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CHAPTER NINETEEN

UNDERSTANDING THE PRODUCTIVE ECONOMY DURING THE BRONZE AGE THROUGH ARCHAEOMETALLURGICAL AND PALAEO-ENVIRONMENTAL RESEARCH AT KARGALY (SOUTHERN URALS, ORENBURG, RUSSIA)

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Introduction: Research Design

Vast regions of Eurasia have little or no copper ore. Accordingly, Evgenii Chernykh (1992; 1993; Chernij *et al*. 1990; Chernykh, Avilova *et al*. 2000; 2002) has posited that metallurgy is the critical factor for understanding the long-distance interactions of eastern European and north-west Asian societies from the Chalcolithic to the Iron Age. He has defined various metallurgical provinces based on the technical and typological characteristics of the centres of metalworking and/or production. The oldest and most important mining and metallurgical centre of the great Eurasian steppes is Kargaly. Production at this centre corresponds to the successive Circumpontic and Euroasiatic Metallurgical Provinces (Chernykh 1996, 87–8). The copper deposits of Kargaly lie in the steppe in Orenburg *oblast*, about 150 km north-west of its capital city. Kargaly's 11 principal mining districts cover about 500 km^2 (Fig. 1).

Since 1990, the Russian Academy of Sciences in Moscow has conducted research in Kargaly under Chernykh's direction. This research has shown that mining activity began in the Early Bronze Age (the Yamnaya-Poltavka culture) and peaked during the Late Bronze Age (the Srubnaya culture), which was a period of both sedentarisation and intensive metallurgical activity. At about 1400 BC, settlements were abandoned and metallurgy ceased abruptly. There is no evidence for mining until about AD 1745, when Russian industrialists began to exploit the deposits in this region again. These mining operations lasted until 1900, at which point they stopped being profitable (Chernykh, Kuzminykh *et al*. 1999; Chernykh, Lebedeva *et al.* 2002, 12, 109).

