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ROMAN HYDRAULIC GOLD MINING IN CENTRAL EUROPE

This contribution brings together and summarises the evidence for Roman gold mining using the hydraulic techniques of aqueduct-fed ground-sluicing and hushing in central Europe. Roman hydraulic mining in the Iberian peninsula, and in Wales at Dolaucothi, is well known, but the central European evidence has been largely overlooked. In Bosnia, nineteenth-century mining engineers described what are almost certainly Roman hydraulic mines at Bistrica near Gornji-Vakuf/Uskoplje, at Crvena Zemlja, Uložnica, and Zlatno Guvno in the region of Mt Vranica, and probably also at Tješilo in the Fojnička valley, but their descriptions lack detail and there has been no study of these mines since. Hydraulic mining is also known in Romania, at Bucium and Pianul de Sus. Recent work at Bucium, using high-resolution DEMs produced from aerial drone survey, has transformed our understanding of surface mining here, while on the Karth plateau in Austria, LiDAR and ground survey have revealed a mining landscape unknown before 2010.

Keywords: Roman hydraulic mining; gold mines; Dalmatia; Bistrica; Crvena Zemlja; Uložnica; Zlatno Guvno; Bucium; Pianul de Sus; Karth.

Ancient gold mining techniques varied, naturally, with the geology in which gold deposits were found. The primary gold deposits that were exploited in antiquity in Europe occur principally in quartz veins or stockworks, either as natural gold, or as gold compounds which need to be smelted out of the ore. These were dug as opencast mines where veins of ore outcrop on the surface, or exploited by underground mining where the veins run deep. Secondary deposits, or placers, form as weathering processes over millions of years erode particles and nuggets of gold out of the parent rock and deposit them in alluvial soils. Streams that cut through these placer deposits in turn erode the free gold out of the alluvium, and these particles can be recovered by panning for gold in streams or rivers.

Panning for gold was used from prehistoric times onwards. The process consists of swirling stream sediment or gravels in a pan, repeatedly discarding the lighter fraction until all that is left in the pan is the denser stones, with from time to time, one hopes, a few specks of gold gleaming among them. The process can be scaled up by shovelling river sediment onto an inclined board and washing buckets of water over it: the lighter material is washed away and the heavier material, including dense particles of gold, remains on the board. This method was still employed on the river Drava in Croatia in the twentieth century (for photographs and a video taken in 2016 of one of the Croatian gold prospectors, Mate Horvat who was then aged 94 and started working the deposits in 1937, see Bradbury 2016). Traces of large-scale washing operations

Fig. 1. Water channel and stone clearance dumps at the gold mines (second- to first-century BC) at Bessa, Italy (photo by A. Wilson, 2020).

conducted over years, decades, or even centuries, may be found in some river valleys as dumps of sterile gravel that has been washed by such processes.

From the second century BC, if not before, the tribe of the Salassi in the Biella alps in northern Italy realised that alluvial gold-bearing deposits could be exploited by an artificial version of natural stream erosion. They diverted water from the Viona stream through a series of artificial channels dug into the placer deposit at Bessa, which is essentially a reworked glacial moraine now forming a river valley terrace. Earth was shovelled into these channels, and larger pebbles and boulders picked out and piled in dumps besides them (Fig. 1). Within the channels themselves, some form of sluice box must have been used, as described by Strabo and Pliny in their accounts of gold mining in Spain—a wooden trough with riffles or battens at intervals across the base, and heather (*ulex*) or a similar plant wedged in to help trap gold particles (Strabo, *Geography* 3.2.8; Pliny *NH* 33.21.76). As water was run through the trough, heavier, denser particles including gold settled behind the riffles or were trapped in the heather, while most of the soil was washed away. Larger stones were picked out and discarded. In this way an area over 7 km long and varying in width from a few hundred metres to 1.1 km was heavily worked out by ground-sluicing, and is now littered with massive stone piles. The territory of the Salassi was taken over by Rome in 143–141 BC, after which Roman *publicani* rented out the contracts for working the area (Strabo, *Geography* 4.6.7, 5.1.12; Dio Cassius, 22.74.1). The vast amount of labour necessary for digging the channels and shovelling the earth into them is indicated by the fact that Pliny records a law of the censors forbidding the contractors employing more than 5,000 men (*NH* 33.21.78).

The ground-sluicing techniques used by the Salassi seem to have been the model for Roman mining of placer deposits in the Iberian peninsula, in the Ta-

Fig. 2. Map of hydraulic gold mines in Central Europe (by A. Wilson, 2023).

gus valley in the Republican period (Currás and Sánchez-Palencia 2021), and on a massive scale in north-western Spain after Augustus's conquest of the Callaeci and Astures (Domergue & Hérail 1978: 129–40; Domergue 1990; 2008; 2012). Here the techniques of hydraulic mining were refined and extended to include arrangements of initially parallel ditches which then converged into a single outflow channel in which washing sluices could be constructed. Thicker deposits were worked by hushing, involving the storage of water in earth-banked reservoirs above the opencast, from which water could be suddenly released with great erosive force to break up the deposit. At Las Medulas and a handful other sites (As Borreas, La Leitosa and Montefurado in north-west Spain, and El Hoyo de la Campana south-east of Granada: García-Pulido 2011; 2014), networks of tunnels were dug through placer deposits and then flooded with water to collapse them, and then the deposits further worked by hushing and ground-sluicing. The ground-sluicing operations and hushing tanks were fed by leats or aqueducts, sometimes running for several kilometres, and in the case of the longest aqueduct at Las Medulas, up to 143 km (Matías Rodríguez 2008: 58–9). Mostly these were contour-hugging ditches but across mountainous terrain they might be cut into the rock, and Pliny (*NH* 33.21.74–5) talks of wooden troughs being supported on wedges hammered into sheer cliffs. Over 500 sites in north-west Spain are known where hydraulic mining techniques were used for gold extraction in the Roman period, together with a handful in other parts of Spain and the Franco-Spanish border, including La Cerdanya in the Pyrenees (Cauuet 2005: 251–3; Cauuet *et al.* 2014).

The purpose of this contribution is to draw attention to the few hydraulic gold mines known in central Europe, in the Roman provinces of Dalmatia (Bosnia-Hercegovina), Dacia (Romania), and Pannonia Superior (Austria) (Fig. 2).

