A ferritic “disc” from the territory of Bienno (Val Camonica, Brescia, Italy)

Costanza CUCINI(1), Marco TIZZONI(1),
Angelo AGOSTINO(2), Maria Pia RICCARDI(3)

(1) IRAMAT UMR7065, (2) Université de Turin, (3) Université de Pavie

DOI : https ://doi.org/10.17184/eac.9857

Résumé : Un objet métallique de forme ronde a été découvert il y a quelques années en surface, à proximité du site sidérurgique de Valle delle Forme, dans la région de Bienno (Val Camonica). Il a récemment fait l'objet d'une étude archéométallurgique visant à en caractériser la composition et les techniques de fabrication. Les analyses préliminaires (métallographie, XRF, SEM-EDS) ont révélé une microstructure ferritique avec quelques lamelles résiduelles d'austénite, ainsi qu'une composition chimique compatible avec les minerais d'hématite provenant de la mine de Piazzalunga. L'absence de manganèse dans le métal, malgré sa présence dans les gisements locaux de sidérite, ainsi que la détection d'éléments traces (Cu, As, Pb), suggèrent un procédé médiéval. Le matériau peut être classé comme un acier à faible teneur en carbone.

Abstract: A round-shaped metallic object was discovered some years ago on the surface near the ironworking site of Valle delle Forme, in the area of Bienno (Val Camonica). It has recently been subjected to archaeometallurgical investigation aimed at characterizing its composition and manufacturing process. Preliminary metallographic, XRF and SEM-EDS analyses revealed a ferritic microstructure with isolated retained austenite lamellae and a chemical composition compatible with hematite ores from the Piazzalunga mine. The absence of manganese in the metal, despite its presence in local siderite deposits and the trace elements detected (Cu, As, Pb), support the interpretation of a medieval ironmaking process based on local raw materials. The material can be classified as a low-carbon steel.

1 Introduction

From 1994 the territory of the municipality of Bienno in Val Camonica was surveyed with the aim to find a study early metal working sites. A group of ironworking sites was discovered in two small valleys called Val Gabbia and Valle delle Forme. These sites are along a footpath leading to the village of Bienno and they date from Late Antiquity to the Renaissance (Figure 1).

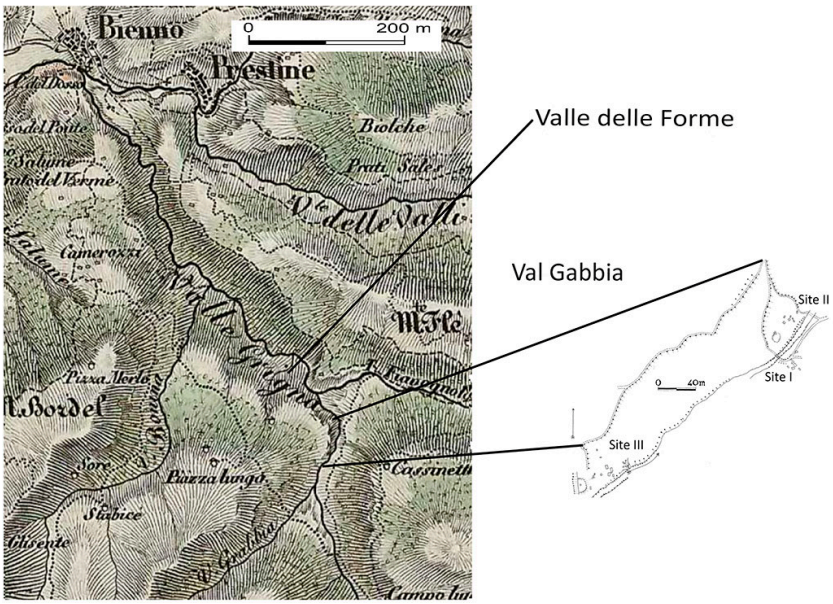


Fig. 1 : Map of Val Gabbia and Valle delle Forme (Bienno) with the sites archaeologically explored.

Many years ago, an inhabitant of Bienno discovered this iron manufact on a footpath in Valle delle Forme. In theory this iron “disc” could come from any of the abovementioned sites and it had been lost during its hauling to the village. This “disc” is not a bloom, so the two Lombard bloomeries (Ponte di Val Gabbia I and II) can be ruled out. The Late Antiquity forge hut seems to have been too small to house the large hearth there this “disc” was heated. Among the many archive documents dealing with ironmaking in Lombardy during the Late Middle Ages and the Renaissance there is not a single hint that could suggest the production of iron disc shaped semifinished products. Therefore, this object could come from the 11^{th}-13^{th} century ironmaking sites of Ponte di Val Gabbia III. It was lost during its hauling to Bienno when the rope tying this and other similar discs to the pack animal gave way and this specimen was not recovered.