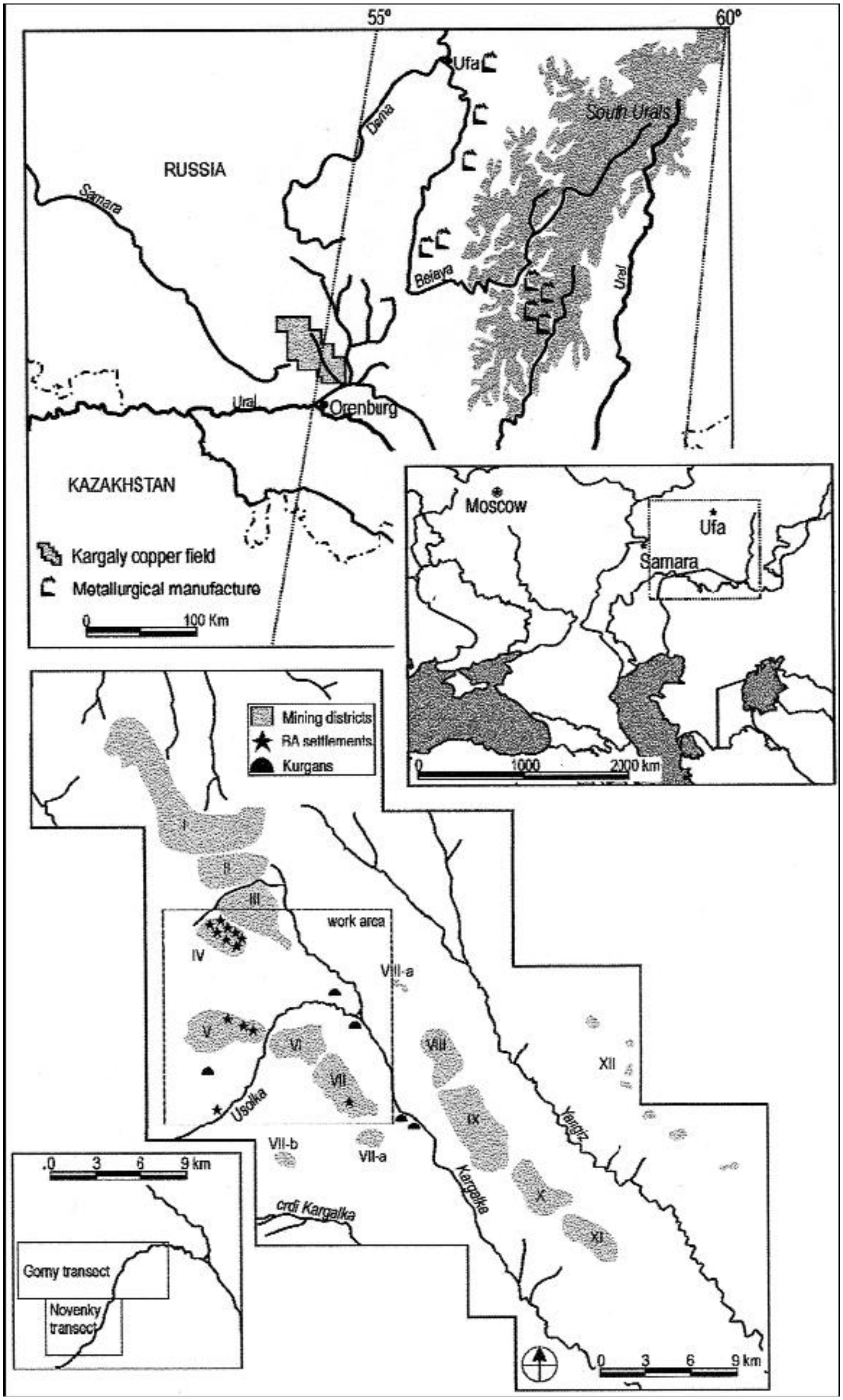


Fig. 1. Regional context of Kargaly Project and Kargaly mining districts (after Chernykh, Lebedeva *et al.* 2002, 34, fig. 2.13; 49, fig. 3.2).

Metal analyses of Early Bronze Age artefacts carried out by the Moscow Institute of Archaeology show that smelted copper from Kargaly was distributed as far as the Donets and Oka rivers (an area of nearly 1 million km^2) and that ores from Kargaly are found over an area of 80000–100000 km^2 (Chernykh 1996, 90, fig. 1; 1998b, 132, 130, fig. 1). The ore body is formed by veins and pockets of malachite in the thick layers of sandstone in the subsoil. There are no slag-heaps because copper was obtained by direct reduction of the ore, in which the resulting slag was crushed to recover entrapped metal prills and droplets (see below). We must rely on other archaeological and historical evidence in order to evaluate Kargaly mining and metallurgical production. Eighteenth-century Russian miners were guided by the remains (pits and galleries) of the prehistoric mining operations. These pits and galleries have been identified and dated by archaeological research, which has also documented domestic and funerary contexts related to them (Chernykh, Kuzminykh *et al*. 1999; 2000; Chernykh. 2002, 128–39; Zhyrbin 1999). Both phases of exploitation, Bronze Age and modern, correspond to the same archaic technology, one that only used charcoal for fuel and only smelted copper oxide ores (Chernykh 1998b, 131; 1996, 88). This evidence indicates that mining and metallurgical activities reached considerable intensity during the Bronze Age. Chernykh (1994, 63–7; 1998b, 132–3) has suggested that this intensification could well have been the cause of the sudden end of the prehistoric occupation at Kargaly (over-exploitation of the limited forests of the region would have made continued smelting impossible).

Since 1993, a multidisciplinary Russian-Spanish team has undertaken a project specifically designed to understand the prehistoric mining and metallurgical activities at Kargaly and the causes of its sudden collapse (1). These investigations have focused on the central mining zone (B) of the Kargaly complex, where Chernykh's team were conducting excavations of the mining and metallurgical site of Gorny (District V) (Fig. 1) (Rovira 1999, 2004; Vicent *et al.* 2004). Three parallel and complementary research programmes have been directed towards a comprehensive analysis of the socio-economic, metallurgical and environmental conditions of prehistoric production.

The first research programme is archaeological in focus. The Russian members of the team have conducted archaeological research to define the chronological, cultural, social and economic character of the settlements during the two periods of mining activity in the region (Bronze Age and 18th–19th centuries AD). This programme has included an extensive systematic survey to locate ancient and modern period settlements, a survey complemented by historical research. This survey and research has led to the discovery of some 20 Bronze Age settlements and burial mounds (*kurgans*), as well as of a number of later occupations (Chernykh 2002, 59–69). In addition, the Russian members of the team have a) conducted intensive excavations at the Srubnaya-phase site of Gorny, a settlement with rich evidence of metallurgical activity; b) test-pitted other Srubnaya occupations, in particular Gorny 2 and Novenki; and c) conducted excavations at the Yamnaya-Poltavka-, Abashevo- and Srubnaya-phase *kurgans* of Pershin, Uranbash, and Komisarovo (Chernykh, Lebedeva *et al*. 2002, 58, 71, 74; for the 21 C14 dates of the settlement of Gorny, see Chernykh 2002, 126–7, 136–7). In order to contribute to recent debates concerning Bronze Age subsistence practices, Spanish members of the team have intensified the recovery of palaeo-economic evidence aimed at analysing the nature of the prehistoric steppe economy, with sub-programmes devoted to archaeozoology, palaeocarpology (including flotation of numerous samples of archaeological sediments), anthracology and palynology (Antipina 1999; Černych *et al*. 1998; Morales-Muñiz and Antipina 2003; López *et al.* 2001; López Sáez *et al*. 2002a; Uzquiano 2002).