Dalmatia

The Illyrian peoples of the Balkans seem to have obtained their gold by panning or gold-washing, and large-scale gold-washing certainly continued into Roman times. Dumps of worked-out gravels from gold-washing operations in the Lašva valley downstream of Travnik in Bosnia are associated with both Illyrian and Roman sites and artefacts (Rücker 1896: 47–52). The second-century historian Florus talks of gold-mining in Dalmatia in terms that suggest that it was developed under Roman rule, apparently under compulsion, to provide tribute (*Epitome* II.25.10–12):

> *Delmatae plerumque sub silvis agebant; unde in latrocinia promptissimi. Hos iam pridem Marcius consul incensa urbe Delminio quasi detruncaverat, postea Asinius Pollio gregibus, armis, agris multaverat — hic secundus orator — sed Augustus perdomandos Vibio mandat, qui efferum genus fodere terras coegit aurumque venis repurgare; quod alioquin gens omnium cupidissima eo studio, ea diligentia adquirit, ut illud in usus suos eruere videantur.*
>
> The Dalmatians for the most part lived in the forests, whence they frequently made predatory raids. Marcius the consul had already crippled them by burning Delminium, their capital; afterwards Asinius Pollio—the second greatest of Roman orators—had deprived them of their flocks, arms and territory; Augustus entrusted the task of completely subjugating them to Vibius, who forced this savage people to dig the earth and to melt from its veins the gold, which this otherwise most greedy of peoples acquires with such zeal and diligence that you would think they were extracting it for their own purposes.
>
> (Text and translation adapted from Forster 1984: 330–1, rejecting as unnecessary Graevius' emendation to *stupidissima* of the *cupidissima* of the manuscripts, and Vinetus's emendation to *anquirit* for *adquirit* of the manuscripts.)

Florus does not say anything about the mining techniques used, and nor does Statius, who mentions gold-mining in Dalmatia in general terms in *Silvae* 4.7.14ff. Pliny the Elder mentions the discovery of an extraordinarily rich deposit in Dalmatia in the reign of Nero (*NH* 33.21.67):

> *Aurum qui quaerunt, ante omnia segutilum tollunt; ita vocatur indicium. alveus hic est harenae, quae lavatur, atque ex eo, quod resedit, coniectura capitur. invenitur aliquando in summa tellure protinus rara felicitate, ut nuper in Delmatia principatu Neronis singulis diebus etiam quinquagenas libras fundens.*
>
> Those who search for gold first of all dig up the *segutilum*; this is what the tell-tale earth is called. This is a bed of sand, which is washed, and from the residue an estimate is made about the content. Sometimes gold is found straight away in the surface earth, a rare success, as happened recently in Dalmatia in the reign of Nero, which yielded up to fifty pounds of gold a day.

Pliny does not say where in Dalmatia this occurred, but the find of gold in surface soil suggests the exploitation of placer deposits. Besides the traces of

gold washing in the Lašva valley already mentioned, ancient gold washing is attested in the central Bosnian mountains by gravel dumps in the upper Vrbas valley and the valley of the Fojinicka and its tributary the Zeležnica, some of which were undoubtedly worked in Roman times, although there were also medieval and more recent workings here (Conrad 1871: 222; Walter 1887; von Foullon 1893; Rücker 1896). In addition to the washing dumps in the river valleys, though, there are also several sites in the upper Vrbas valley and the Fojinicka valley which show traces of developed hydraulic mining, fed by aqueducts of substantial length, that appear characteristic of Roman workings. The fundamental information on these sites comes from studies by mining prospectors and engineers working for the Austro-Hungarian empire in the late nineteenth century (Conrad 1871; Walter 1887; von Foullon 1893; Rücker 1896; and also a travel description, Bordeaux 1904), and later studies have simply repeated and summarised this information (Škegro 2000: 73–8; Hirt 2010: 73–4; Trubelja and Barić 2011: 14; Glicksman 2018: 268–71). If there is any justification for doing so yet again here, it is to call attention to these sites, and to attempt to locate them more accurately using modern satellite imagery. The exercise suggests that the nineteenth-century sketch-maps and plans in the works by von Foullon and Rücker are surprisingly accurate.

Placer workings at Bistrica/Batusa

Just to the north of the modern town of Gornji-Vakuf/Uskoplje, two tributaries, the Krupa or Krušćica, and the Bistrica, flow into the Vrbas river from the Mt Vranica range to the east. Between their confluences the Austro-Hungarian mining engineers described a large area of ancient placer workings. Figure 3 is a plan of these from Anton Rücker's study (1896: 85), which lacks a scale, but which it was possible to georeference tolerably accurately over modern satellite imagery using the the 'Freehand raster georeferencer' plugin for QGIS, with reference to the configuration of the Vrbas and its tributaries (Figure 4). Rücker's description (1896: 86) shows that the features marked within each of his areas A–F, which might be interpreted from the plan either as hollows or pits where alluvium was worked out, or as mounds where sterile tailings were piled up, are to be read as hollows or pits ('Pingen').

In the south of the area, between the Vrbas and the Krupa or Krušćica stream, an area of washing dumps (Fig. 3, area D) was partly covered in the late nineteenth century by the village of Batusa, which has now expanded across nearly all the rest of the remains here (Fig. 4). Baron H. B. von Foullon describes these dumps as extending for over 1,100 metres by over 400 metres, dimensions which tally well with the georeferenced plan, and says that the stone-clearance piles lay in rows, both in the village and around it, merging into large masses of sterile dumps to the west and north up to the confluence of the Krupa/ Krušćica and the Vrbas. The channels that had led water to them were already hardly recognisable in the late nineteenth century (von Foullon 1893: 14).

Between the Krušćica and the Bistrica stream to the north, however, a system of water leats is clearly shown on Rücker's plan, marked *alte Wasser-*

