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PLINY'S ARRUGIA
WATER POWER IN ROMAN GOLD-MINING

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Abstract: There are two kinds of evidence available for the study of Roman period water-powered gold-mining: surviving archaeological evidence and the writings of contemporary authors. Problems with the first include the difficulties of accurate dating, and the interpretation of the remains. Interpretation is also a problem with the ancient texts. The Elder Pliny gives the most important description we have of water-powered Roman gold-mining, but his writing is still misquoted and misunderstood; one recent work manages almost to reverse the true meaning of key words (Healy 1999, 277-283). It is therefore the aim of this paper to make clear what Pliny was actually talking about, by a careful examination of the text and by comparison with surviving remains and useful recent parallels. Some of the remains of Roman period working indicate that different but related techniques were also in use.

Introduction

The use of water in connection with gold-winning has a very long history, based on the comparative density of gold and the possibility of finding it naturally in a more or less pure form. Presumably the technique of panning for gold was discovered early on, and from there it would be a simple matter to move on to shovelling auriferous alluvial material into artificially created channels with running water. In due course these channels could be taken further afield, so as to flow more closely to deposits situated well away from existing streams. Passing references in ancient authors make it clear that diversion of streams to tackle auriferous deposits in this way was practiced in the Roman world. Thus the geographer Strabo refers to the gold-mines of the Salassi in northern Italy: 'The Durias river was of the greatest aid to them in their mining - I mean in washing the gold; and therefore, in making the water branch off to numerous places, they used to empty the common bed completely' (Strabo, 4.6.7). This may have been as early as the middle of the second century BC (Davies 1935, 63).

Strabo also notes 'gold-washeries' (chrysoplusia) in Spain: '*They flood the waterless districts by conducting water thither, and thus they make the gold-dust glitter; and they also get the gold out by digging pits, and by inventing other means for washing the sand: and the so-called 'gold-washeries' are now more numerous than the gold mines* [by which he means shaft and gallery mines] . . . *The soil is carried along in the stream and is washed nearby in troughs: or else a pit is dug and the soil that has been accumulated is there washed*' (Strabo, 3.2.8). These 'gold-washeries' may have been the same as the workings Pliny calls alutiae, in which he notes that tin is also sometimes found. There are very few details, but the term is specifically used of gold mines and the technique involves water being 'sent in' (aqua inmissa) (Bailey 1929, 156). Gold and tin-stone may be found together in placer deposits (Charles 1975, 63). The meaning of alutia is discussed further below. Although these techniques use the force present in flowing water, there is nothing to suggest that water power in a true sense is involved.

Pliny, however, also gives us a description of a technique which undoubtedly involves using the power of water created by leading it to places high above the area to be worked. Difficulties of understanding have been caused because of the way the text alternates between descriptions of conventional mining and of large-scale workings using water power. They have also been caused by attempts to match the text to all of the remains of Roman period gold-mining using water power. In fact it is not difficult to recover Pliny's description of the technique he says was called arrugia, or to show that it is most likely to have referred to the working of deep alluvial deposits. The key text is part of Pliny's wide-ranging and very important work, the Natural History.[1] A fairly literal translation is offered here; it is not proposed to discuss every part of the text in detail but it is included, apart from a few irrelevant asides, to place the rest in context.

[66:] *Gold is found in our* [part of the] *world in three ways* . . . : [firstly] *in what rivers throw up on their banks, as in the Spanish Tagus, the Italian Po, the Thracian Hebron, the Asian Pactolus* [and] *the Indian Ganges; and no gold is purer as it is thoroughly polished by the very motion and friction.* [67:] *Otherwise it is mined from shafts* [putei] *or sought by causing the collapse of mountains* [ruina montium]; *let each method be explained.*

Those seeking for gold take up segutilum first of all and so it is called the sign. This is excavated and the sand is washed and from that which sinks to the bottom conclusions are drawn. Sometimes it is found immediately on the surface by a rare stroke of luck, as recently in Dalmatia while Nero was emperor, actually yielding as much as 50 [Roman] *pounds in a single day.* [68:] *When it is found like this, on the surface, they call it talutium* [or talutatium] *if there is also gold-coloured* [aurosa] *earth underneath. Mountains of Spain which are otherwise dry and barren and from which nothing else is gained, are forced to produce this wealth.*