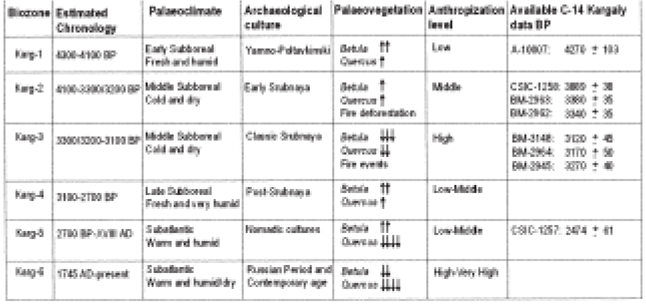
In complement to this research, Salvador Rovira (1999; Chernykh and Rovira 1998; Chernykh, Frère-Sautot *et al*. 1999) has directed archaeometallurgical research aimed at determining the technological characteristics of Kargaly metal production, with particular attention to energy efficiency models. To this end, three sub-programmes have been developed: a) characterisation of Kargaly mineral and metallurgical process through the analysis of copper slag; b) experimental smelting using the technology suggested by archaeological evidence, all of which offer precise indications on energy consumption and other production factors; and c) a comparative analysis of the experimental and archaeological results. These three lines of evidence allow us to draw accurate and reliable conclusions on metallurgical production and energy consumption, a key element when discussing Kargaly's model of metallurgical production and its historical trajectory.

Lastly, our environmental research involved two related programmes: a) systematic recovery of palaeo-environmental data from archaeological and natural deposits and b) modelling the present-day landscape, with particular attention to the formation processes of the palynological record (Khotinsky 1984; Chibilev 1996; Gaillard *et al*. 1994). As part of our palaeo-environmental work, we developed six palaeopalynological sequences supported by radiocarbon dates (Fig. 2.1). Four sequences came from Srubnaya-phase archaeological sites under excavation, two from natural deposits. We also analysed charcoal and other botanical remains recovered by flotation from archaeological deposits at Gorny (López *et al.* 2001; 2003; López Sáez *et al.* 2002a; 2002b; Uzquiano 2002). These data permit us to define five bioclimatic phases. Our modelling of the present-day landscape combined observations in the field with analysis of multiband images from the Landsat 5 satellite's Thematic Mapper (TM) sensor in order to develop analytical regional maps of the vegetation, soils, distribution of humidity, etc. Relief morphology was mapped using a digital terrain model (D'Antoni and Spanner 1993; Vicent *et al*. 2000). Finally our research design involved collection of data on the present-day pollen rain (Fig. 3). Two transects were defined: one (10 km x 5 km) was placed around the Srubnaya site of Gorny, in an area of intense mining activity in both prehistoric and modern times. The other transect (5 km x 5 km) was placed some 10km south of the former around the Srubnaya site of Novenki, in an area with no mining activity. These two areas were sampled independently. Using a 500 m grid we randomly selected 55 sampling units. These represented about 10% of the two transects. In each of those unit we took pollen samples in the upper 10 cm of the topsoil, established a detailed inventory of the flora, and described other relevant variables (such as the incidence of farming and stock-raising) (Chibilev 1996; López-Sáez 2002). These observations established the effect of geographic factors on vegetational distribution in the present-day landscape and thus help us understand representations of that vegetation in the palynological record. This enables us to interpret palaeopalynological sequences in terms of past vegetation distributions. At the same time, differences in mining and metallurgy between the sampling units demonstrate the impact of these activities on the landscape (Fig. 2.2).

Results of the Archaeometallurgical and Palaeo-Environmental Research at Kargly

The archaeometallurgical survey at Gorny benefits from the large collection of smelting debris and metal objects uncovered during archaeological field work

Fig. 2.1.



Biozone	Estimated Chronology	Palaeoclimate	Archaeological culture	Palaeovegetation	Anthropization level	Available C-14 Kargaly data BP
Karg-1	4300-4100 BP	Early Subboreal Fresh and humid	Yamno-Poltavkinski	*Betula* ↑↑ *Quercus* ↑	Low	A-10807: 4270 ± 103
Karg-2	4100-3300/3200 BP	Middle Subboreal Cold and dry	Early Srubnaya	*Betula* ↑ *Quercus* ↑ Fire deforestation	Middle	CSIC-1250: 3869 ± 38 BM-2963: 3380 ± 35 BM-2962: 3340 ± 35
Karg-3	3300/3200-3100 BP	Middle Subboreal Cold and dry	Classic Srubnaya	*Betula* ↓↓↓ *Quercus* ↓↓ Fire events	High	BM-3148: 3120 ± 45 BM-2964: 3170 ± 50 BM-2945: 3270 ± 40
Karg-4	3100-2700 BP	Late Subboreal Fresh and very humid	Post-Srubnaya	*Betula* ↑↑ *Quercus* ↑	Low-Middle	
Karg-5	2700 BP-XVIII AD	Subatlantic Warm and humid	Nomadic cultures	*Betula* ↑↑ *Quercus* ↓↓↓↓	Low-Middle	CSIC-1257: 2474 ± 61
Karg-6	1745 AD-present	Subatlantic Warm and humid/dry	Russian Period and Contemporary age	*Betula* ↓↓ *Quercus* ↓↓↓↓	High-Very High	

Fig. 2.2.