2 The archaeological context

The Lombard Iron Basin is one of the main Italian mining districts. An early iron making production developed in the Lombard Alpine valleys because of the high

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

quality of the ore, mainly siderite, well characterized by its content of manganese and lack of phosphorous (analyses Leroy 2010, p. 176-180, 223-231, 242-245, 308-311). There is also a smaller number of hematite lodes with arsenical and copper sulfides as accessory minerals and limonite deposits formed by the weathering of sulfides. These limonitic ores were already exploited in the Celtic-Roman period (Fluzin 2006).

In the years 1994 - 2006 some metallurgic sites were discovered in the area of Val Grigna in the Municipality of Bienno. At the site of Ponte di Val Gabbia (1,300-1,375m a.s.l.) three metallurgic sites were investigated. One belonged to the late Roman period (site III), here iron ore was reduced and in the annexed forge-hut proofs of an early intentional cast iron decarburization were found. In the two other sites there were low furnaces and iron was made by the direct method, they have been dated to the Lombard period (sites I and II). After some centuries metallurgic activities started again at the site of Ponte di Val Gabbia III. An archaic blast furnace and another forge-hut were built here in the 11th-13th centuries (Cucini & Tizzoni 2025, 56-64) (Table 1).

Fig. 2 : Site' chronology

Site	Structure	SU	C14 methodology	Calibrated age (2σ, 95,4%)
Ponte di Val Gabbia III	Hut-forge Building A	34	Charcoal	410-600 CE (BM-3052)
Ponte di Val Gabbia III	Charcoal warehouse	17	Charcoal	590-680 CE (BM-2938)
Ponte di Val Gabbia III	Charcoal wareouse	4	Charcoal	560-760 CE (BM-2988)
Ponte di Val Gabbia III	Hut-forge Building B	16=51	Charcoal	1170-1280 CE (BM-3053)
Ponte di Val Gabbia III	Charcoal platform	101	Charcoal	1030-1270 CE (GU-10620)
Ponte di Val Gabbia III	Furnace	202	Charcoal	1030-1260 CE (GU-10621)
Valle delle Forme	Trip hammer, First trial trench	1	Charcoal	1310-1360 CE, 1380-1440 CE
Valle delle Forme	Trip hammer, two samples A12-06	127	Metal and metal	1271-1391 CE and 1250-1385 CE
Valle delle Forme	Trip hammer, two samples, A4-01	129	Metal and metal	1223-1295 CE and 1256-1385 CE
Valle delle Forme	Trip hammer, sample A11-09	125	Metal and metal	1277-1393 CE
Valle delle Forme	Trip hammer, sample A2-03	120	Charcoal	1296-1408 CE
Valle delle Forme	Trip hammer, sample A8-03	116	Charcoal	1309-1431 CE
Valle delle Forme	Blast furnace, tree samples C1-04	402 trench C	Metal, metal and charcoal	1410-1465 CE, 1302-1420 CE, 1320-1453 CE
Valle delle Forme	Dump	Bspor01	Charcoal in slag	Modern
Valle delle Forme	Dump	Bspor	Charcoal in slag	Modern
Valle delle Forme	Dump	Bspor11	Charcoal in slag	Modern

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

A fourth site was partially excavated in 1997 and in 2006 (Cucini & Tizzoni 2025, p. 256-279 ; Cucini et al. 2019) at Valle delle Forme where there was an archaic blast furnace and a forge with a water-powered trip hammer used for the decarburization of cast iron for the production of semi-finished wrought iron. The iron scraps and the slags from the site were the subject of a PhD dissertation (Uda 2015-2016) at Pavia University and were studied at CEA of Saclay (France) under the direction of Dr. Philippe Dillmann. The iron working plant of Valle delle Forme was in use between the year 1223 and the year 1453 (Uda 2015-2016, cap. IV) (Table 1).

The iron making sites of Val Grigna used the ore from the large hematite deposit of Piazzalunga, which was exploited from the 5th till the 15th century (Morin 1999). Both the ore from the mine and the '*archaeological*' ore from the site of Ponte di Val Gabbia II were analysed (Serneels 1999).

