GEOARCHAEOLOGY OF THE LANDSCAPES OF CLASSICAL ANTIQUITY

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Geomorphology and Archaeology in the Las Médulas Archaeological Zone (ZAM) (Leon, Spain): Evaluation of Wastes and Gold Production[1]

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The Las Médulas archaeological zone was included in the World Heritage List in 1997 because it is an outstanding example of innovative Roman technology, in which all the elements of the ancient landscape, both industrial and domestic, have survived to an exceptional degree (*Fig. 1*).

In the Pre-Roman Age (Iron Age) the territorial unit of population was the hillfort (*castro*) as territorial units. The communities of *astures* who inhabited them settled in prominent places in the landscape surrounded by a wide range of resources that made them self-sufficient. In this way, the transformation of the countryside was limited to the crops grown in the dry regions, pastures or orchards in wetter regions and near springs, and small-scale mining. It was a rural landscape that only changed in the immediate vicinity of the village. The analysis of the archaeological record (metallurgy, pottery, pollen, etc.) of Castrelín de San Juan de Paluezas and its surrounding resources confirms this equilibrium between the population and the rural environment (Fernández-Posse, Sánchez-Palencia, 1998).

Although gold had been known in the northwest of the Iberian Peninsula since Pre-Roman antiquity (Perea, Sánchez-Palencia, 1995; Sánchez-Palencia, Fernández-Posse, 1998), gold mining only developed with the reorganisation of the Roman monetary system undertaken by Augustus in which the gold standard (the *aureus*) was established.

The mark left by Roman mining survives to the present. There are more than five hundred gold mines in the Northwest (Domergue, 1990: cartes 5-6; Sánchez-Palencia, Orejas, 1994: fig. 12-17; Perea, Sánchez-Palencia, 1995: 102-109; Sánchez-Palencia, Álvarez, López 1997). The older mines used a hydraulic system, either to remove the barren overburden or to exploit the gold-bearing rocks and gravels. Many kilometres of flumes (*canales* or *corrugi*) flowed through the mountains, carrying water to the opencast mines (underground mining was rare).

These impressive remains that mark the landscape of the northwest suggest substantial gold production. However, the amount of gold extracted was very modest, perhaps 227 tonnes for *Asturia* and *Gallaecia* regions together over the course of the 1st and 2nd centuries A.D. (Sánchez-Palencia, 1996: 93-94)

The Las Médulas Roman mine is the most typical alluvial gold deposit from a Miocene alluvial fan. Here, Roman mining completely transformed the landscape, producing new geomorphological features over an area of 1,215 ha in three ways (fig. 2-3):

- The opencast mine (Sectors S-I, S-II and S-III, fig. 2 = 5,422,800 m^2).
- The accumulation of wastes or sterile tailings (E-1 to E-6, fig. 2 = 5,711,310 m^2).
- Post-Roman changes in the pattern of drainage, with the formation of the Carucedo lake, and the new deposits that developed as a result of the valleys being filled (1,013,000 m^2).

One of the main tasks outstanding in relation to the Las Médulas gold mine is to evaluate the extent of the mining carried out in the Roman period and to estimate the gold obtained as a result. These two aspects are closely linked and they both require careful geoarchaeological analysis. Various authors have so far tried to make an approximation without having reached entirely satisfactory conclusions. Domergue (1987, II, 306-8, as a summary on the question) has already pointed out the wide differences of opinion in this respect: from 60 to 300 million cubic metres. More recently, Herail and Pérez (1989, 21) reduced the amount to 200 million. Finally, we ourselves (Sánchez-Palencia, *et alii*: 1999, 73) suggested about 100 million on the basis of the area mined.

Taking into account the hydraulic systems used in the Roman period, we believe that the key to the question is to evaluate the volume of sterile tailings produced by Roman mining, since practically all the material removed must have been deposited in the resulting tailings or the waste fan. Their size can be determined relatively easily from an interpretation of the various aerial photography series available. The geomorphological analysis thus obtained (*Fig. 2* and *4*) is the