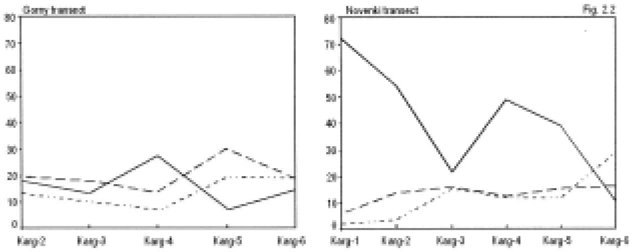


Fig. 2.3.

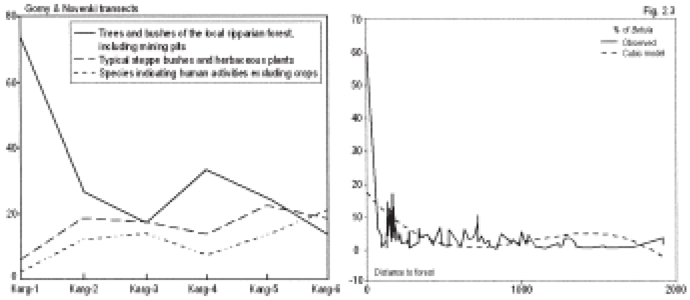


Fig. 2. 1. Bioclimatic phases: estimated chronology BP and palaeoclimate (after Khotinsky 1984) and archaeology (after Chernykh, Avilova *et al*. 2000; 2002). Arrows up and down (1–4) suggest the evolution of arboreal pollen (López *et al.* 2001; López-Sáez *et al*. 2002a; 2002b); 2. Representation of selected ecological groups. Each pollynomorph has been assigned to a single ecological group. The correlation is based on the floral catalogue of the Kargaly region and on the species identified during our field work. These pollynomorphs might correspond to several other ecological groups in other regions; 3. Cubic regression model: distance to forests explains .27646 of *Betula* pollen variance.