2.1 The technological and historical context

Hundreds of Lombard, Tuscan and French documents of the Middle Ages and of the Renaissance inform us that the Alpine valleys in the territories of Bergamo and Brescia were known for their production of high-quality iron and steel (Braunstein 1966, p. 288. Menant 1987. Belhoste 1991, p. 329-33. Tizzoni 1997. Tizzoni 1998. Menant 1999, p. 60-62, 139, 145-146. Braunstein 2001).

For example, the Bergamasque documents show that by the 13th century there was already a large-scale production. A document of the year 1255 deals with a single haulage to Bergamo of 1.17 tons of steel (*azalis*) and 6.63 tons of iron bars (*tayolis ferri cocti*, a semi-finished product shaped like a short bar) from the valleys by a freight company (Mainoni 1997, p. 69-73). Also the documents of Archivio Francesco Datini of Prato (Florence) certify continuous transports of iron and steel – *acciaro*, *aciaio* – from the firm's warehouse in Brescia to Lucca, Pisa and La Spezia, from where they were shipped to Barcellona, Rome and Avignon (Braunstein 2001, p. 455-456). The quantities traded between 1379 and 1400 were in the range of tons of *lamiere sotile, belle, e petorali d'aciaio e fero saldo* (Braunstein 2001). Each iron master punched his semi-finished product with his mark. The accounting books of La Grande Saline at Salins (Franche-Comté) for the years 1307 -1434 circa show many purchases of iron sheets – *fer en table* or *fer roigne* – from Val Camonica or from Brescia (Claerr Russel, Philippe 2001). They were used to make large cauldrons (diameter 5-6 m, weight 1 ton) employed to heat the salt solution.

The area of the village of Bienno and of lower Val Grigna was renowned for its production of iron and steel sheets used also in the manufacture of cuirasses (Da Lezze 1609-1619. Gregorio di Valcamonica 1698, p. 626-628. Mainoni 2012, p. 260). The steel masters were active here and in the other Brescian valleys, their product reached Milan where there were famous armourers whose production was sought-after all-over Europe. At Bienno steel making had an ancient tradition. In the 5th – 6th century CE at the site of Ponte di Val Gabbia III mining chisels of fully quenched eutectoid steel (0,8 % of carbon) were made. They were quite hard (HV 100 median 650) and perfectly homogeneous (Fluzin 1999, p. 192-193, 247. Fluzin, 2000, p. 28-30. Fluzin, 2003, p. 143-144, 287. Cornacchia et al. 2015, analysed again

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

this find reaching the same conclusions). This tool was found in sealed archaeological stratigraphic units and it was made of a homogeneous lump of highly depurated metal with very few residual inclusions. This steel was made of decarburized cast iron.

2.2 The semi-finished product from Valle delle Forme

It is a ferritic "disc" roughly oval in shape with rounded edges (Figure 2). It was found by Mr. Mario Comensoli of Bienno over forty years ago on the surface of the footpath in Valle delle Forme. Although it was discovered near an archaeologically investigated site, its precise origin and dating remain unknown.



Fig. 3 : The "disc" from Valle delle Forme, Bienno.

The "disc" is well preserved. It presents a very thin patina and shows no signs of corrosion, not even along the edges, except for two areas where ancient damage is visible. One surface displays numerous impact marks ; however, without proper surface cleaning, it is not possible to determine which are ancient and which are more recent, as the object was used by its owner as a domestic anvil. Near one edge, a long, rectilinear mark is visible, apparently hot-formed using a tool while the metal was still malleable. It remains unclear whether this feature resulted from an accidental event during melting or was an intentional mark used to identify the ingot.

The opposite face of the "disc" is significantly affected by a layer of corrosion, likely due to prolonged contact with the damp floor of the owner's cellar.

This "disc" is characterized by its smooth and regular surfaces, with no visible bubbles or surface irregularities. At its center is a hot-formed hole (Figure 3), very regular in shape and possibly produced using a clay-covered wooden stick. The rounded edges and absence of slag inclusions suggest that it solidified in a bed of compressed charcoal powder, typical of traditional decarburization hearths. Its thickness varies slightly from one side to the other, likely due to uneven positioning during cooling. The measurements are : 28 × 34 cm ; thickness 3.3–4.2 cm (4.3 cm at the center) ; hole diameter 2.3 cm ; and weight 18.15 kg.