What is extracted from shafts [putei] *they call canalicium* (others [call it] canaliense), *embedded in marble gravels* . . . *embracing the grains of the marble.* [69:] *These networks* [canales] *of veins* [run] *this way and that along the sides of the shafts, hence the name* [they are] *given, and the earth is held up by wooden props. What is extracted is crushed, washed, roasted and ground. They call the dust apitascudis [or: the fine dust from the mortar they call scudes]* [and] *the argentum which comes out of the furnace* [they call] *the 'sweat'. The impurities which are cast out of the furnace are called slag* [scoria] *in all metals. In* [the case of] *gold, this is pounded and heated again. The crucibles are made from tasconium, which is a white earth rather like potters' clay, for nothing else withstands the blast and fire and blazing matter.*

[70:] *The third method has surpassed the achievements of the Giants. Mountains are hollowed out by underground passages* [cuniculi]

driven over great distances by the light of lamps. The same light is the measure of the shifts, and for many months daylight is not seen. This class of working they call arrugiae, and collapses occur suddenly and crush the miners . . . and so arches [fornices] *are left at frequent intervals to support the mountains.*

[71]: *Silex* [quartzite?] *occurs in both types of mine [ie putei and* arrugiae*]. They break it with fire and vinegar, but more often, since that process chokes the galleries with fumes and smoke, they cut it to pieces with crushing machines* [fractaria] *carrying 150* [Roman] *pounds of iron, and they carry out the debris on their backs through the gloom by night and day, passing it on to the next in line; and the last one sees the light of day. If the silex seems too thick, the miner follows its edge and circumvents it, and yet working in silex is considered easier,* [72:] *for there is a kind of earth composed of a sort of clay mixed with gravel - they call it gangadia -* [which is] *almost impossible to overcome. They attack it with iron wedges and the hammers mentioned above . . .*

When the operation has been completed, they cut through the necks of the arches [fornices] *starting from the furthest end. A subsidence gives the signal, and the only one who notices it is the watchman on the top of the mountain.* [73:] *He, by shouts and by signal, gives the order for the workmen to be called out and at the same time himself flies down* [from his station]. *The shattered mountain falls right away from itself with a roar that cannot be imagined by the human mind, and with an equally incredible rush of air; the conquerors observe the collapse of nature. And yet there is no gold so far, nor were they sure there was to be any when they were digging, and it was reason enough for such dangers and expense to hope for what they desired.*