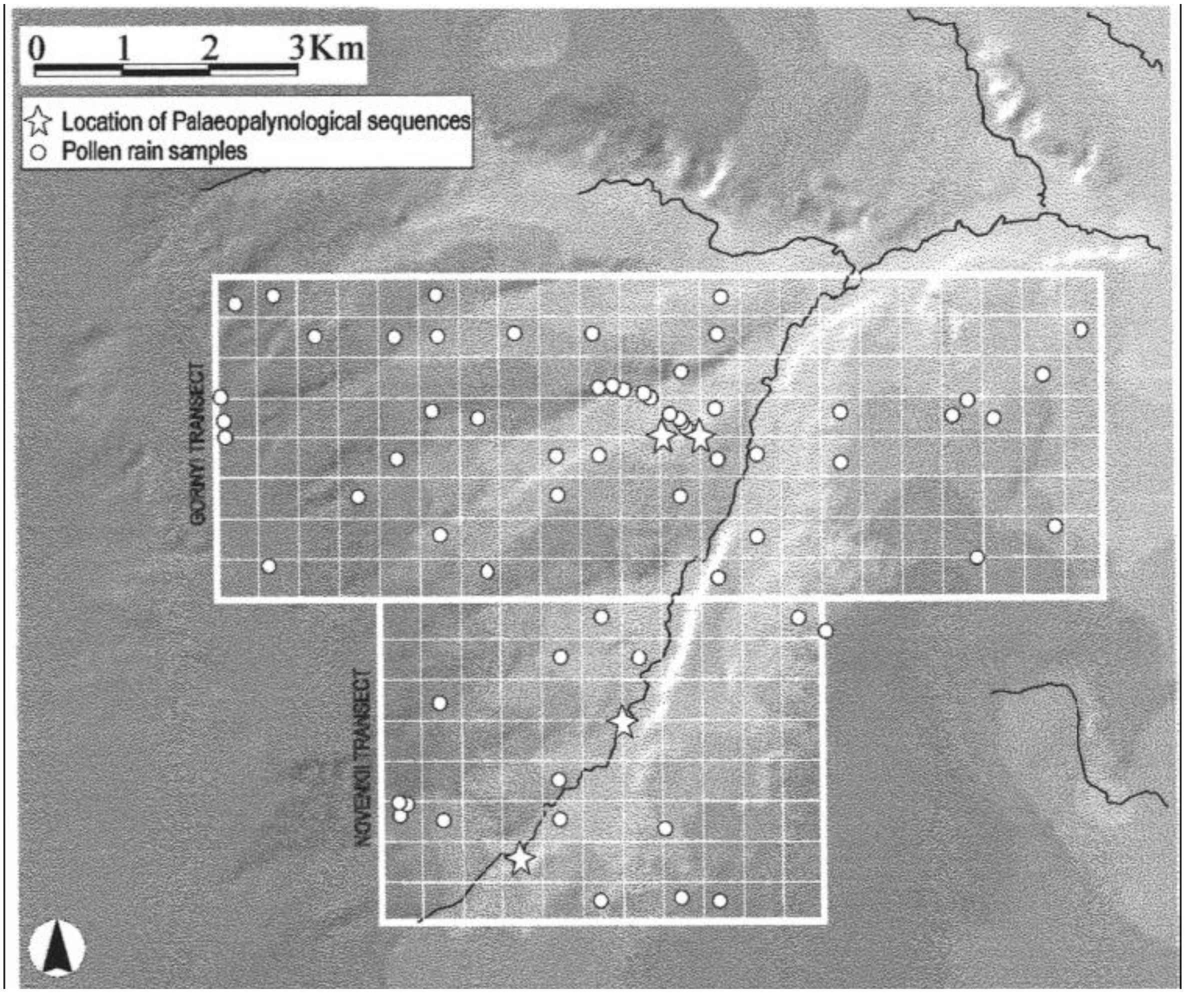


Fig. 3. Sampling model on *digital terrain model*: location of paleopalynological sequences and pollen rain samples at Kargaly (South Urals, Russia).

(Chernykh, Kuzminykh *et al*. 1999; Chernykh 2002, 24–5, 54, 72, 85, 88, 92, 105, 111, 119). The results of their analysis by scanning electron microscopy, X-ray fluorescence spectroscopy and metallography show that metallurgical technique was a primitive one that worked copper oxide ores by a non-intentional slag smelting process. That is to say, without adding fluxes to get a low viscosity and lower melting point slag. A glassy matrix containing silica compounds forms the copper slag. Some samples exhibit well-formed lathes of pyroxene and akermanite crystals. Fayalite is usually absent. Thus, this must be slag obtained from a direct ore reduction process. As the slag viscosity is very high, most of the copper formed during that process remains trapped within the matrix. Cast objects were finished by cold hammering and, occasionally, annealing.

The experimental replication of copper smelting started with copper ore selection. After this, the ore was crushed into small pieces and charged in the furnace mixed with charcoal. After four hours, some big lumps of slag were obtained. Analysis using scanning electron microscope facilities allowed us to determine the chemical composition of the crystallographic phases. The identification was completed using an optical microscope. Remarkably, both archaeological and experimental slags are very similar in composition and phase structure. Copper was recovered by crushing the slag into stone mortars, taking apart the prills visible to the naked eye, and washing the slag dust onto a dish to remove the smaller portions by difference of density. The copper obtained in this way was heated into a crucible, melted and poured into a small ingot-mould carved in wood.

As we know the charcoal consumption in each step of the process, we are in a position to calculate the amount of fuel needed to obtain copper *in situ*. Based on the experimental results, to obtain a 1 kg ingot of copper one would have to burn 65 kg of charcoal (obtained from about 500 kg of dry wood). Thus, our experimental smelting leads us to estimate that over the 300-year occupation of Gorny the copper production would have been 21.4 mt (requiring 10700 mt of wood as fuel) (Rovira 1999, 109–10; Horne 1982). We will now focus on what our research has discovered about the amount, composition and distribution of the region's woodlands and the implications of this in evaluating the scale of metallurgical production at Kargaly.

Based on archaeological, archaeometallurgical and archival evidence, Chernykh (1994, 63, 65; 1998b, 130, 132) considers that the entire cycle of mining, smelting and ingot-casting was practised intensively at Kargaly during the occupational spans of the permanent settlements of the Srubnaya culture, with most of the products of this process being exported from the region. Chernykh (1998a, 72) calculates that a 150,000 mt of copper were produced in the Kargaly region during the Bronze Age, 100,000 mt of which were created during the Srubnaya period. Given the large amounts of fuel required in ore smelting, Rovira (1999, 111) estimates that 75 million mt of wood would have been consumed in the Bronze Age. Based on the simplest assumption that production was constant over time, this would amount to 37500 mt of wood per year. Following Chernykh's estimate of forest productivity in the Orenburg region, this implies the annual felling of 150 ha of woodland (Chernykh 1994, 60).