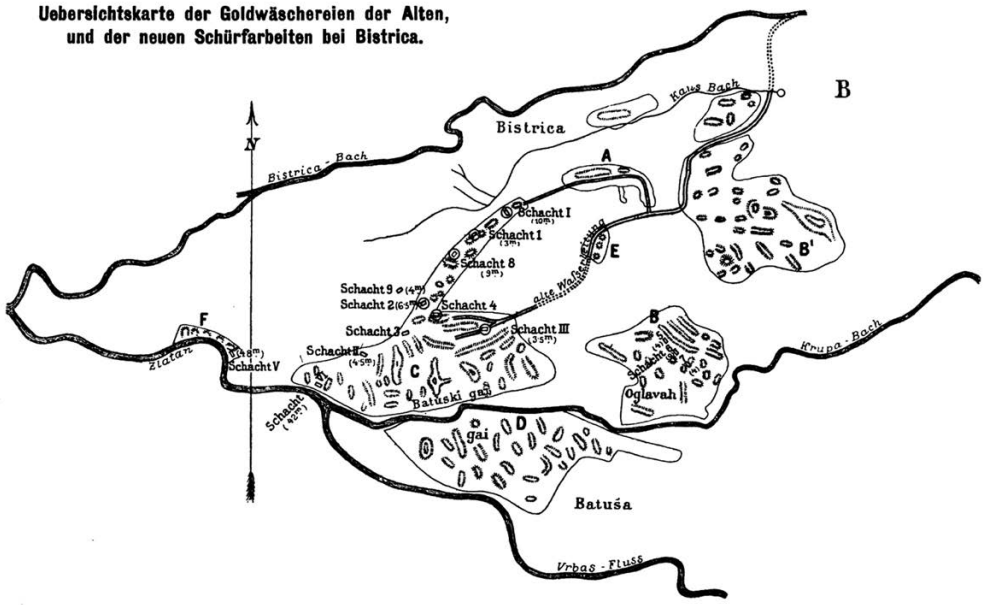

Fig. 3. Sketch map of the workings at Bistrica/Batusa in Bosnia (Rücker 1896, 85).

leitung; von Foullon in 1893 described the channel ditches as well preserved (von Foullon 1893: 16). This originated either from the Bistrica stream, or from the spring of the small Kalus stream, and flowed south and westward past the workings marked as area B′ to area E, and appears to have continued beyond E westwards to feed the large zone of placer workings known as the Batuski gai on the north side of the Krušćica stream (area C); here its trace was picked up again and it bifurcated within these workings. This constitutes a total length of 1.7 km from the Kalus spring; more if it came in fact from the Bistrica to the north. To this should be added another 630 m of channel which branches off it about halfway along, running north and west through area A into a linear depression running north-east to south-west into the northern part of area C. This is still visible on the modern satellite imagery as a narrow strip of trees and bushes, probably growing in this hollow. The eastern half of area C has today disappeared under a modern industrial estate, whose refuse dumps are fast covering the western half, although satellite imagery shows some parallel linear alignments of bushes or trees (just south-west of Rücker's Schacht II) which look like lines of stone dumps or of worked-out trenches. Further to the east, the workings in the region marked Oglavah (area B) have also been partly destroyed by the industrial estate, although the northern and southern margins remain. Von Foullon's description and Rücker's plan agree that the placer deposits extend for *c.* 2 km east-west × 1.75 km north-south, and were worked in antiquity as far up the slope towards the east as the elevations to which it was possible to lead water would allow (von Foullon 1893: 16). Looking at the satellite photos today one would have little or no inkling of these remains, as much is under vegetation, and cultivated fields or modern buildings obscure the rest. But Rücker's plan agrees well with a variety of features in the landscape, and this is an area where LiDAR survey could well reveal detail of surviving channels, pits, and stone dumps.

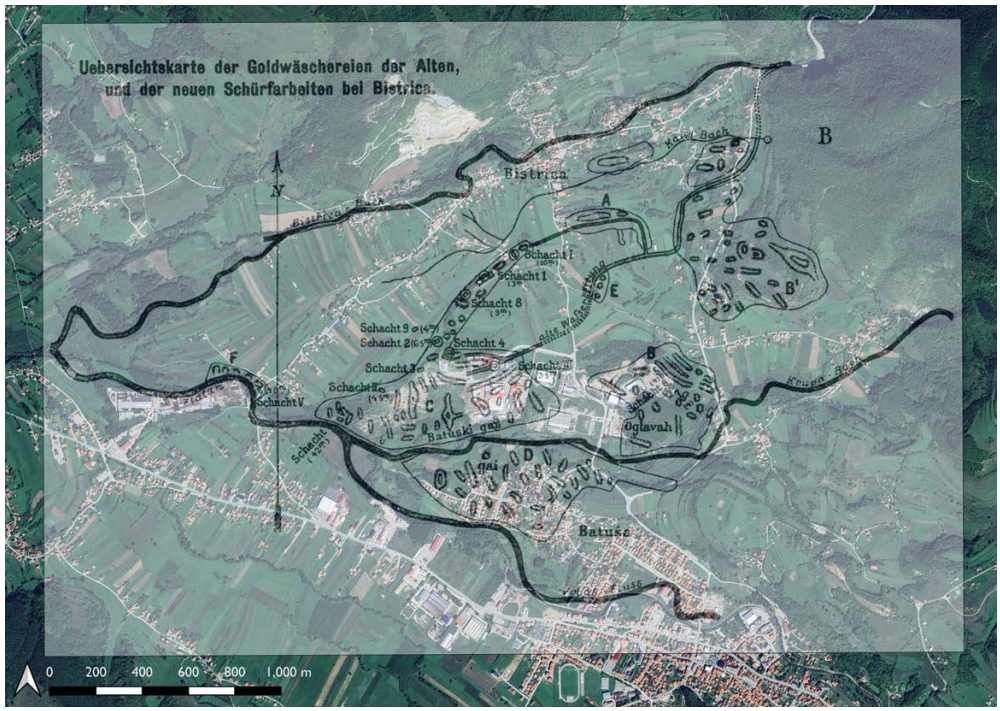

Fig. 4. Anton Rücker's plan of the Bistrica/Batusa workings georeferenced over modern satellite imagery, with scale added (by A. Wilson, 2023, after Rücker 1896, 85; satellite image: Google Satellite).

Direct evidence for the date of these workings is lacking. Roman activity in the region generally is confirmed by finds of Roman coins around the village of Wrse, 2.8 km SE of the Oglavah placer workings; and by the Stražice ruin on a limestone bluff on the left bank of the Voljica stream in the gorge between Podgradje and Volijce, 2.3 km SW of the Batuski gai workings, whose mortar and bricks show a clearly Roman date, and the find of a Roman gold signet ring in the field below it (Rücker 1896: 25–6). All that, of course, proves nothing about the date of the workings at Batusa and Bistrica. It is the artificial water leats, characteristic of Roman hydraulic gold mining, but not known for medieval or early modern placer workings in the region, that strongly suggest a Roman date. Both Jireček (1879: 42) and Rücker (1896: 19) asserted that Pliny, in referring to the find of a deposit yielding fifty Roman pounds of gold a day (*NH* 33.21.67, quoted above), meant the Bistrica region in the Vrbas valley; there is no direct evidence of this, and the nearby sites of Crvena Zemla and Uložnica are alternative possibilities.