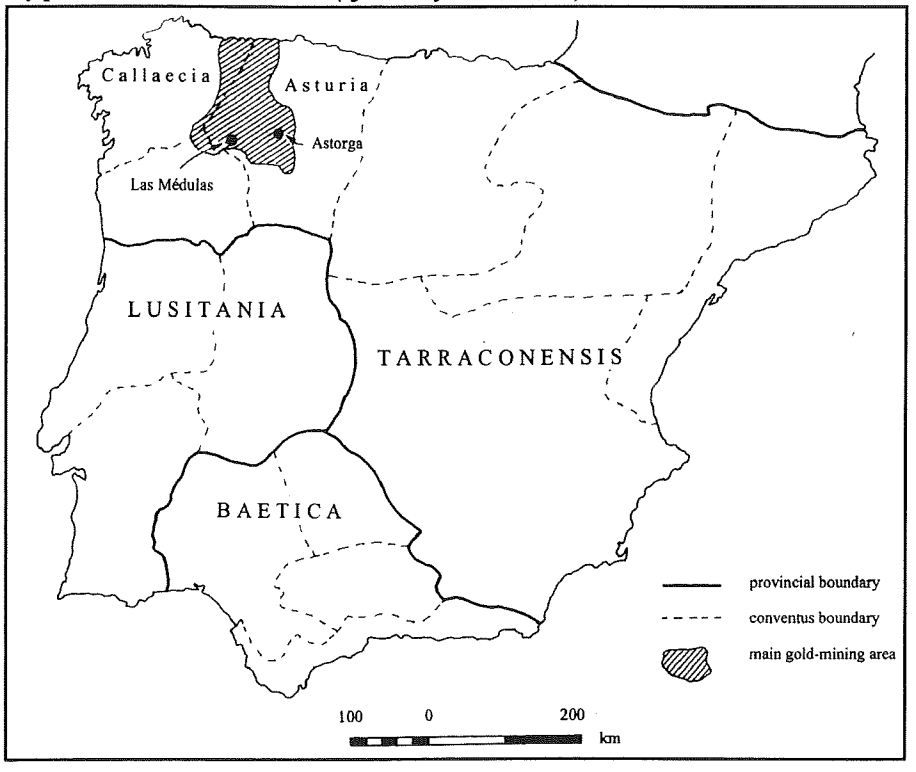
[74:] *There is another operation, equally laborious, and even involving greater expense. They have previously led rivers flowing along the ridges of mountains for the washing of the collapsed material and often from a hundred* [Roman] *miles away. They call* [the channels] *corrugi, I believe from conrivatio. And this involves a thousand tasks: the fall of the water* [at the mine] *must be headlong, so that it rushes down rather than flows, and so it is led from the highest places. Valleys and gaps are bridged by built-up channels. Elsewhere impassable rocks are cut away and compelled to provide a bed for hollowed-out wooden troughs. The man who does the cutting hangs from ropes, so that to someone looking from afar he has the appearance not just of a wild beast but a winged one.* [75:] *They take the levels for the most part suspended by ropes and mark out the lines for the course, and where there is not room for someone's feet to stand, streams are led by man. Also* [there is] *a fault in the washing if the flowing stream brings down mud in its flow; this kind of earth they call urium. Therefore they make the course through rocks or pebbles and they avoid the urium. At the head of the drop on the brow of the mountain they dig out reservoirs, 200* [Roman] *feet on each side and 10 in height. In these they leave five outlets roughly three feet square, so that when the tank is full and the blocks are struck away a torrent shoots out with such force that it can roll boulders forward.*

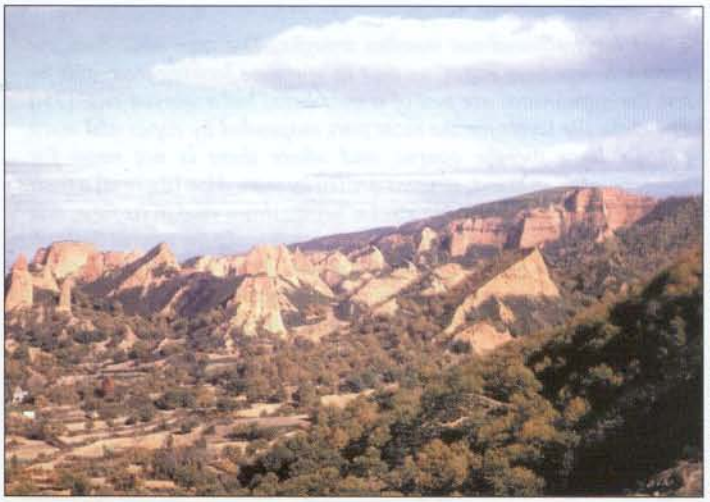
[76:] *Even now there is another task on the level ground. Ditches are dug out -they call them agogae - through which the torrent of water can flow, and they are strewn at intervals with ulex. This bush is like rosemary, rough and able to catch the gold. The sides* [of the agogae] *are enclosed with boards and the channels are supported over broken ground. Thus the earth flowing onwards slides away into the sea, and the shattered mountain is washed away, and owing to these causes Spain has already moved its earth from afar into the sea. The debris which is removed with tremendous effort in the previous method, so that it does not choke the shafts* [putei], *in this* [method] *is carried away by water.* [77:] *Gold sought by arrugia is not smelted, but has its own properties at once. Thus nuggets* [massae] *are found, not as in shafts, and exceeding 10* [Roman] *pounds* [in weight]*; they call them palagae, others palacurnae, and what is smallest balux. The ulex* [from the agogae] *is dried, burned and its ash washed over grassy turf so that the gold settles.*