These estimates stand in contrast to the limited amount of woodlands in the region today. If they are correct, either the availability of forest resources has diminished drastically since the Bronze Age or one must propose an alternative model of how prehistoric metallurgy operated. Palaeobotanical evidence suggests that birch (*Betula pendula*) and oak (*Quercus robur*) were the main fuels (Uzquiano 2002; López-Sáez *et al*. 2002). It is unlikely that dung was used as a permanent fuel-source (Lebedeva 2004, 244-7). We must, therefore, evaluate the local and regional energetic potential by analysing the distribution of forests of these species over time. Based on our cartographic analysis at Landsat TM images we estimate that today forest covers about 2.6% of the Kargaly region. For the most part this is gallery forest located along the sides and headwaters of the numerous seasonal watercourses that make up the region's drainage network. This is constituted predominantly of birch and poplar (*Populus tremula*). The only forest composed of willow (*Salix*) and poplar occurs along the banks of the river Usolka, the only permanent watercourse in the study area. If we assume a fully sustainable exploitation of forests with a cycle of 60 years for full recovery of initial productive capacity, Chernykh's estimation of metallurgical production would demand 9000 ha of woodland (2). Given our estimate of a current forest cover of 2.6%, this would require a territory of 3500 km^2, an area seven times the size of the whole mining complex of Kargaly. If we reduce the exploitation cycle to 30 years, the forested area would be more than 1700 km^2, more than three times the size of the mining district. These estimates establish a threshold beyond which forest regeneration is impossible. In short, the present amount of woodland is incompatible with a sustainable metallurgical model over the long term. It should be noted that the current situation is the result of the massive impact of agriculture and stock-raising (particularly connected with Soviet colonisation) added to the effects of the long recent phase of mining (from 1745–1900). We must suppose, therefore, that the available forests observed in the present constitute only a fraction of what existed in the Bronze Age. According to Chernykh (1994, 63–7; 1998b, 132–3), the mining complex collapsed at the end of the Bronze Age mainly because forests were exploited above the level of sustainability.

To evaluate this hypothesis we examined the variability of the representation of different species of trees at Kargaly over the course of the palaeopalynological sequences obtained in our research (Fig. 2.2). Our results suggest that the process of change is fairly close to the expectations of Chernykh's model. The proportion of the ‘autochthonous arboreal’ pollen category is from bottom to top as follows: a) a relative minimum very close to present values during the Srubnaya occupation (pollen phase 3); b) a certain recovery during pollen phases 4 and 5; and finally c) an absolute minimum in the present (pollen phase 6).

Nevertheless, the palynological evidence alone cannot corroborate any of these hypotheses because it does not permit a quantitative evaluation of the areas covered by pollen-producing species. We can, however, establish the significance of these changes for the shape of the landscape on the basis of our research on the formation processes of the pollen record. Results indicate that the representation of ‘autochthonous arboreals’ (and especially of its most important component, birch) depends on the distance between the point where pollen is obtained and the location of groups of trees (Fig. 2.3, Fig. 4).

Analysis of the present-day pollen rain permits us, therefore, to model the significance of quantitative variations in arboreal pollen in terms of the local distribution of forests. To do this we compare the values obtained in the different palaeopalynological samples with the variability observed in present-day samples in relation to their location in the map of regional forests. This research demonstrates that values in Srubnaya times correspond with the situation today in contrast with what occurs in pre- and post-Srubnaya phases. We must conclude, then, that forest distribution, at least around Gorny, was similar to that seen now, that is, it was limited to gallery forest. Before and after Srubnaya times, values suggest sampling points were closer to forests, and, thus, that these forests were denser with respect to the points of observation.

In order to confirm and generalise these conclusions we carried out a numerical classification of all the pollen spectra obtained in the sampling areas in terms of the proportion of the different ecological groups represented in them. In a first trial, a hierarchical classification using k-mean method identified five groups of spectra. Then using Landsat TM images of the areas within 250 m of the sampling points of present-day pollen rain, we measured the present-day distribution of the Normalised Difference Vegetation Index (NDVI) (Fig. 5.1). As is to be expected, these values proved to be relatively homogenous within each group of the classification. This permits us to conclude that NDVI values for palaeopalynological samples classified within a group would fall within the observable distribution for that group today. Seventy-five percent of the samples attributable to the Srubnaya period (Biozone Karg-3) from Gorny are classified, interestingly, within group 2, which presents a mean NDVI value of about 66 (Fig. 2.1). When the Geographical Information System displays the points