Crvena Zemlja

To the east of Gornji-Vakuf/Uskoplje rises Mt Vranica, where traces of hydraulic mining are found in three locations—Crvena Zemlja, Uložnica, and Zlatno Guvno—two at least of which were fed from the spring at the head of the Suhodol stream, a tributary of the Bistrica stream just described (Fig. 5). Again, it is the aqueducts feeding the mines that show their Roman date (Rücker 1896: 19–20).

The workings at Crvena Zemlja consist of two large opencasts ('Pinge') on the western flank of the ridge running from the summit of Bijela Grom-

lica to the Gradski Kamen, fed from the Suhodol spring below the peaks of Bijela Gromlica and Nadkrstac. Bruno Walter describes the larger of these as a trough-like excavation oriented east–west, and von Foullon gives its dimensions as *c.* 250–300 m long by 50–60 m wide at the eastern end, widening towards the west (Walter 1887: 158; von Foullon 1893: 20). The base of the opencast slopes downwards to the west, but it is deeper at the eastern end—up to *c.* 30 m deep—as the terrain at the natural surface rises more steeply here (von Foullon 1893: 20). Towards the lower, western, end of the opencast is a large mound of reddish earth, which gives the place its name: Crvena Zemlja, meaning 'the bloody plot' (Conrad 1871: 220; Evans 1885: 13; von Foullon 1893: 21). Walter (1887: 158–9) gives its dimensions as equivalent to *c.* 135 m × 15–38 × 16 m high.[1] This is a dump from washing operations within the opencast, the lower part now covered by trees, but the upper part still bare. In the north-eastern and eastern faces of the opencast there emerge two ferruginous springs, which Walter thought perhaps came from ancient underground mine galleries; von Foullon does not exclude this possibility but considers that they are probably natural springs emerging where the opencast has intersected the water table (Walter 1887; von Foullon 1893: 20–1).

The second opencast lies to the north of the first and is described by von Foullon as arcing from the western end of the first opencast first to the north-east and then to the south-east, for a total of length of about 0.75 km, by up to 50 m wide and 8 m deep. Within it von Foullon mentions stone clearance piles arranged in long rows, remains of water supply channels, and basins, indicative of ground-sluicing within the developed opencast (von Foullon 1893: 21).

The water for these workings was supplied by two parallel aqueducts 8 m apart (both horizontally and vertically) running for some 2.5 km from the Suhodol spring. In places these were cut through hard quartz porphyry outcrops and parts must have been bridged by wooden gutters or pipes (Walter 1887: 150; von Foullon 1893: 21; Rücker 1896: 20; Bordeaux 1904: 118). Both Walter and Bordeaux mention the outline of what they interpreted as a washing basin estimated variously at 18 paces or 15–20 m across, and traces of ancient buildings, possibly Roman, along the edge of the northern opencast (Walter 1887: 158; Rücker 1896: 22; Bordeaux 1904: 118). The 'basin' is more likely however to be a hushing tank, suggesting that the opencasts were excavated by means of hushing and then the debris processed at the lower end of the opencast by ground-sluicing.

Both von Foullon and Rücker puzzled over why two parallel aqueducts were constructed over a distance of 2.5 km with a mere 8 m of elevation difference between them, and considered that it was only possible because the use of slaves meant that labour was cheap in the Roman period (von Foullon 1893: 21–2; Rücker 1896: 20). Presumably however the lower aqueduct was built first and the upper one later when it became apparent that there were deposits

1 180 Schritt long by 20–50 Schritt wide, and 16 metres high; a Schritt (or 'step') is equivalent to about 0.75 m. Cf. von Foullon 1893: 21. (Škegro 2000: 74, confuses heaps and opencast pits, given dimensions for both opencasts and the mound of Crvena Zemlja indiscriminately as though they are all heaps.)

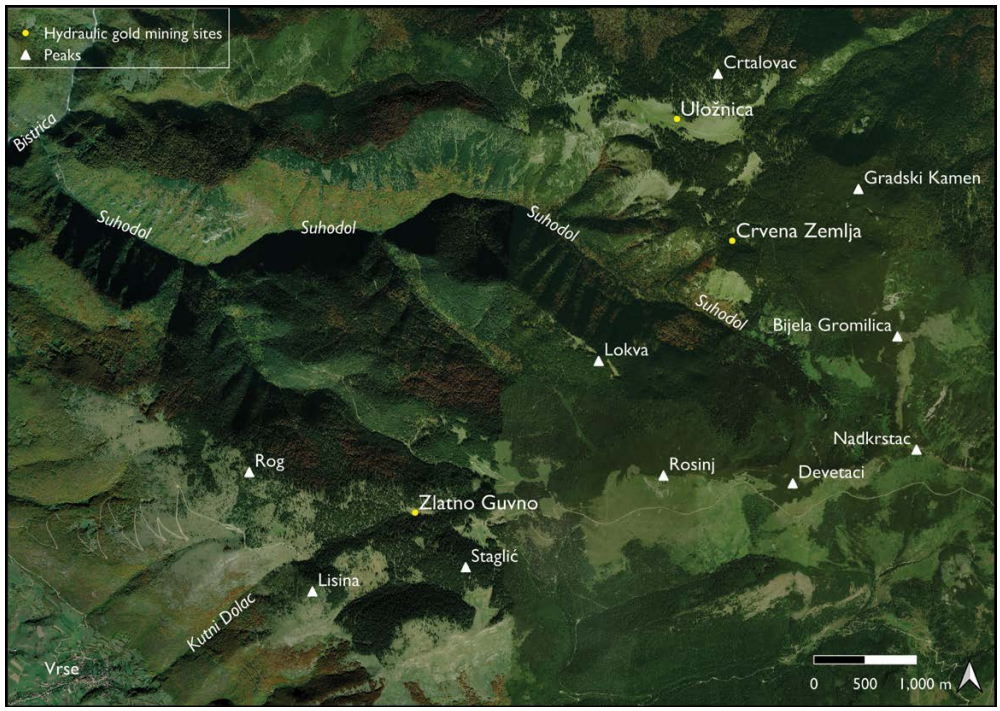

Fig. 5. The hydraulic mine workings in the Mt Vranica region to the east of Gornji-Vakuf/Uskoplje, Bosnia. (by A. Wilson, 2023; satellite image: Google Satellite).

to be worked at a higher level; perhaps the aqueducts each fed one of the two opencasts, or possibly the higher one was needed at this elevation because it actually ran past Crvena Zemlja to supply the workings at Uložnica (below), as Bordeaux (1904: 117) seems to suggest.