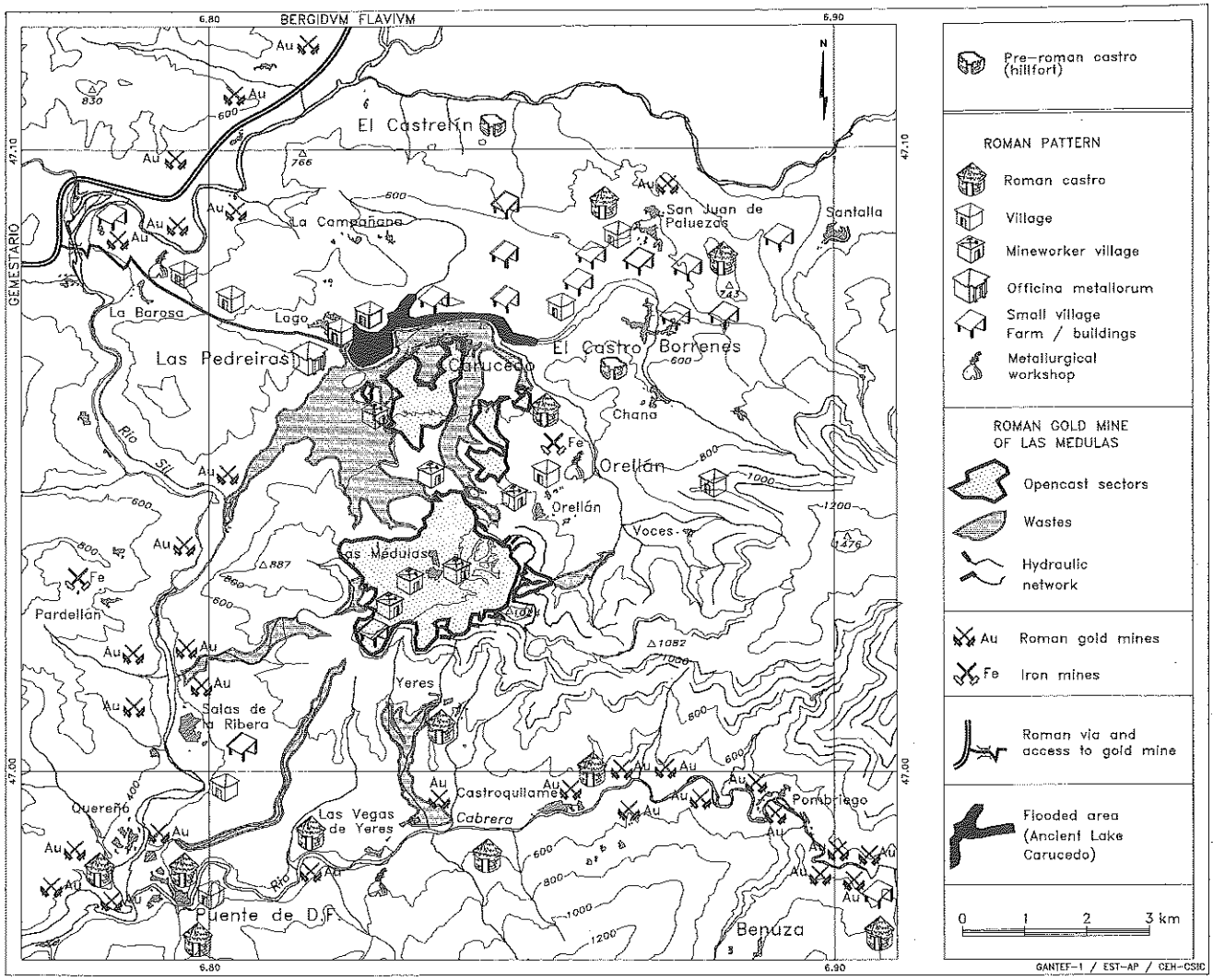

Fig.1: The Las Médulas Archaeological Zone (ZAM). Main ancient structures and settlements.

point of departure for estimating the area filled with wastes. However, the large area and apparent depth of these landfills precludes a reliable calculation using conventional methods. For this reason, in the summer of 1997 we proposed a geophysical survey on the main waste fan or sterile tailing of the Las Médulas gold mine, situated at the place known as Chaos de Maseiros or El Oucedo.

This survey was carried out by means of 33 points of resistivity readings,[3] which covered practically all the wastes in the artificial waste fan or sterile tailing from the mine (*Fig. 4*). They were distributed along seven traverses (*Fig. 5*), six of them almost parallel to each other with about 400/500 m between them, and the other at more of an angle, traverse III, situated between the east and western ends of II and IV, which, because of its position, has not been taken into account for calculating volume, but which served for comparing and confirming the depth of the wastes.

In addition to calculating the volume from the resistivity readings we also wanted to differentiate, where possible, the various layers of sterile tailings formed as the mine was worked, so that we could determine the volume of material removed in each sector more exactly (*Fig. 3*). It proved impossible to do this, because the whole of the mass surveyed gave very homogeneous resistivity readings, doubtless because

