal remains. ' *Appl. Geochem.* **1999**, *14*, 163–169.
39. Nielsen-Marsh, C.M.; Hedges, R.E.M. Patterns of diagenesis in bone II: Effects of acetic acid treatment and removal of diagenetic CO_3. *J. Arch. Sci.* **2000**, *27*, 1151–1159. [CrossRef]
40. Sillen, A.; Sealy, J.C. Diagenesis of strontium in fossil bone: A reconsideration of Nelson *et al.* (1986). *J. Arch. Sci.* **1995**, *22*, 313–320. [CrossRef]
41. Koch, P.L. Isotopic Reconstruction of Past Continental Environments. *Annu. Rev. Earth Planet. Sci.* **1998**, *26*, 573–613. [CrossRef]
42. Sillen, A. Biogenic and diagenetic Sr/Ca in Plio-Pleistocene fossils in the Omo Shungura Formation. *Paleobio* **1986**, *12*, 311–323. [CrossRef]
43. Sillen, A. Diagenesis of the inorganic phase of cortical bone. In *The Chemistry of Prehistoric Human Bone*; Price, T.D., Ed.; Cambridge University Press: Cambridge, UK, 1989; pp. 211–229.
44. Driessens, F.C.M.; Verbeeck, R.M.H. *Biominerals*; CRC Press: Boston, MA, USA, 1990; ISBN 0-8493-5280-0.
45. Fabig, A.; Herrmann, B. Trace elements in buried human bones: Intra—population variability of Sr/Ca and Ba/Ca ratios—Diet or diagenesis? *Naturwissenschaften* **2002**, *89*, 115–119. [CrossRef]

46. Kohn, M.J.; Schoninger, M.J.; Barker, W.W. Altered states: Effects of diagenesis on fossil tooth chemistry. *Geochim. Cosmochim. Acta* **1999**, *63*, 2737–2747. [CrossRef]
47. Corti, C.; Rampazzi, L.; Ravedoni, C.; Giussani, B. On the use of trace elements in ancient necropolis studies: Overview and ICP-MS application to the case study of Valdaro site, Italy. *Microchem. J.* **2013**, *110*, 614–623. [CrossRef]
48. Muynck, D.D.; Huelga-Suarez, G.; Heghe, L.V.; Degryse, P.; Vanhaecke, F. Systematic evaluation of a strontium-specific extraction chromatographic resin for obtaining a purified Sr fraction with quantitative recovery from complex and Ca-rich matrices. *J. Anal. At. Spectrom.* **2009**, *24*, 1498–1510. [CrossRef]
49. Kasyanova, A.V.; Streletskaya, M.V.; Chervyakovskaya, M.V.; Kiseleva, D.V. A method for 87Sr/86Sr isotope ratio determination in biogenic apatite by MC-ICP-MS using the SSB technique. *Am. Inst. Phys. Conf. Proc.* **2019**, *2174*, 020028. [CrossRef]
50. Nier, A.O. The Isotopic Constitution of Strontium, Barium, Bismuth, Thallium and Mercury. *Phys. Rev.* **1938**, *54*, 275–278. [CrossRef]
51. Kiseleva, D.V.; Shagalov, E.S.; Zaytseva, M.V.; Streletskaya, M.V.; Karpova, S.V. Izotopno-geokhimicheskoye (Sr, Pb) issledovaniye razreza pochvenno-rastitelnogo sloya v rayone arkheologicheskikh pamyatnikov epokhi bronzy na Yuzhnom Urale [Isotope-geochemical (Sr, Pb) study of the soil-vegetation layer section in the area of Bronze Age archaeological sites in the Southern Urals]. *Geoarchaeology Archaeol. Mineral.* **2018**, *5*, 37–41. (In Russian)
52. Kiseleva, D.V.; Ankusheva, P.S.; Ankushev, M.N.; Okuneva, T.G.; Shagalov, E.S.; Kasyanova, A.V. Opredeleniye fonovykh izotopnykh otnosheniy biodostupnoy strontsii dlya rudnika bronzovogo veka Novotemirskiy [Determination of background isotope ratio of bioavailable strontium for the Bronze Age mine Novotemirsky]. *KSIA* **2021**, *263*, 176–187. (In Russian) [CrossRef]
53. Kuznetsov, A.B.; Semikhatov, M.A.; Gorokhov, I.M. The Sr isotope composition of the world ocean, marginal and inland seas: Implications for the Sr isotope stratigraphy. *Stratigr. Geol. Correl.* **2012**, *20*, 501–515. [CrossRef]
54. Kuznetsov, A.B.; Konstantinova, G.V.; Mel'nikov, N.N.; Turchenko, T.L. Sr isotope composition in inland seas of the Mediterranean-Black Sea belt. *Dokl. Earth Sci.* **2011**, *439*, 1026–1029. [CrossRef]
55. Dobrovolskaya, M.V.; Mastykova, A.V. Izotopnyye issledovaniya skeletnykh ostantsev lyudey iz grobnits khrama v Gorzuvitakh: Khronologiya, osobennosti pitaniya, mobil'nost [Stable isotope studies of the deceased from the sepulchral vault at Gorzuvity: Chronology, diet pattern and mobility]. *KSIA* **2020**, *260*, 428–440. (In Russian) [CrossRef]
56. Aydarkozhina, A.S.; Lavrushin, V.Y.; Kuznetsov, A.B.; Sokol, E.V.; Kramchaninov, A.Y. Izotopnyi sostav strontsiya v vodakh gryazevykh vulkanov Kerchensko-Tamanskoy oblasti. 2021 g. [Sr Isotope Composition of Mud Volcanic Waters in the Kerch–Taman Province. 2021]. *Dokl. Earth Sci.* **2021**, *499*, 19–25. (In Russian)