[78:] *Some have shown that Asturia, Callaecia and Lusitania yield 20,000* [Roman] *pounds weight in a single year by this method in such a way that Asturia produces the most. And in no other part of the world has there been this abundance over such a long period.*

It is very likely that Pliny's knowledge of arrugia was gained at first hand. Gaius Plinius Secundus, known to us as the Elder Pliny, was of equestrian rank, and in the 1st century AD this could lead to a career starting with minor military commissions before going on to high-ranking posts in financial administration. Pliny's own career seems to have included a spell as Procurator of the Province of Hispania Tarraconensis in AD72-4 (Syme 1969, 215-27). The area (Fig. 1) can be seen to include the hugely important gold-mining region of North-West Spain. As Procurator, Pliny's duties included receiving revenue and superintending the emperor's financial interests. He would have been directly responsible to the emperor, thus serving to some extent as a check on the provincial governor. It is therefore reasonable to assume that Pliny's office was directly concerned with the production figures for the gold mines, and that the figures he gives are both accurate and up-to-date. It is interesting that it was possible for him to know something of the spread and production of arrugiae separately from other mine-production figures, which suggests that mines were actually recorded as different types.

Fig. 1. Map of Spain showing the provinces at the time of Pliny, the districts (conventus) of Asturia and Callaecia, the main gold mining area in the North-West and location of key places mentioned in the text (after Keay 1988, 61; 66).

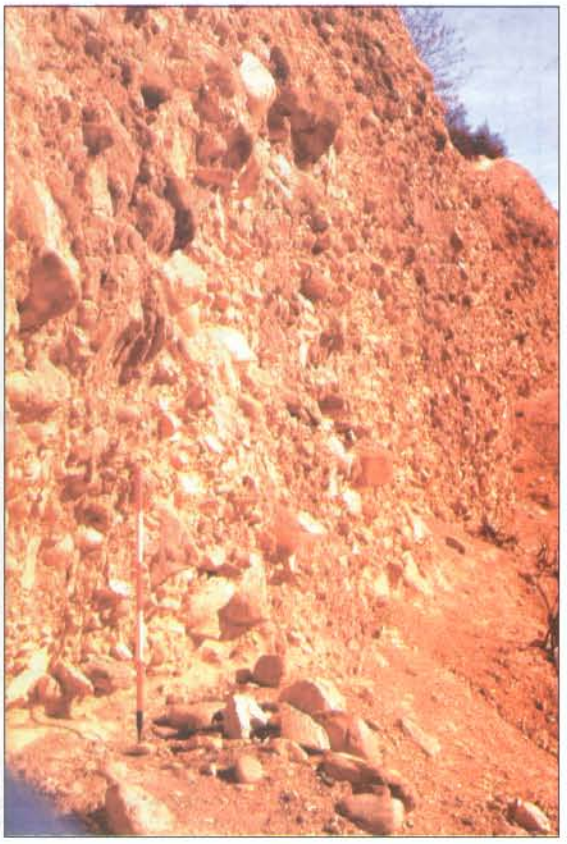




Las Médulas - *photos by David Bird*

Plate 1 (top left). the main opencast; village buildings in the foreground give some idea of the scale.
Plate 2 (top right). Supply aqueducts in the Cabrera valley. Traces can be seen on the foreground hills to left and right, and as lines brought out by the snow in the distance.
Plate 3 (above left). View across the main effluent route from the main opencast.
Plate 4 (above right). Spread of debris washed-out from the main opencast: some idea of the depth can be judged from the section in the foreground.

Plate 5 (below left). La Leitosa: effluent fan below the main working.
Plate 6 (below). Detail of a compacted gravel part of the deposit.