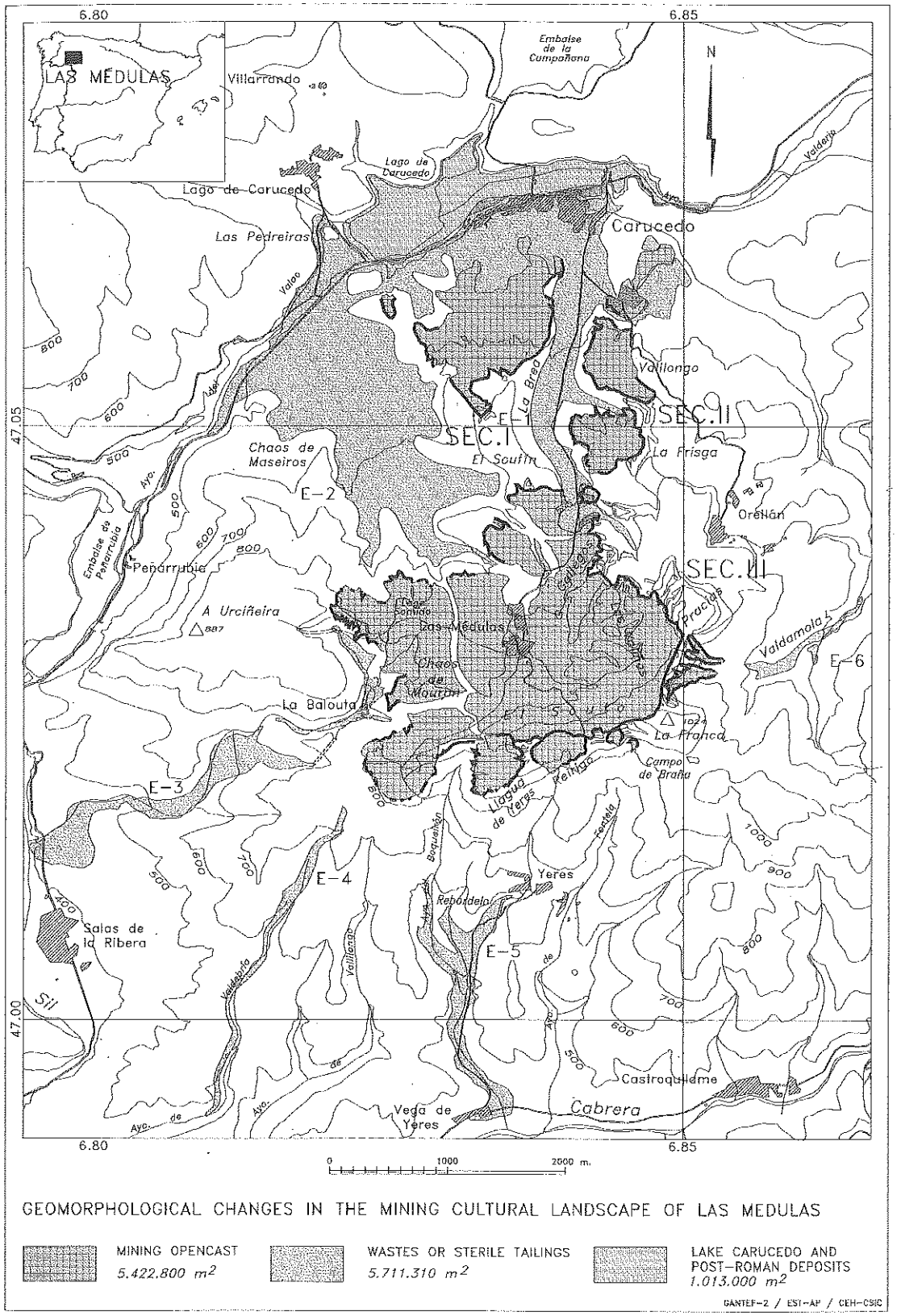

Fig.2.: Geomorphological changes in the mining cultural landscape of Las Médulas.

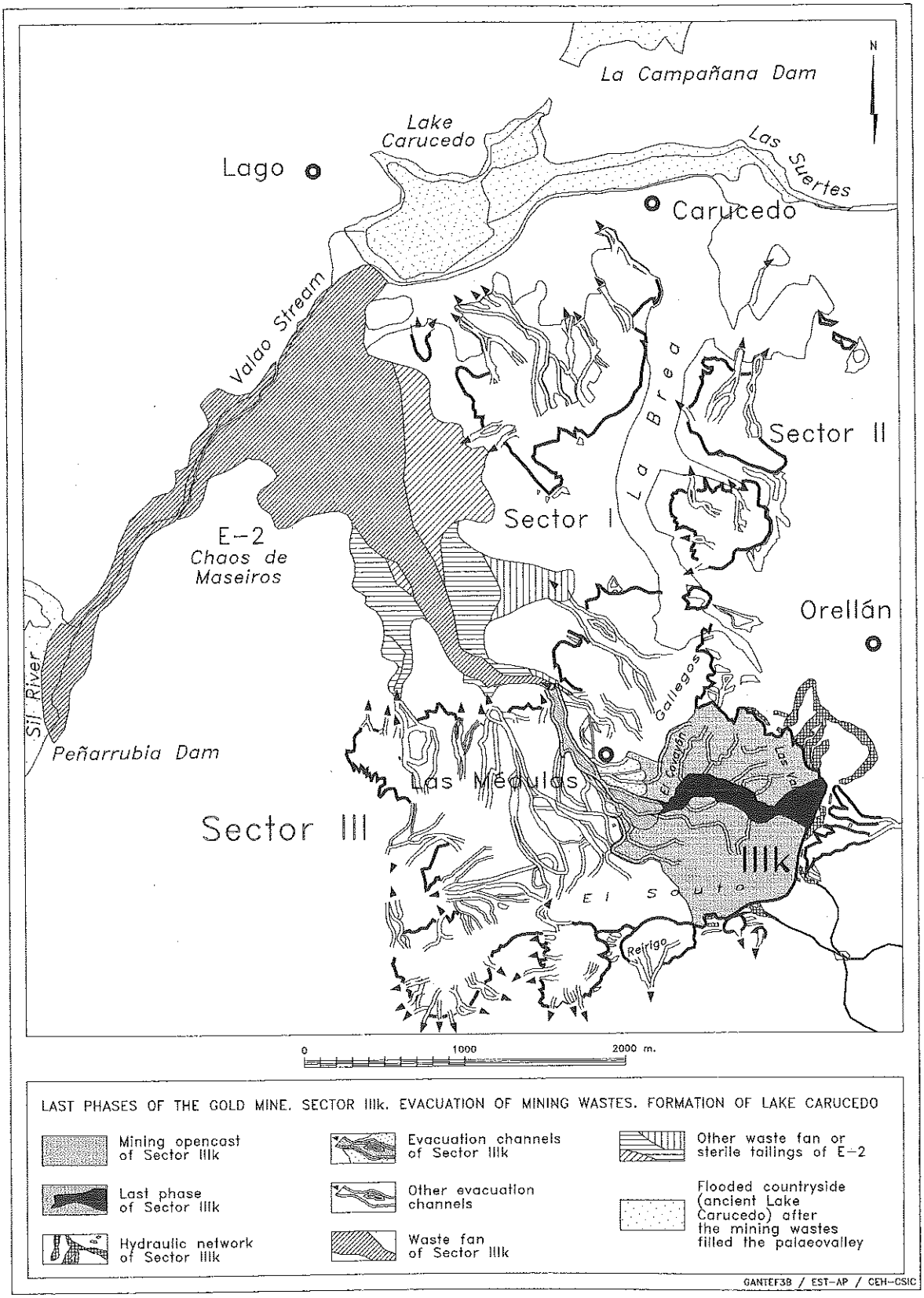

Fig.3.: Last phases of the Roman gold-mine of Las Médulas.