Uložnica

The site of Uložnica lies about a kilometre north of Crvena Zemlja (Fig. 5). Both Walter and von Foullon describe opencast mining here—a large opencast originating near the watershed between the Suhodol valley and the valley of the Zlatan porok to the east, running westward for almost a kilometre as a trench 10–150 m wide and up to 10 m deep, with some side branches (Walter 1887: 154–5; von Foullon 1893: 22–3). Sunk into the floor of the opencast were 31 shafts, 3–5 m across; it is unclear whether they represent underground mining or unsuccessful prospecting (Walter 1887: 154; Glicksman 2018: 269). Walter describes a water channel 850 m long, and on the lip of the opencast, a small water tank and the remains of a ditch for water (Walter 1887: 155); this is a clear indication of hushing (as Glicksman 2018: 269 tentatively pointed out). Bordeaux gives similar details and adds that water was supplied by an aqueduct coming from the springs of the Suhodol, almost a kilometre in length, which passed near Crvena Zemlja (Bordeaux 1904: 117). This cannot however be accurate since the Uložnica workings are over 3.5 km from the Suhodol spring. Either the Uložnica aqueduct originated to the north of Crvena Zemlja, or, if it did come from the Suhodol spring, it may have been one of the two parallel aqueducts heading for Crvena Zemlja, and Bordeaux's figure for its length would refer only to the section beyond Crvena Zemlja.

Zlatno Guvno

To the south of the Suhodol valley rises the hill of Rosinj, at the western end of which is another ancient mining site, at Zlatno Guvno, 'the golden threshing floor' (Fig. 5). Here von Foullon describes a stepped ditch-like opencast running down the upper part of the valley between the peaks of Rog and Lisina, before it falls away to the Kutni Dolac valley which leads down to the village of Vrse. The opencast is 700–800 m long and 4–5 m (occasionally up to 10 m) wide, and a maximum of 6–8 m deep (von Foullon 1893: 18–20). It was fed by a contour-hugging leat, 9.3 km long, from the spring of the Sudohol that ran initially north-west along the southern side of the Suhodol valley, before doubling around the two ridges projecting to the north-west of Rosinj, to head back towards Zlatno Guvno (Walter 1887: 161; von Foullon 1893: 19–20). Von Foullon (1893: 19–20) saw what Walter did not, that the opencast was worked by water from the leat—Walter had assumed (improbably) that material mined in shallow pits on the southern slope of Rosinj was carried to Zlatno Guvno, pounded in mortars, and washed there. There are two further opencasts, less obvious, one about 500 m north-west of Zlatno Guvno running from the south-east slope of Rog into the Kotni Dolac, and the other on the east slope of Lisina (von Foullon 1893: 19).

The Austro-Hungarian mining engineers also recorded numerous (at least 60–70) small pits on the southern slopes of Rosinj and Devetaci, and around the spur leading northward from Biela Gromlica. Conrad and Walter thought these were mining pits (Conrad 1871: 221; Walter 1887), but both von Foullon and Rücker observed no ore veins within them, and concluded that they were largely unsuccessful prospecting operations (von Foullon 1893: 28; Rücker 1896: 23–4). Their date is unclear but given their number, the persistence that this prospection seems to imply in the face of negative yields would only seem to make sense if it was carried out during the Roman period when the placer deposits were worked by hydraulic means, and was a fruitless attempt to locate veins in the parent rock.

Tješilo in the Fojnička valley

The Fojnička valley runs from the eastern side of the Vranica range eastwards towards the Bosna. Between the town of Fojnica and Gromiljak/Gomionica, and also along the Fojnička's southern tributary, the Zeležnica, large areas of gravel and sand dumps attest ancient gold washing activity along the rivers (Fig. 6). Some of this is almost certainly Roman, but these areas were worked in medieval and early modern times as well. However, von Foullon also notes a number of areas, especially on the southern bank of the Fojnica, where the placer deposits lie at some distance above the river. He mentions large opencasts at Ostružnica, but gives no indication as to whether they were worked by hushing or excavated by hand; there were underground mines here too. However, in one case there certainly were hydraulic workings: an aqueduct from the northern slope of the Matorac hill served the deposits below the village of Tješilo, on the slope 200 m above the town of

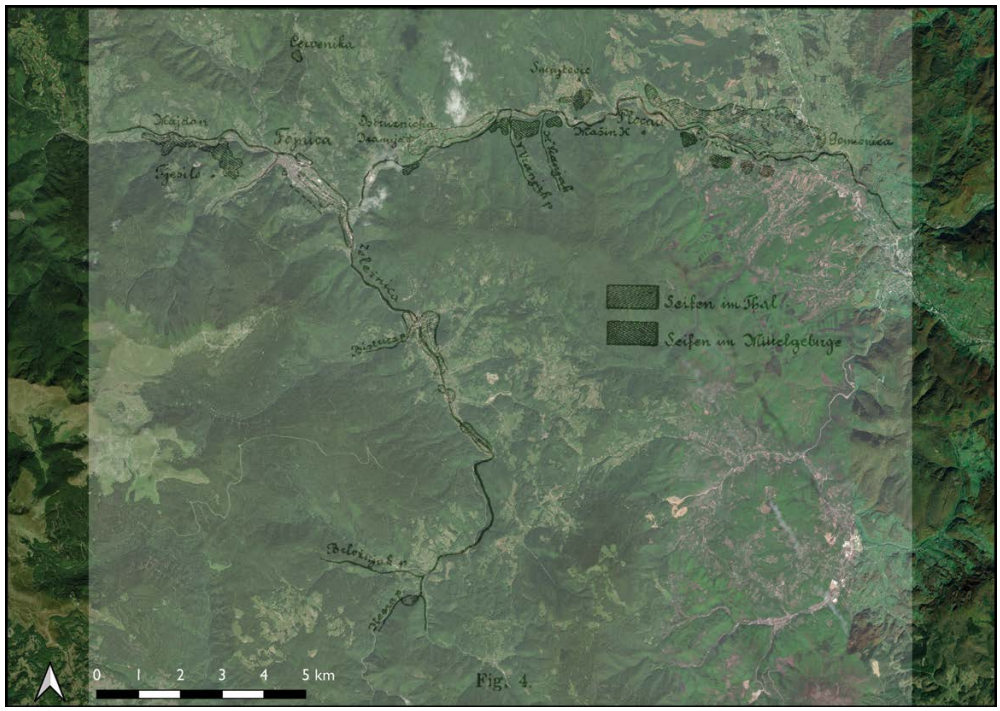

Fig. 6. Rücker's plan of the placer deposits in the Fojnička and Zeležnica valleys, Bosnia, georeferenced over modern satellite imagery. The diagonal hatching, labelled 'Seifen in Thal', marks the placer deposits in the valleys, while the dark cross-hatching, labelled 'Seifen im Mittelgebirge', marks placer depsits on the hillside flanks (by A. Wilson, 2023, after Rücker 1896, 85, georeferenced in QGIS using the 'Freehand raster georeferencer' plugin; satellite image: Google Satellite).