Pliny was a prolific author. He read (or was read to) extensively and made copious notes. His most important (surviving) work is the Natural History (NH). Much is gathered from other writings, some already centuries old, but Pliny evidently liked to see for himself when possible, and some of his writing is based on first-hand experience. Thus his first work was about throwing the javelin from horseback, written when he was a junior cavalry officer *(The Letters of the Younger Pliny* 3, 5). The description of water-powered gold-mining he gives is clear and comparatively lengthy and includes many touches which suggest the eye witness (for example, the descriptions of the mountain collapse (NH 33, 73) and of aqueduct construction (NH 33, 74). His unique description of Asturica Augusta (modern Astorga) as 'urbs magnifica' (NH 3, 28) suggests that he had been there. Astorga is in the very centre of the main mining area to the south of the Cordillera Cantabrica, and, probably from some time not long after Pliny, became the base for a procuratorial post with direct responsibility for all the mines in the North-West (Nony 1970; Bird 1978, 301-2).

Pliny indicates that large-scale gold production had been in progress in North-West Spain for many years. The area was not finally conquered by the Romans until about 19BC, and probably did not feel secure for some time after that. Pliny's statement that 'in no other part of the world has there been this abundance over such a long period' (NH 33, 78) is strongly suggestive of a new goldfield, and invites comparison with the early years of the Californian gold rush. Current evidence suggests that the Romans were the first to work the secondary alluvial deposits and the hard-rock deposits of the North-West on a large scale (Bird 2001, 265).

The text may be interpreted as follows. In paragraphs 66-7 Pliny notes that gold is found in three ways, which here and subsequently he explains as in river placers, in putei and in arrugiae. 68-9 makes it clear that putei are shaft and gallery workings, with gold in quartz veins, requiring further processing. Note that wooden props are used and that waste material must be removed from the mines (see 76). Pliny is consistent in his use of putei for this sort of mine.

The third method is specifically named as arrugia and is huge in scale (70). It is described in much more detail than putei workings, covering the whole of sections 70-77 except for occasional digressions to refer to putei, always specified. Arrugia involves the creation of underground galleries sustained by arches of undug material, not wooden props (70). In 72-3 Pliny explains that these arches (he uses the same word, fornices) are cut to cause the collapse of a large area. He notes that at this stage it is not certain that there is any gold. In 74-5 there is a lengthy description of the construction of long aqueducts to provide water to large tanks placed high above the workings. There is considerable stress on the need for the water to be high enough to rush down onto the collapsed material. Pliny notes that the force is strong enough to move boulders. In 76-7 we learn that the water is guided into lengthy sluices (agogae), where the gold is recovered, and that the gold found using this method does not require processing and may include large nuggets. This is specifically contrasted to the results of mining using putei. The scale of the operation is again made clear by the indication that vast amounts of debris are washed away. Finally, in 78, we learn that large quantities of gold were won using arrugia, the bulk of it in Asturia (but also in Callaecia and Lusitania (see map, Fig. 1), and that this had happened over such a period of time that, for Pliny, it was the most productive gold field ever.

In order to match Pliny's description to surviving remains a number of criteria must be satisfied. The deposit must be deep and firm enough to take tunnelling without props (although it may be unstable), but soft enough to be washed away by water power once broken up. It will include gangadia and silex, and may contain boulders. The deposit is expected to be auriferous but this will not be confirmed until the broken material is washed through sluices. Nevertheless in general the method provides very good returns. Gold from the deposit is free and requires no processing; large nuggets may be present. A copious and continuous water supply is required, delivered by lengthy aqueducts and controlled through large tanks sited above the mine.

There can be little doubt that only a deep secondary alluvial deposit will fit these criteria. In fact almost all of Pliny's description can be paralleled more or less exactly in 19th century California. There, methods had to be developed to deal with deep alluvial deposits where the gold was contained mostly in the lower beds; in some cases the material had been laid down in such a way that there were 'false bottoms', so that gold was present in significant quantities in different layers within the deposit. Of particular interest is the fact that the lower part of the deposit could contain layers so compacted that they were known as 'cement', which had to be dealt with by the use of explosives: a closer parallel for gangadia ('a sort of clay mixed with gravel') would be hard to find. In California it was possible to use hose-pipes to work the collapsed material, in a method that came to be known as 'hydraulicking', but in every other respect it is a parallel for Pliny's arrugia. Huge amounts of water were required; the material washed away caused massive silting up of river valleys; in the preparation stages it was not clear that much gold would be found, but in general the method provided very good returns over a lengthy period of time. [2]