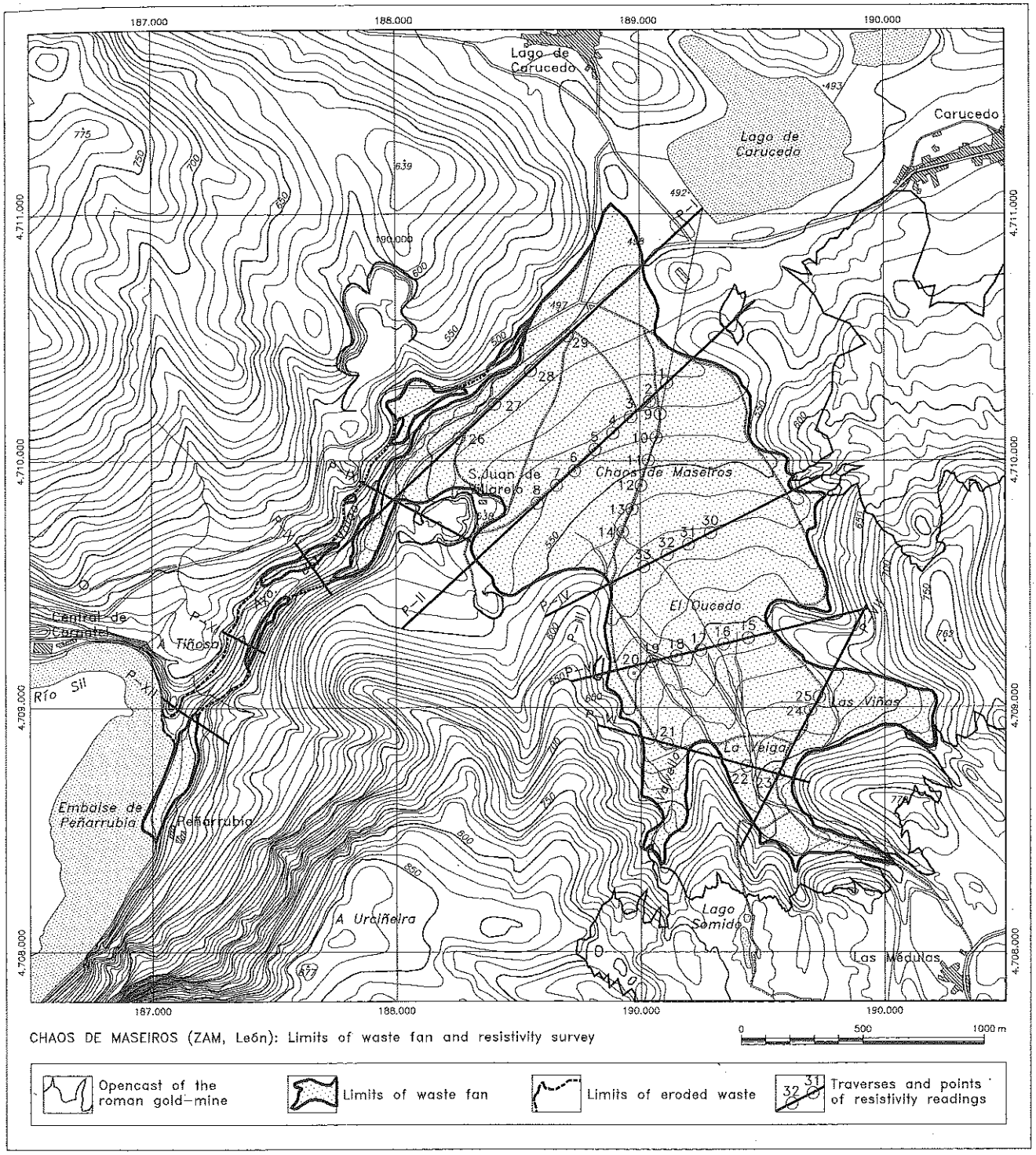

Fig.4.: The waste fan of Chaos de Maseiros. Limits of waste fan and resistivity survey.