Fojnica (von Foullon 1893: 44). This too was probably therefore Roman, but no details are known.

Dacia

The main gold mines of Dacia are in hard rock deposits in the so-called 'Golden Quadrilateral' of the Apuseni Mountains, and were mined by underground tunnelling or, in the case of the Cetate area at Roşia Montană, by large manually excavated opencasts. The best known of these complexes is the mining region of Roşia Montană, the ancient Alburnus Maior, famous among other reasons for the finds of wax writing tablets hidden in several mine galleries when Dacia was invaded in AD 167 during the Marcomannic Wars (Wilson *et al.* 2011). But there are also two sites where hydraulic working is evident, at Bucium and Pianul de Sus.

Bucium

The Roman gold mines of Bucium lie about 10 km south-east of Roşia Montană, on the Vâlcoi-Corabia massif in the Apuseni mountains. The Petru şi Pavel mine is a Roman adit driven into the north side of the hill, whose date is evident from its characteristic trapezoidal cross-section, lamp niches, and Roman tools found within it (Ciugudean 2012: 224, fig. 10; 225; Ciugudean and Thomas 2020: 117). Much larger scale surface mining works were located on the southern flank of the massif: two linear trench opencasts, Ieruga and Gaura Perii, and a series of channels and tanks on the plateau known as Poduri. The area has been studied since 2018 by a German-Romanian project, whose work has included drone survey mapping to create an extremely high-resolu-

Fig. 7. Bucium, Romania: rectangular hushing tank with the lower part of the Ieruga opencast in the background (photo by A. Wilson, 2022).

tion digital elevation model (DEM), test excavations, and ground-penetrating radar (GPR) surveys (Ciugudean and Thomas 2020).

Both the opencasts are dug in hard rock to exploit quartz veins. The Ieruga opencast, 600 m long and up to 40 m deep, has however a series of channels approaching its eastern side, ending in long tanks, and although the excavation of the upper part must have been done by hand, it seems that water was used either for ore sorting (as suggested by Ciugudean 2012: 225) or for prospection hushing or ground-sluicing within the opencast. Lower down, and certainly below the modern track that runs along the contour here, it appears to have been worked as a hushed opencast, fed by a rectangular tank (*c.* 46 × 13 m) on the western side (Fig. 7). The interpretation of this tank as a hushing tank is further supported by the fact that a test trench here showed an absence of sediments formed by standing water at its base (Ciugudean and Thomas 2020: 124–5, 128); these would have been scoured out as the tank was emptied in hushing operations. Further west, channels and ponds for concentrating crushed ore are visible at the Poduri site, shown in remarkable detail on the high-resolution DEM (Ciugudean and Thomas 2020: 121). Among the dumps here, pottery confirms a Roman date of the workings (thus between AD 106 and 271 at the outside), and pounders for crushing ore have been found (Ciugudean 2012: 232, Pl. VIII–XI; Ciugudean and Thomas 2020: 123). Further south on the Poduri plateau is a Roman cemetery.

Study of the site is incomplete and the function of the various channels and tanks is not yet fully understood, but already the investigators, Horia Ciugudean and Peter Thomas, make a distinction between the features on the Poduri plateau, most of which appear to be for ore concentration or processing, and the channels and tanks running up to either side of the Ieruga opencast (Ciugudean and Thomas 2020: 128). Given the elevation here, the water for

Fig. 8. Satellite view of the workings at Pianul de Sus, Romania. 1: Area of small pits to the east of the modern golf course. 2: Plateau incised by channels which develop into deeper hush-gullies at the eastern edge. 3: Hushing tank with channel discharging into 4, a now wooded hush-gully. 5, 6, 7, 8: Ridges whose flanks are dissected by ground-sluicing channels. The village of Pianul de Sus extends along the road to the right of the centre of the image (satellite image: Bing Virtual Earth, with annotations by A. Wilson, 2023).

at least some of these systems may have come from meltwater as the winter snows thawed in the spring. LiDAR survey is necessary to understand the topography of the wooded parts of the site, including the Ieruga opencast itself, and geological investigation here might also have a bearing on whether some of that opencast was worked by hushing, as the morphology and arrangement of the channels and tanks associated with it would appear to suggest.

Pianul de Sus

To the south of the Apuseni mountains, a large area of alluvial deposits was worked in antiquity on the left bank of the Pianul stream, one of the tributaries of the river Arieş, to the west of the village of Pianul de Sus. Pianul de Sus has been recognised since the nineteenth century as a Roman gold mining site; it is described briefly in the *Repertoriul arheologic al județului Alba* (Moga and Ciugudean 1995: 145–6) and in Volker Wollmann's study of mining in Dacia (Wollmann 1996: 149–50), and an aerial photograph was published by Ioana Oltean (2007: 183, fig. 5.40). It was apparently studied by a Franco-Romanian team in 1999, but, apart from an analysis of gold samples collected by panning (Bedelean and Bedelean 2001), no report was published as the focus of the mission was then diverted entirely to Roşia Montană (Cauuet 2005: 265–6). The description given here is based on study of publicly available satellite imagery (Google Earth and Bing Virtual Earth), and a visit in August 2022.