There are extensive remains of Roman gold-mining in North-West Spain, but not many workings in deposits of the right type and deep enough to match all the details of Pliny's description.[3] In brief, north of the Cordillera Cantabrica there are major mines with evidence for the use of water power, but these seem to have been developed in the gossans of hard rock deposits; alluvial workings in the area seem to be relatively small-scale. South of the mountains, alluvial deposits on rivers in a wide area around Astorga have been worked on a very large scale, but in most cases the deposits are too shallow to fit Pliny's description. On rivers such as the Duerna there is some evidence for working in deeper deposits, but these do not seem sufficiently stable to take tunnelling (Jones and Bird 1970, 62-70). Only a few sites are known to the author where the deposit and the remains are a good match to Pliny's description and of these the best fit is undoubtedly the mine at Las Médulas, around 50km (as the crow flies) to the west of Astorga.

The remains of mining in the area around Las Médulas are spectacular, especially the huge amphitheatre-like opencast carved out of the massive orange-red alluvial deposit, littered with pinnacles of varying sizes where parts of the deposit have survived (Plate 1).[4] These pinnacles frequently show a profile that slopes on one side but on others is more or less vertical; the horizontal bedding planes of the deposit make clear that this cannot be a natural phenomenon (in which the tops should be created by flat caps of harder material) and it is possible as

a result to reconstruct something of the shape of the original hills that have been largely removed. Extensive traces survive of very long aqueducts (Plate 2), whose lines along the Cabrera valley frequently recall Pliny's description, and a number of water tanks are known, sited at the highest points of the mine. There are in fact a number of mining areas at Las Médulas, but the main opencast is the working most likely to have been seen by Pliny. In places this preserves vertical faces around 100m in height, which clearly show a sequence of horizontal layers varying from fine silty material to large compacted gravels (Plate 6). There are a number of large caves and small tunnels which may or may not be Roman but demonstrate the stability of parts of the deposit (see rear cover). There is evidence to show that gold is present in some but not all of the levels, some of which might be Pliny's gangadia, while the blocks of quartzitic material within the gravels might explain the presence of silex. The shape of the 'amphitheatre' makes clear the route that must have been taken by the debris-laden water as it flowed away from the mine (Plate 3); it passes first across an area littered by rock piles, presumably created by the removal of the larger boulders to prevent them blocking the flow; Pliny's reference to the rush of water being strong enough to move rocks comes to mind (NH 33, 75). The effluent route then passes between two small hills, beyond which the washed-out material has completely filled what must have been a deep and wide valley. A useful parallel, where the effluent fan is even more obvious, can be found below the mine at La Leitosa (Plate 5), another site with a very deep alluvial deposit and evidence for large water tanks surviving above the working face (Bird 1972, 58).

It can be seen that the mine at Las Médulas, and in particular the main working area, provides evidence to match every aspect of Pliny's description. It is reasonable to conclude that Pliny saw it or some other similar site (for instance La Leitosa) in operation, and as he would no doubt have wanted to visit the 'showcase' working it is most likely that he went to Las Médulas, as it was by far the biggest enterprise. There is sufficient evidence to suggest that the mine was in operation in the 70s AD, and in fact it is so large that it has been calculated that it continued in operation for as much as 250 years (a calculation based on the area worked and the probable amount of water available to work it) (Bird 1978, 167-8).

Although it is most likely that Pliny based his description of the technique of arrugia on the working at Las Médulas, he specifically states that the method was in use not only in Asturia but also in Callaecia and Lusitania. As has already been said, it is difficult to find evidence for sites that completely match Pliny's description except in a few places, but evidence for the use of water power in mining may certainly be found in all three areas. It is possible therefore that the term arrugia was used in a wider sense by the miners, and perhaps not even confined to alluvial deposits.