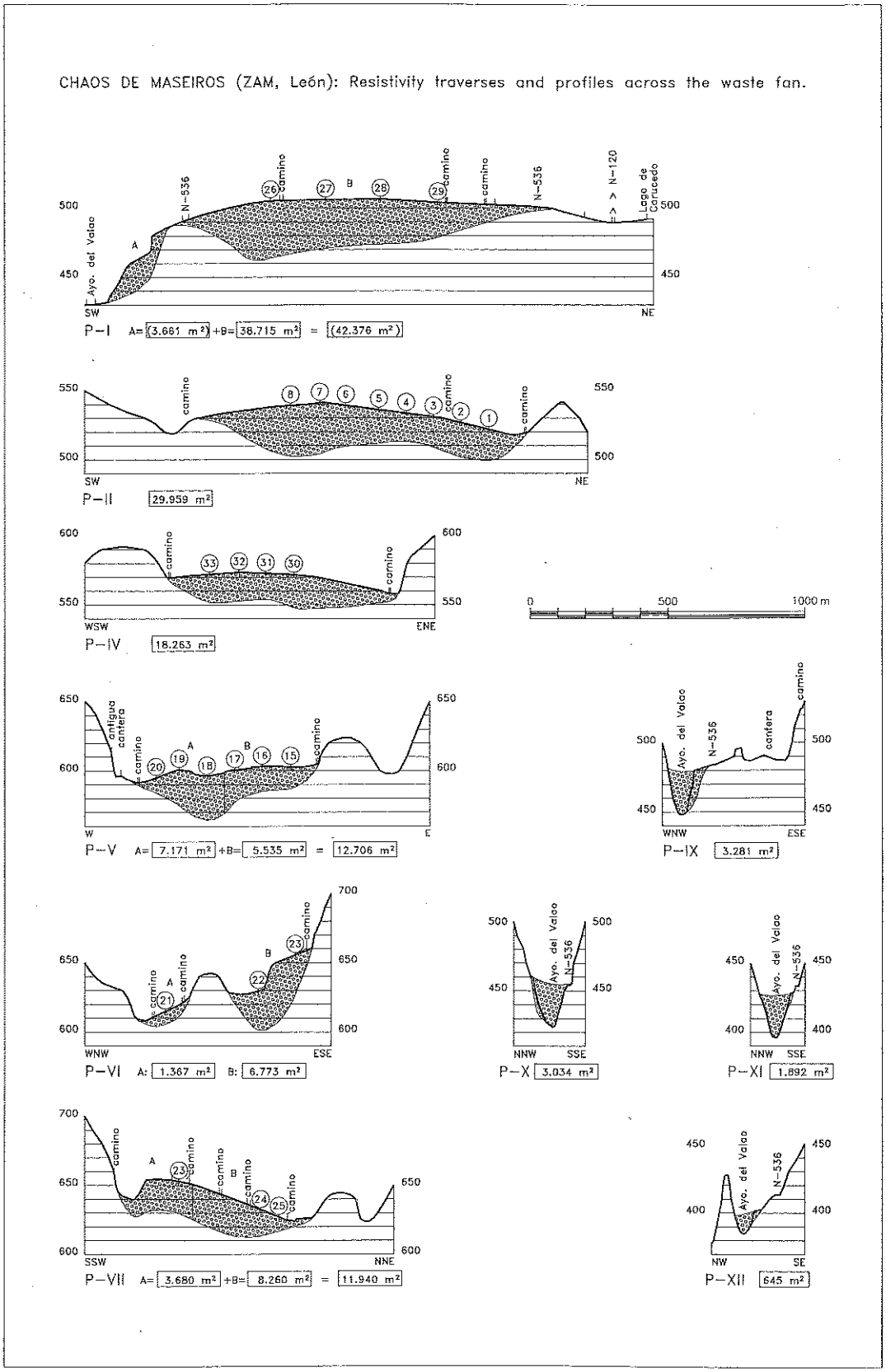

Fig.5.: Resistivity traverses and profiles across the waste fan.

only a very thin layer of soil was formed between the successive phases of operation over the approximately two centuries of mining activity.[4] In fact, even today, the surface is very arid, with hardly any kind of humus, and is covered only by heather, rockrose and similar xerophilous species. Only two layers can be distinguished, the lower one being the Palaeozoic stratum and the upper one the wastes. The high resistivity of the latter makes the stratum of slates and Ordovician limestones act as a conductor to it, despite the fact that their values would also indicate high resistivity.

The readings did enable possible contact between the limestone and slate situated to the west and east respectively to be distinguished below the wastes, which would coincide with a small ridge that crossed the floor of the ancient valley, now filled in, in a longitudinal direction. The cross-section of the valley was therefore not a V, but more of a W (traverses II-V in *Fig. 5*). This contact should be determined more exactly in the future.

In short, the main objective was to determine the volume of the wastes deposited over the whole of the waste fan or sterile tailing, and this was achieved with considerable accuracy, in our opinion. The volume was obtained through a series of sectors (*Fig. 6*), which were defined from the various traverses and their average length was multiplied by the average section of the defining traverses (*Fig. 5*). At the ends where the sterile tailing begin (sectors 5c, 6, 7 and 8 in *Fig. 6*) the average of the only traverse available has been used and for the tailing that extends along the length of the Valao gully, between Chaos de Maseiros and the river Sil, the section that provided the actual topography of the terrain and the infill of the area of wastes that still remains *in situ* has been used in order to define the upper level of its original