The ancient workings here extend across an area of *c.* 4.6 km N–S by up to 1.8 km E–W. In the north, to the north, east, and south of the modern golf course, are numerous small sub-circular pits (Fig. 8, 1). These and the other pits on the site may be post-Roman; some are certainly from nineteenth-century workings. A small stream valley running south-west to north-east into an

Fig. 9. Oblique aerial photograph of the Pianul de Sus workings, facing south across areas 5–8 on Figure 8 (photo by Horia Ciugudean, 1998).

artificial lake separates these from more groups of pits on a terrace which is criss-crossed by artificial channels which feed into gullies—exploitation workings—at the north-east edge of the terrace (Fig. 8, 2). Further pits lie on a lower terrace to the east of area 2. To the south-west is another group of pits, and an L-shaped tank at the head of a gully that becomes steeper and widens to the east (Fig. 8, 3); the lower part of the gully lies within a heavily wooded depression (Fig. 8, 4). To the south-east, four ridges each running from south-west to north-east, are heavily dissected by deep channels and gullies resulting from intensive ground-sluicing operations fed by channels along the spine of each ridge (Fig. 8, 5–8; Fig. 9). These are characteristic of Roman hydraulic mining with a combination of hushing and ground-sluicing (Fig. 10). The probably post-Roman pits for artisanal gold-washing are found only where the Roman workings were less intensive. Much could be clarified by a drone survey to create a high-resolution DEM, as was done at Bucium, and LiDAR survey to determine the detailed topography of mining systems in the wooded areas of the site.

Pannonia Superior

Karth

The Karth plateau, in the foothills of the Eastern Alps, some 80 km south of Vienna, is part of the Loipersbacher Rolehmserie, an accumulation of scree composed of loam and layers of weathered quartz and quartzite eroded out of the mountains and containing placer deposits of free gold (Cech 2012 [2014]: 67–8). Various earthworks, linear features, and artificial opencasts in the woodland here were first recognised as the remains of Roman hydraulic mining works in 2010, and an initial field survey with the aid of LiDAR scans

Fig. 10. Pianul de Sus, Romania: view of the hush gulleys and parallel ground-sluicing works on the south side of area 6 shown in Figure 8. (Photo: A. Wilson, 2022).

was carried out, with a follow-up project from 2018–2022 under the direction of Brigitte Cech that involved detailed landscape survey with GPS and total stations (Cech 2012 [2014]; Cech *et al.* 2013; Cech 2018; 2019; Cech *et al.* 2019; Cech 2020; 2021; Cech and Urban 2021; Cech 2022). Eleven distinct mining areas were identified (Fig. 11), with a total of 17 reservoirs and nine smaller tanks, fed by five long-distance water leats (Cech 2019; 2021; 2022).

The mining areas each have one or more larger collection basins from which water was distributed to hushing tanks above the steeply sloping opencasts (Cech, *et al.* 2019: 98–101, 104–7). At the lower ends of the opencasts alluvial fans represent the tailings from mining and washing activities. The reservoirs were supplied from the west and south by five leats collecting water from perennial streams. In recent centuries many have been used as paths and their true function had already been long forgotten by the 12th century, when a monastic document of AD 1134–1144 refers to one of them as a *gygantea via* and as *Aentiskenwek*, 'giant's road' (Cech, *et al.* 2013: 8). The longest, to the south, ran for 64.3 km (Fig. 11, WL2); another, the Schwartztaler Entweg, ran (in the first of its two phases) for 35.5 km from the west (Fig. 11, WL1). The total length of all five aqueducts was about 123 km (Cech, pers. comm. 8 April 2023, updating previously published information).

Two levelled terraces some 500 m apart either side of the largest mining area (Fig. 11, A1) were probably platforms for living or working; Roman tools for woodworking, smithing, and mining have been found here (Lang *et al.* 2010; Cech 2012 [2014]: 71–6; Cech, *et al.* 2013: 32–45). The mining tools include picks and hoes for digging channels and tanks, and for breaking up and loosening the soil prior to hydraulic mining. Crucible tongs and a variety of lead weights suggest that the gold recovered was cast into ingots on the site (Cech, *et al.* 2019: 91).

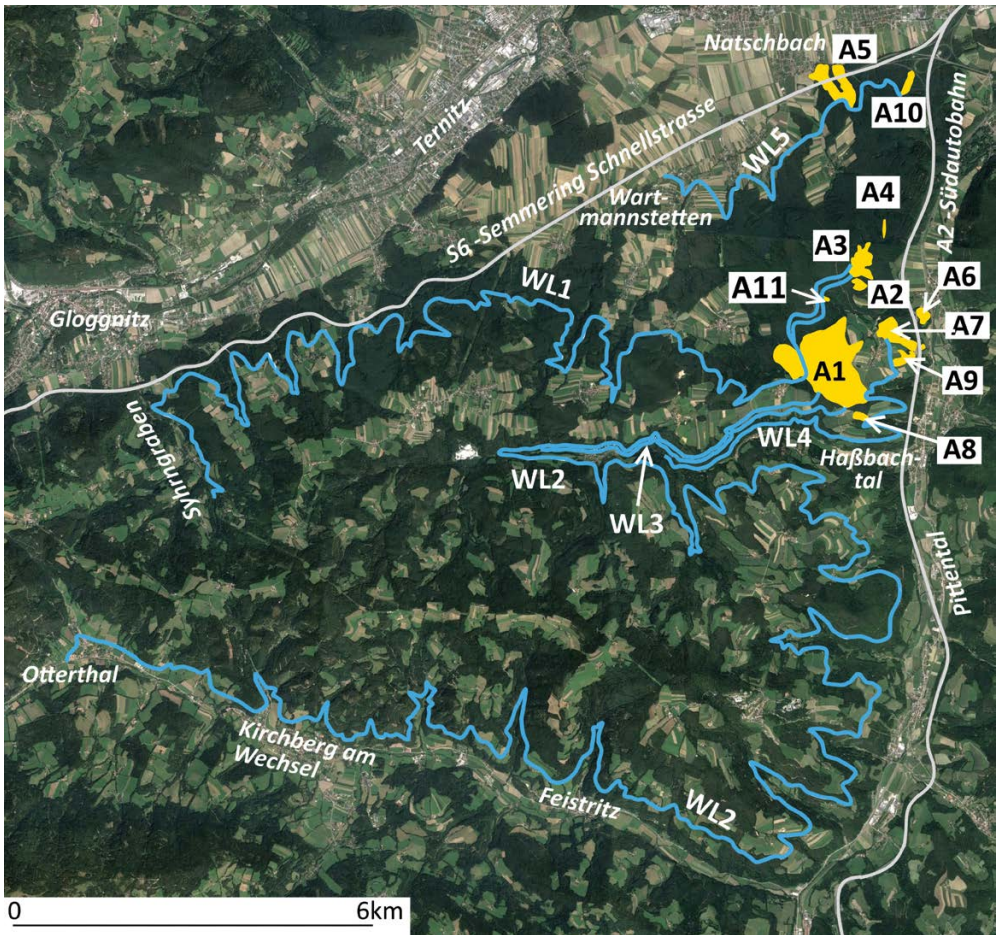

Fig. 11. The Karth, Austria: plan of the eleven mining areas (A1–A11), and the five aqueducts (WL1–WL5) supplying them (Cech *et al.* 2023, 17, Abb. 4).