In a broad area around Astorga there is evidence for the working of shallow alluvial deposits on an industrial scale, particularly on the Rivers Omañas, Duerna and Eria. Here, water brought in by aqueducts was run into a series of parallel gullies which were gathered together into one at the foot of the shallow slope. Presumably material was worked into these gullies and the gold was extracted in sluices placed in the exit channel. There are many of these workings, one after the other along each river. The organisation and scale, together with evidence for mining procurators and Roman settlements in the immediate area, all point to Roman-period working. It is possible that this type of working was what Pliny calls alutia (see above), the word perhaps having some link to luere, with a meaning of 'to wash away'. Alternatively, it may be that there has been some copying error, and it is actually the same word as arrugia, because it is otherwise odd that Pliny does not mention alutia in the main gold-mining passage. This suggestion would have the further advantage that a possible derivation for arrugia might be to link it with the word rugare, which can indicate a corrugated or wrinkled effect - a good description of the shallow parallel gullies of the lower workings on the Duerna and the Eria. A similar explanation might account for the word corrugi, because seen from afar aqueduct channels look like a crease across the landscape. But this can only be speculation.

Other workings on these rivers show that different methods were developed in an attempt to cope with deeper deposits, where the gold-bearing levels were effectively sealed by several metres of worthless material. Here it is likely that water was fed to dams from which water was let out in a rush into prepared channels in order to cut rapidly down to the 'pay dirt'. The channels were taken round a central area and probably men with picks and shovels pushed more material into the stream in order to increase the effect. It is possible that this idea was then developed further to deal with the much greater depth of material at places like Las Médulas. In effect, therefore, a range of methods was used to deal with the circumstances provided by different alluvial deposits. Each made use of water and they could all have been thought of as belonging to the same general type of mine.

North of the Cordillera Cantabrica, in modern Asturias, there are opencast gold mines in hard rock deposits which also seem to have used water power. In each case they have aqueducts delivering a water supply to tanks placed at the top of the working, and a related series of channels and other aqueducts to take water to other parts of the opencast as required. These opencasts seem to have been worked into the gossans of auriferous sulphide ore bodies, where there may have been free gold contained in a mixture of mushy quartz and earth. There is little evidence for waste heaps, but valleys below the mines show signs of having been filled by water-borne effluent material. It is evident that water was used in some way to work the deposit and then to remove unwanted material, perhaps all in one operation, with sluices placed in channels between the opencast and the effluent in order to recover the gold. A similar technique was probably used for initial Roman-period working at Dolaucothi, in Carmarthenshire (Bird 2001, 266-9). The part of the deposit that could be worked in this way is unlikely to have been sufficiently stable to take tunnels, and some other aspects (such as gangadia) would also not match Pliny's description of arrugia, but it may be that a Roman mining engineer would have used the term, because of the use of water.

Pliny only mentions three ways of winning gold in his main discussion. The first seems to be contemporary river placers; to judge by the examples given it is most unlikely that secondary alluvial deposits are meant. The second is shaft and gallery mines, evidently for auriferous quartz. The third is arrugia. We have archaeological evidence for three broad categories of mining using water power in some way, all of which fit best with Pliny's final category, because they are not river placer mining or shaft and gallery workings. They are: shallow alluvial workings using parallel channels; deeper alluvial workings; the gossans of Asturias. Possibly therefore Roman

mining engineers thought of them all as arrugia. If the word started because of the 'corrugations' created by the shallow workings on rivers such as the Duerna, then as work turned to deeper and more difficult deposits it could have been applied to all mining involving water on a large scale. Certainty on this matter may never be possible, but it is clear that Pliny himself was describing work in deep alluvial deposits, so care must be taken when applying what he tells us to the mining of any other kind of deposit.

Acknowledgements

To Lynn Willies for use of the rear-cover photograph of the large excavated cavern at Las Médulas.

Notes

1. For the Latin and a helpful translation see Bailey 1929; the Latin is also given in Bird 1984.
2. In general see Paul 1965, and Bird 2001, 270-2, appendix, in which an early 20th century description of hydraulicking is matched paragraph by paragraph to Pliny's description of arrugia.
3. For a recent summary and references see Mangas and Orejas 1999, 291-313. For a general but now rather dated overview in English, with examples of the different mining types, see Bird 1972.
4. The description of Las Médulas is based on personal observation, recorded in Bird 1978, 151-72 and partially published in Bird 1972, 56-8 and Bird 1984, Fig 12.3.

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