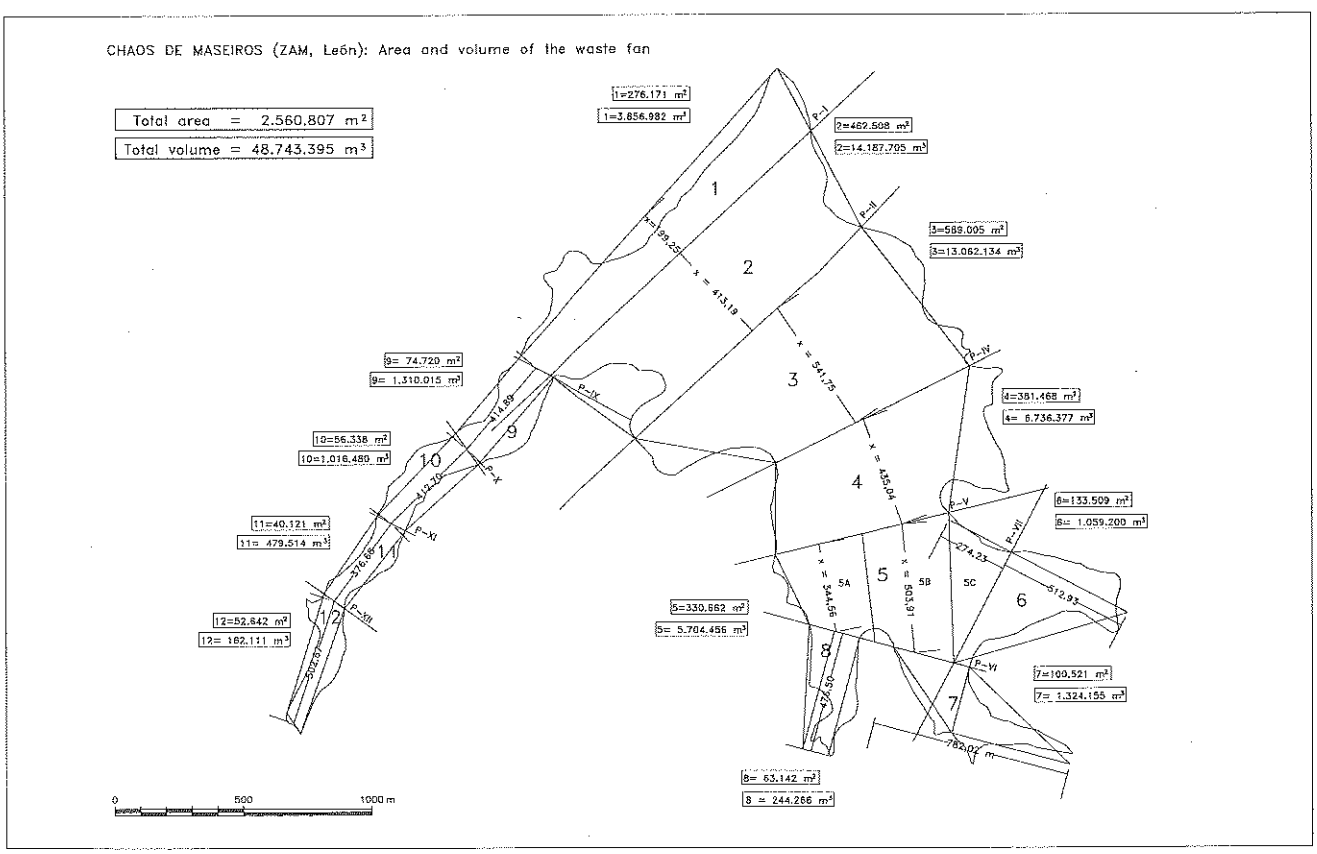

Fig.6.: Evaluation of the volume of the waste fan of Chaos de Maseiros.

depth. The slight distortion inherent in this volume, as a result of using ultimately geometric figures, is not very appreciable, only 1.2%, as demonstrated by comparing the true area occupied by the wastes (2,560,807 m^2) with the sum of the areas of the sectors used for the calculation (2,529,553 m^2).

Once the total volume of the wastes deposited on the Chaos de Maseiros was found (48,743,395 m^3), we could attempt to calculate the volume of the gold-bearing material that had been removed. To do this we had to correct for two factors:

- The swell of the mass of wastes that obviously makes it considerably less dense than the conglomerate material mined by the Romans. This can be estimated at 11% of the total volume (Caterpillar: 1974).
- The loss of fine grain materials produced by washing the gold-bearing conglomerates and which affects the clayey or finer bedrock. This can be estimated at 20% of the total (based on Pérez: 1977, table 13).

After making these corrections, our calculation of the washout material whose wastes were deposited on the Chaos de Maseiros is as follows:

Volume of wastes = **48,743,395 m^3**
- 11% (swell): 5,361,773 m^3 = 43,381,622 m^3
+ 20% (loss of fine grain materials): 8,676,324 m^3
= **52,057,946 m^3** of material removed.

Once we knew the relationship between the accumulation of wastes deposited on the main waste fan of Las Médulas and the volume of material removed to which it would correspond, we could apply the same formula to the other waste fans produced by Roman gold mining. In this case we do not have the precise calculations provided by traverses produced by resistivity readings, but we can use the correlation between the areas of wastes deposited in each one, which we do know (*Fig. 7*), and the volumes removed. Obviously we cannot apply a ratio relating to all the wastes of Chaos de Maseiros, E-2 in *Fig. 7*, since their dimensions and depth are notably greater than those of the rest of the sterile tailings. But we can establish that correlation by taking the initial ends of the sterile tailings of E-2 as a point of reference, since their dimensions and depth are surely similar because of their topographical situation. So, in order to evaluate the areas not surveyed, we have used:

- For Sectors of La Brea, E-1 (only in section C), La Balouta, E-3 (only in section B) and Yeres, E-5, we are guided by sector 7 of Chaos de Maseiros (ratio of m^3/m^2 = 13.17).
- For Sectors of La Brea (sections A and B), La Balouta, E-3 (only section A), Valdebría, E-4, and of Valdamola, E-6, we have followed the reference of sector 8 of Chaos de Maseiros (ratio m^3/m^2 = 3.87).

The results are as follows:

- La Brea, E-1 = 1,868,859 m^2 = 16,714,746 m^3
- La Balouta, E-3 = 616,084 m^2 = 7,020,221 m^3
- Valdebría, E-4 = 160,306 m^2 = 620,394 m^3
- Yeres or Rebordelo, E-5 = 421,300 m^2 = 5,548,521 m^3
- Valdamola, E-6 = 83,954 m^2 = 324,902 m^3

- Total of E-1 + E-3 to E-6 = 3,222,503 m^2 = 30,228,784 m^3

And if we repeat the corrections for swell and loss of fine grain materials applied to Chaos de Maseiros, the result would be as follows:

Volume of wastes = **30,228,784 m^3**
- 11 % (swell): 3,325,166 m^3 = 26,903,618 m^3
+ 20 % (loss of fine grain materials): 5,380,724 m^3
= **32,284,342 m^3** material removed.