57. Miller, A.R.V.; Johnson, J.; Makhortykh, S.; Gerling, C.; Litvinova, L.; Andrukh, S.; Toschev, G.; Zech, J.; le Roux, P.; Makarewicz, C.; et al. Re-evaluating Scythian lifeways: Isotopic analysis of diet and mobility in Iron Age Ukraine. *PLoS ONE* **2021**, *16*, e0245996. [CrossRef]
58. Giblin, J.I.; Knudson, K.J.; Bereczki, Z.; Pálfi, G.; Pap, I. Strontium isotope analysis and human mobility during the Neolithic and Copper Age: A case study from the Great Hungarian Plain. *J. Arch. Sci.* **2013**, *40*, 227–239. [CrossRef]
59. Reinhold, S.; Eger, J.; Benecke, N.; Knipper, C.; Mariaschk, D.; Hansen, S.; Pichler, S.L.; Gerling, C.; Buzhilova, A.P.; Mishina, T.A.; et al. At the onset of settled pastoralism—Implications of archaeozoological and isotope analyses from Bronze age sites in the North Caucasus. *Quat. Int.* 2023; *in press*. [CrossRef]
60. Rud'ko, S.V.; Kuznetsov, A.B.; Piskunov, V.K. Sr Isotope Chemostratigraphy of Upper Jurassic Carbonate Rocks in the Demerdzhi Plateau (Crimean Mountains). *Stratigr. Geol. Correl.* **2014**, *22*, 494–505. [CrossRef]
61. Shishlina, N.I.; Larionova, Y.O.; Idrisov, I.A.; Azarov, E.S. Variatsii izotopnogo sostava strontsiya v obrastsach sovremennykh ulitok vostochnoy chasti Kavkaza [Variations in the isotopic composition of strontium in samples of modern snails from the eastern part of the Caucasus]. *Arid. Ecosyst.* **2016**, *22*, 32–40. (In Russian)
62. Depaermentier, M.L.C.; Kempf, M.; Bánffy, E.; Kurt, W.A. Modelling a scale-based strontium isotope baseline for Hungary. *J. Arch. Sci.* **2021**, *135*, 105489. [CrossRef]
63. Shvedchikova, T.Y.; Charlamova, N.V.; Rasskazova, A.V.; Chagarov, O.S. Srednevekovoe naselenie Severo-Vostochnogo Prichernomoriya (po materialam raskopok chistianskogo chrama u s. Veseloe IX–XI vv.) [Medieval population of North-East Black Sea region (according to materials from the Christian church near Veseloe 9–11th cent.)]. *Her. Anthropol.* **2016**, *2*, 94–116. (In Russian)
64. Svirkina, N.G. *Naseleniye Fanagorii v III v. do n.e.—V v. n.e. (po Paleoantropologicheskim Materialam iz Vostochnogo Nekropolya) [Population of Phanagoria in the 3rd Century BC—V Century AD (Based on Paleoanthropological Materials from the Eastern Necropolis)]*; Abstract of the Dissertation for the Degree of Candidate of Historical Sciences (5.6.3); Institute of the Archaeology of the RAS: Moscow, Russia, 2022. (In Russian)
65. Gerling, C.; Ciugudean, H. Insights into the Transylvanian Early Bronze Age Using Strontium and Oxygen Isotope Analysis: A Pilot Study. In *Transitions to the Bronze Age. Interregional Interactions and Socio-Cultural Change in the Third Millennium BC Carpathian Basin and Neighbouring Regions*; Heyd, V., Kulcsár, G., Szeverényi, V., Eds.; Archaeolingua: Budapest, Hungary, 2013; pp. 181–202.
66. Borić, D.; Price, T.D. Strontium Isotopes Document Greater Human Mobility at the Start of the Balkan Neolithic. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 3298–3303. [CrossRef] [PubMed]
67. Price, T.D.; Knipper, C.; Grupe, G.; Smrcka, V. Strontium Isotopes and Prehistoric Human Migration: The Bell Beaker Period in Central Europe. *Eur. J. Archaeol.* **2004**, *7*, 10–40. [CrossRef]

68. Vanchugov, V.P. Belozerskiye pamyatniki v Severo-Zapadnom Prichernomorye. In *Problema Formirovaniya Belozerskoy Kul'tury [Belozersk Sites in the North-Western Black Sea Region. The Problem of the Formation of Belozersk Culture]*; Naukova Dumka: Kiev, Ukraine, 1990; ISBN 5-12-001514-X. (In Russian)
69. Sava, E.; Kaiser, E.; Sîrbu, M. Nekotoryye rezultaty issledovaniy na poseleniyakh kompleksa kultur Noua-Sabatinovka-Koslozheni, raspolozhennyk v yuzhnoy chasti Respubliki Moldova [Some results of research on the settlements of the Noua-Sabatinovka-Coslogeni cultural complex located in the southern part of the Republic of Moldova]. In *Connections, Contacts and Interactions of the Ancient Cultures of Northern Eurasia and the Civilizations of the East in the paleometal Era (4th–1st Millennium BC): Proceedings of the International Conference*; Polyakov, A.V., Tkach, E.S., Eds.; IHMC RAS, Neva Typography: St. Petersburg, Russia, 2019; pp. 169–171. (In Russian)
70. Kashuba, M.T.; Smekalova, T.N.; Kulkova, M.A.; Gurov, E.Y. New Results of Interdisciplinary Study of Bronze Age Settlements in Northwestern Crimea. *Vestn. St. Petersburg Univ. Hist.* **2021**, *66*, 1270–1295. [CrossRef]