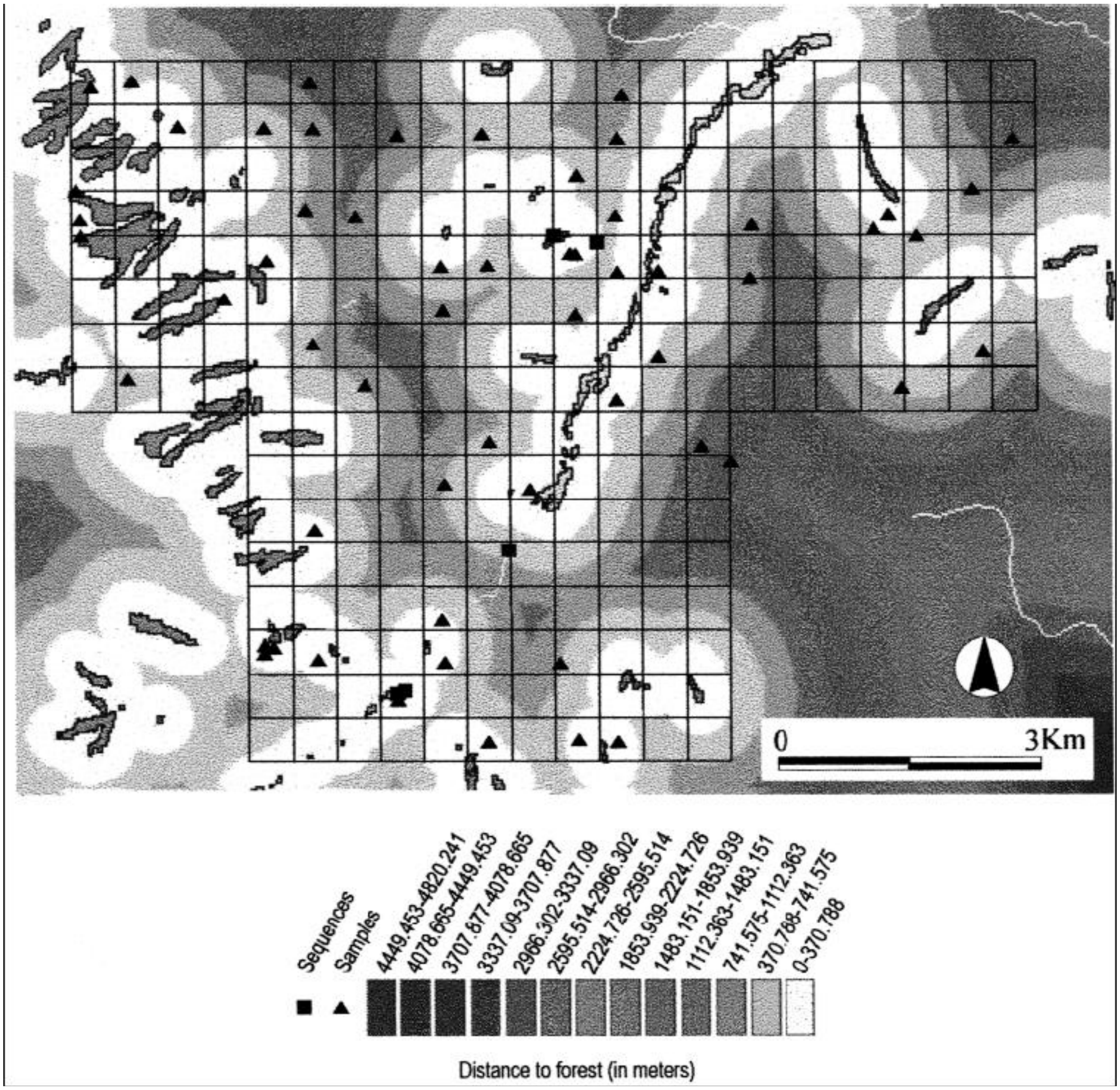


Fig. 4. Map of distances between sampling points and forests at Kargaly (South Urals, Russia).

whose NDVI value is within one standard deviation around the mean of this distribution, we see that all of these correspond to a natural formation of herbaceous steppe modified by mining activities (Fig. 5.2).

We may tentatively conclude, therefore, that the distribution of vegetation around the mining settlement of Gorny was almost identical to what we can observe today, and that the fuel productive potential of forests in the Gorny mining district during Srubnaya phase was similar to that of the present. Taking into account the extensive distribution of Kargaly copper throughout the Srubnaya or Srubnaya-Abashevskaya cultural area, we must then conclude that most of