As a final result, the figures applicable to the Las Médulas gold mine as a whole would be:

Volume wastes:
48,743,395 m^3 + 30,228,784 m^3 = **78,972,179 m^3**
Material removed:
52,057,946 m^3 + 32,284,342 m^3 = **84,342,288 m^3**

Obviously, knowing the volume of material removed in the course of Roman mining influences the estimate that can be made of gold production. For this it is necessary to consider the Au grade of the deposit. The stratigraphic sequence of Las Médulas is divided into three different conglomerate Formations (Hérail: 1984, 167-183; Pérez: 1988, 1992 and in Sánchez-Palencia, *et alii*: 1996, 61-73) (*Fig. 8*):

- Its basal stratigraphic layer is a red, alluvial-colluvial deposit (Orellán Fm.), equivalent to the pre-Miocene weathering surface. No gold is found in this deposit because it overlies non-auriferous bedrock. It ranges in depth from 0 to 20 m.
- The next deposit is in the proximal facies of an alluvial fan (Santalla Fm.), corresponding to the coarsest gravel sediments in the series and rests directly on the bedrock where the Orellán Fm. is eroded. It is the gold-bearing deposit with Au grades of between 1 g/m^3 close to the base and 20-40 mg/m^3 in the upper part. It is about 30 m. thick.
- Above this formation, there is a broad deposit corresponding to medium facies (no confined flow) of the alluvial fan, consisting of alternating beds of gravel and fine sand and silt (Médulas Fm.) The Au grade in this last bed is much lower, 10-30

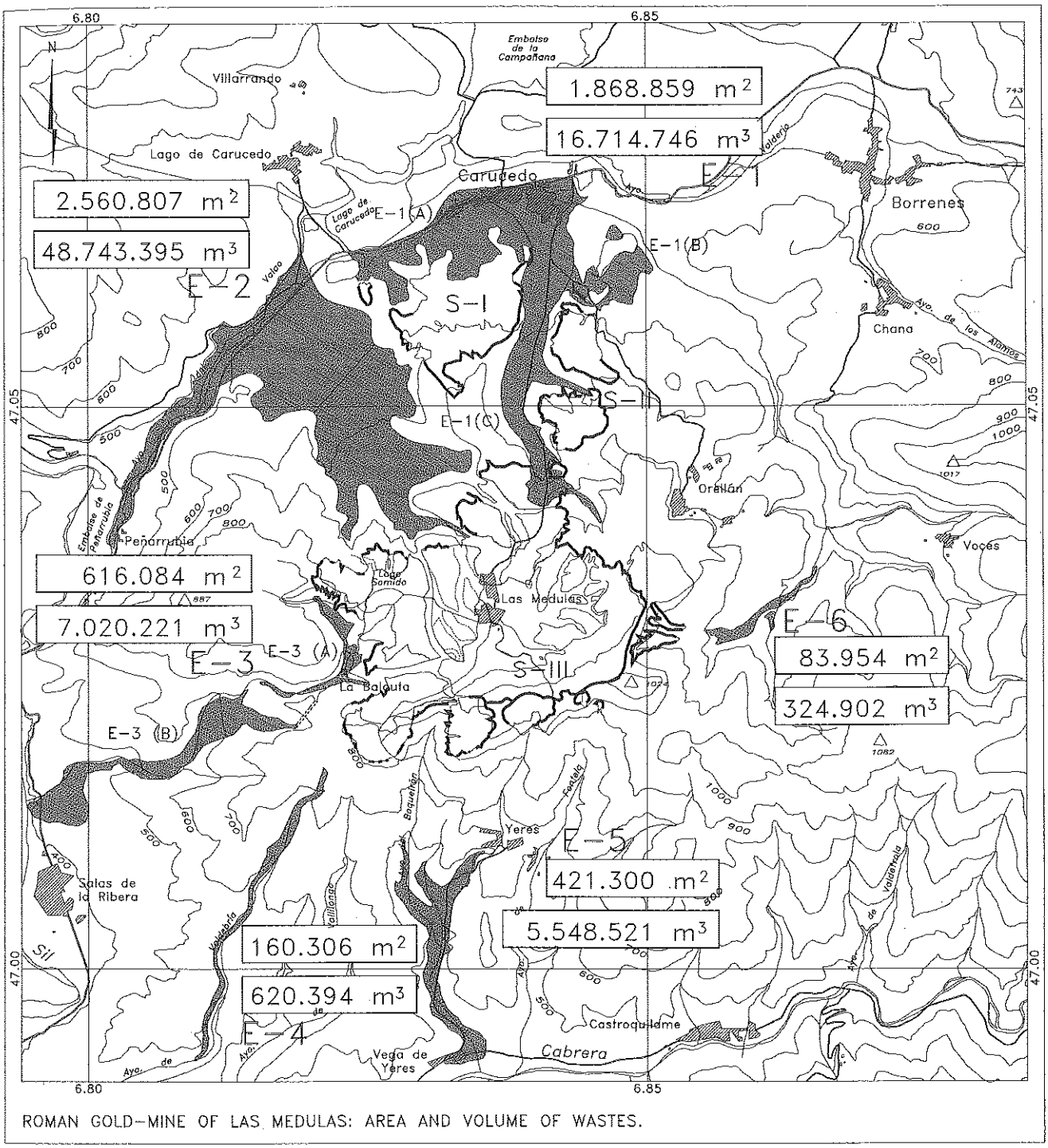

Fig.7.: Evaluation of the volume of wastes from the Roman gold-mine of Las Médulas.