Three coin hoards were found during the survey of the mining landscape (Schindel, in Cech, *et al.* 2013: 48–71). One was a small group of six legionary *denarii* of Mark Antony, which is of little chronological help as these coins remained in circulation for a long time. The second was a hoard of 129 *denarii* closing in AD 168; Schindel (in Cech, *et al.* 2013: 51) suggests that it may have been buried when the Marcomanni and Quadi invaded in 168 and 169. This is certainly very plausible although non-recovery of the hoard as a result of the Antonine Plague is also a possibility. Since this hoard was found actually within the opencast of mining area 1 (Cech, *et al.* 2013: 20, fig. 12), it shows that the opencast here was already being worked by the late 160s. The third hoard was a small group of nine Severan *denarii*, closing in AD 201–206; it was found immediately north of mining area 3 (Cech, *et al.* 2013: 20, fig. 12). This suggests that whatever the disruption to mining in the 160s, whether invasion or plague, mining had resumed again by the Severan period. These hoards, and the dates of other finds including fibulae and a military belt buckle suggest that the main mining operations date from the second and third centuries AD. But the coins from the two working areas (214 coins from one terrace, and 104 from the other) are nearly all of the later fourth century and the early fifth century (Fitz in Lang, *et al.* 2010: 102–4), suggesting that some of the mining on the Karth may have persisted (or resumed) much later than the other mining works discussed here.

Discussion

Not only were the hydraulic mining techniques pioneered by the Salassi in northern Italy transferred to Spain, and there developed and refined, but they were also spread to the Balkans and Eastern Alps in the Roman period. We can assume that the mines of the Central Bosnian mountains were in use perhaps as early as the Augustan period, and certainly by the later first century AD, under Nero and the Flavians, though in the absence of archaeological investigation we cannot say for how long after that their exploitation continued. The area of the Bosnian mines was connected via a road past the Roman fort at Tilurium to the port of Salona, where the provincial procurator had on his staff an official whose title was *a commentariis aurariarum Delmatarum* ('account keeper of the Dalmatian gold mines'), suggesting that the mining administration was headquartered there (Hirt 2010: 162). While the operations at Bistrica and Batusa seem to be ground-sluicing works of a broadly similar nature to those at Bessa in Italy, the descriptions of the mines on Mt Vranica, at Crvena Zemlja, Uložnica, and Zlatno Guvno, suggest that hushing, a technique that had already been developed in Spain by the mid first century AD, was used here. There may therefore have been some transfer of hydraulic mining technology from Spain to Dalmatia, by mining prospectors or engineers, perhaps attached to the army.

It is possible, even likely, that the hydraulic mining in Dacia came not directly from Spain but from Dalmatia; the migration of Dalmatian miners to Dacia in the early second century is well attested (Daicoviciu 1961: 72; Mrozek 1968; Tudor and Vladescu 1972; Sântimbreanu and Wollmann 1974: 241–7; Russu 1975: 183–5; Noeske 1977; Russu 1984; Wilson, *et al.* 2011: 72). They surely brought with them not only their expertise in underground hard-rock mining, but also their familiarity with hydraulic techniques as used at Bistrica and in the Mt Vranica region. The hydraulic mines at Bucium were in operation when Dacia was under Roman control, between AD 106 and 271 at the outside. On the analogy of Roşia Montană we might expect that they were already well developed before work was interrupted in the invasions by the Iazyges and Vandals in AD 167 during the Marcomannic Wars; work perhaps resumed again later in the second century or the third, but this is yet to be demonstrated archaeologically. Similarly the mines at Karth in Pannonia Superior seem to have been worked before 168, and the burial of a hoard then may indicate some interruption around that time, but there was also activity in the Severan period, and later apparently up until the late fourth or early fifth century AD.

Hydraulic mining of alluvial deposits on the scale attested at all these sites is a fantastically labour-intensive business, requiring a large amount of manpower in aqueduct construction, shovelling earth into washing sluices, discarding larger stones onto clearance dumps, etc. In north-west Spain this seems to have been done largely under some form of compulsion, in order to meet tributary requirements (Florus, *Epitome* II.33.59–60). State control, or at least oversight, is implied both by the scale of the workings, and the presence of the army in mining regions. This may also have been the case for the Dal-

matian mines, at least at first. But the implications of the scale of hydraulic mining for the organisation of labour and the overall economic profitability of the enterprises in Dacia and at Karth are still to be worked out—at Roşia Montană in Dacia underground mining was done by free workers, many of them with Dalmatian names, hired for wages by mine operators who may have leased mining contracts from the state. If labour under compulsion was used at the hydraulic mines in Dacia, it may may have been done by slaves or by criminals *damnati ad metalla*, unless any of the Dacian population who may have survived Trajan's wars of conquest were put to work in these mines.

Our understanding of Roman hydraulic mining has advanced substantially in recent decades and continues to develop apace. It is remarkable that the extensive mining areas on the Karth plateau, with their long aqueduct networks, went unrecognised for what they really were until 2010. Likewise the hydraulic mining systems at Bucium have only been the subject of intensive research since 2018. In both cases the use of modern mapping techniques using the creation of digital elevation models, in one case by LiDAR and in the other by drone survey, has been crucial to understanding the complexity and extent of the systems by revealing topographic details that cannot be seen on the ground. LiDAR is especially useful for mapping ground surfaces in wooded areas as it can penetrate trees and vegetation; and it has been used to great effect for mapping mining areas and water supply channels in north-west Spain, and in Portugal (Fernández-Lozano *et al.* 2015; Fernández-Lozano and Gutiérrez-Alonso 2016; Matías and Llamas 2018; Currás and Sánchez-Palencia 2021).

By contrast, some of the areas that have been known as hydraulic mines since the late nineteenth century remain virtually unstudied, such as those in central Bosnia. Here, and also at Pianul de Sus in Romania, there is great potential for LiDAR survey and high-resolution drone survey to clarify the nature of the workings, and the extent of the opencasts and the aqueducts supplying them; the work at Bucium and at Karth shows what can be done. Béatrice Cauuet has suggested that there are traces of hydraulic workings of placer deposits in the Ardennes in Belgium that may be Roman (Cauuet 2005: 256). More Roman hydraulic mining systems may await discovery.

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