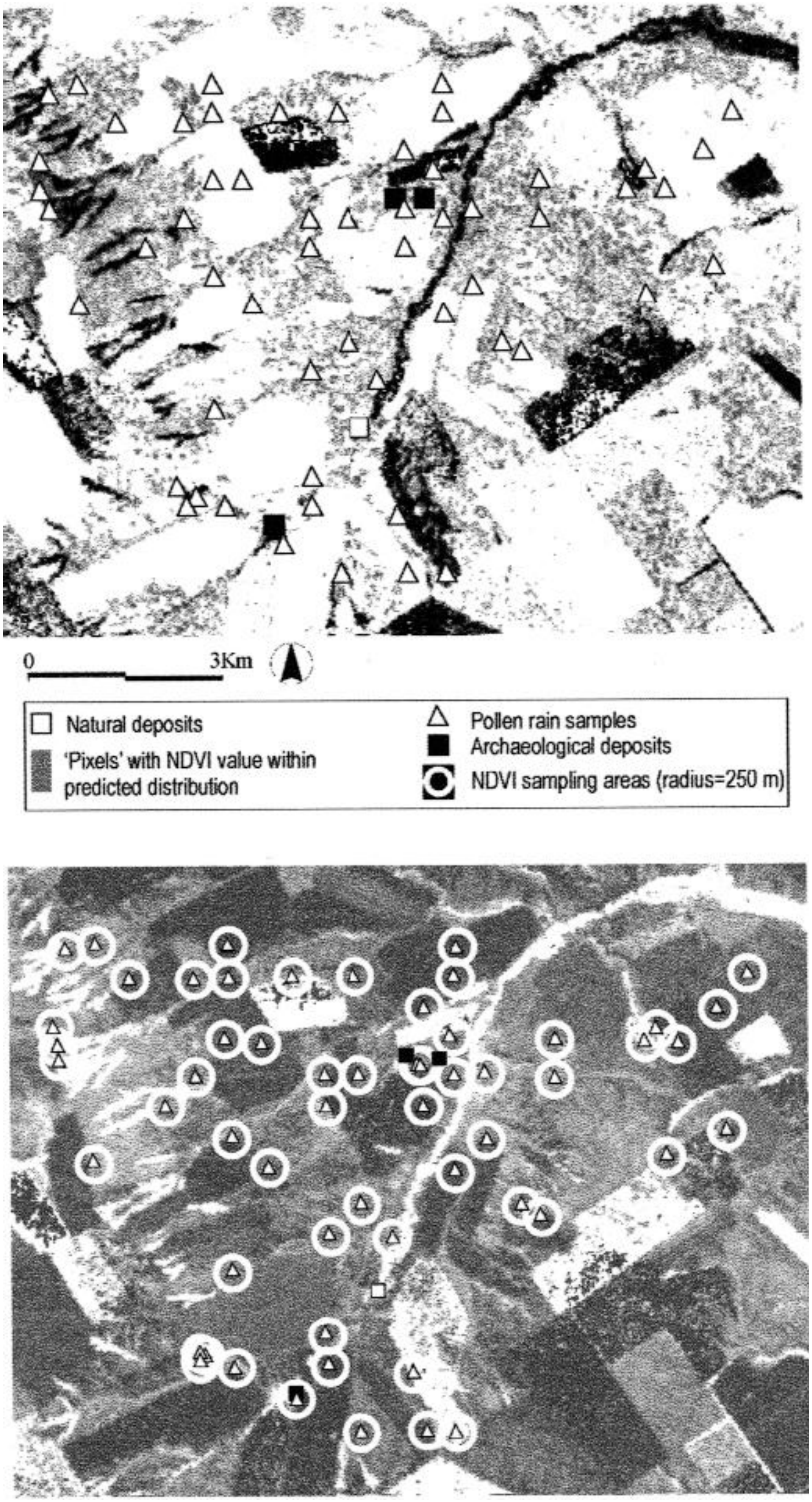


Fig. 5. 1. Normalised Difference Vegetation Index (NDVI) and sampling model; 2. Predictive model at Kargaly (South Urals, Russia).

it was exported, not as metal, but as copper ore or lumps of slag-like material, a hypothesis already proposed by Chernykh (1998a, 132–3; 1994, 65; Rovira 1991, 112) as an alternative to that of intensive metallurgical production at Kargaly. Deciding between these two scenarios has broad implications for all aspects of the historical interpretation of Kargaly metallurgy since they involve opposing models of production, circulation and the social division of labour. Therefore, we must rethink current assumptions about the socio-economic structure of the Late Bronze Age and the nature of regional and trans-regional exchange networks during this period. Because of their temporal and spatial scale and because of the importance of Eurasian metallurgical technology, the metallurgical provinces defined by Chernykh and his collaborators constitute the essential framework within which this reinterpretation must take place.

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Footnotes

p. 345 (1) Spanish funding for this work comes from the agreement between the Russian Academy of Sciences and the CSIC and from projects PS950031 (1996–99) and PB98–0653 (1999–2002) of the Dirección General de Investigación Científica y Técnica. The principal investigator is M.I. Martínez Navarrete.

p. 351 (2) The estimation of the length of the cycle is based on historical evidence (Chernykh 1994, 60). Exploitation may have been based on pruning trees, combined or not with cutting them down.