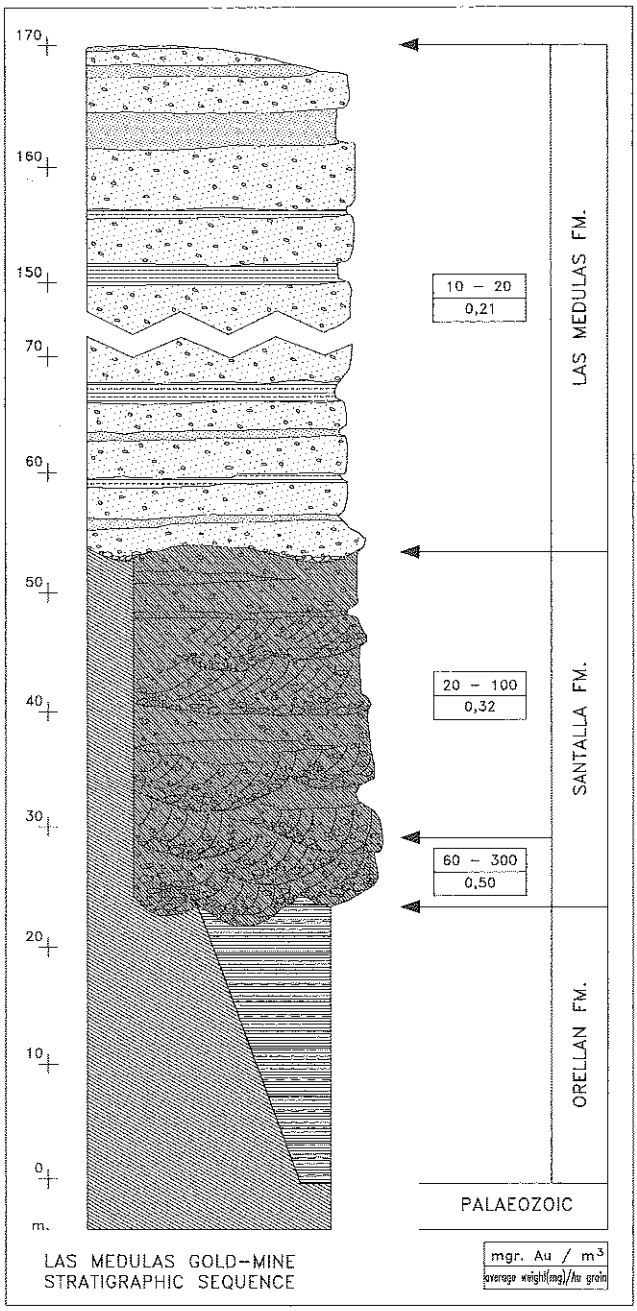

Fig.8.: Las Médulas gold-mine. Stratigraphic sequence.

mg/m^3 and the Roman miners considered it to be barren overburden. It is up to 100 m thick.

In accordance with the laws of this stratigraphic sequence, it would be more than optimistic to expect an Au grade for the site as a whole of more than 50 mg/m^3, as Hérail and Pérez (1989, 30) estimated:
Material removed: 84,342,288 m^3 x 50 mg/m^3 = **4,217.114 kg of gold**
Obviously, this estimate of four and a quarter tonnes should be regarded as an average approximation, so perhaps it would be more accurate to say there were between three and five and a half tonnes. In any case, and on the basis of this initial valuation, more detailed geo-archaeological studies will enable us to be more precise, not only about the total volume mined and how much gold it produced, but its estimation by sectors and geological formations. The first adjustment to the new data obtained will doubtless be made by calculating the volume of the deepest wastes that have accumulated in the mine and which, although they cannot represent a very considerable volume, have not been taken into account in our calculations.

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Notes

[1] This study has been undertaken as part of research project PB97-1129 *"Paisajes antiguos en la Península Ibérica: Teoría y práctica de la Arqueología del Paisaje" ["Ancient landscapes in the Iberian Peninsula: Theory and practice of the Archaology of Landscape"]* subsidised by the Ministry of Education and Culture.

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[3] It was undertaken by the company Geoprosco, s.l. Prospecciones Geológicas y Geofísicas, of Madrid. Thanks to the skill and efforts of its engineers, Mr. Antonio Gómez Castro and Mr. Lucio Villegas, it was possible to overcome the main obstacles to carrying out resistivity readings: the dense scrubland vegetation which made it difficult to operate on the terrain (accentuated by the considerable summer heat), the presence of high voltage power lines in the area and, in particular, the high resistivity and poor surface contacts provided by the layers of Roman mining wastes because of their composition, primarily boulders of quartzite and arenite with little bedrock. We should like to thank these two engineers for their work, which enabled satisfactory results to be obtained despite the difficulties referred to. The readings were taken at almost equal intervals of 100 m and with a constant electrode-separation of 200 m.

[4] The excavations carried out in five Roman settlements in the vicinity of the mine have enabled us to date these from 30/40 A.D. to the late 2nd or early 3rd century A.D.

CONTENTS / *TABLE DES MATIERES*

PEETERS

PEETERS - BONDGENOTENLAAN 153 - B-3000 LEUVEN