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984



Fig. 4 : Detail of the surface of the “disc”.

The central hole may have been intended to facilitate transport and trade (Boisseuil, Rico 2021). Standardizing the weight of such ingots was difficult for early smelters, but the weight of 18.15 kg approximates the value of one *peso* of 20 *libbre grosse* of Bergamo ($0.813 \times 20 = 16.26$ kg), suggesting an intentional effort toward weight regularity.

3 Materials and Methods

3.1 X-ray Fluorescence Analysis (XRF)

The non-invasive analyses were all carried out in Bienno and the measurement session took place *in situ* using portable XRF instruments, adopting a totally non-invasive approach.

XRF analysis was performed with a portable instrument (East Greenbush, NY, USA), model XL3T GOLDD, equipped with an Ag target with a maximum current of 100μA and operating voltages between 8 and 50 kV. The detector is a Large Drift Detector (LDD) with a 25 mm^2 surface and energy resolution of 135 eV at MnKα. Two acquisition modes were adopted (METALS and MINING) with measuring times of 120 seconds. Each analysis included four sequential measurements using four voltages and three different filters to optimize response across the energy spectrum : MAIN A1/Fe (40 kV) ; LOW Cu (20 kV) ; HIGH Mo (50 kV) ; and LIGHT with no filter (8 kV). Analyses were performed on ellipsoidal areas with diameters of 3 or 8 mm. The collected data were compared to background acquisitions (same live time) and certified reference materials (NIST, SGT CORNING, MBH).

X-ray fluorescence (XRF) analysis enables the identification of the elemental (atomic) composition of the materials under investigation. In the present case, concerning a metal object, the technique provides insights into both the alloy composition and the inorganic components forming the surface alteration patina. This method allows for a stratigraphic interpretation of the material composition, without being significantly affected by any organic surface residues. Thanks to the intrinsic characteristics of

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

XRF, it is also possible to obtain information from deeper layers of the object (typically up to 100-200 +m), depending on the atomic weight of the elements present in the alloy.

All measurements were carried out in triplicate and the reported values represent the average of the three readings. Spectral data were processed using PyMCA, an open-source software developed by the Software Group at the European Synchrotron Radiation Facility (ESRF) in Grenoble. The information obtained provides a quantitative profile of the absolute composition, expressed as the percentage by weight of the chemical elements identified within the analyzed volume.

3.2 SEM-EDS Analysis

A small fragment (figure 4) was taken from the inner wall of the central hole and prepared for textural and microtextural investigation under Reflected Light Optical Microscopy (RLOM) and Scanning Electron Microscopy (SEM) coupled with an Energy Dispersive Spectroscopy (EDS) system. The microsample was embedded in epoxy resin, then ground and polished using progressively finer abrasive pastes down to 3μm. The polished surface was examined under a metallographic microscope (RLOM) and the same specimen was analyzed via SEM-EDS. To enable SEM analysis, the surface was coated with platinum to ensure conductivity. Microchemical analyses were performed using a Tescan Mira 3XMU series FE-SEM equipped with an EDX-EDAX detector.

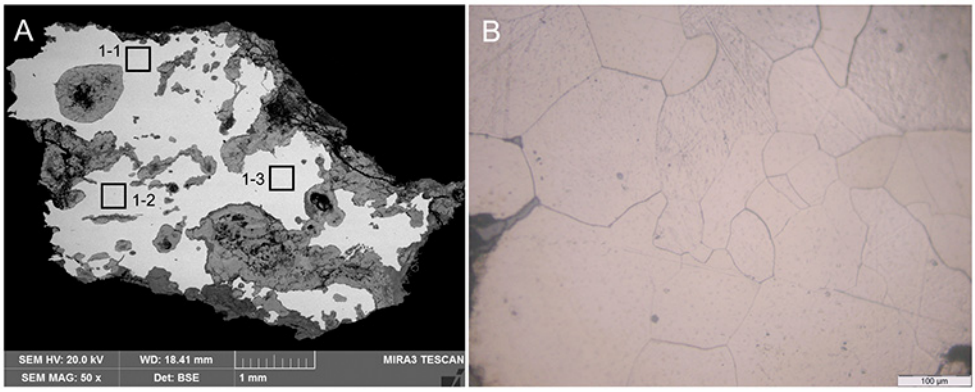


Fig. 5 : A – The fragment of a few millimetres taken from the inner wall of the hole (BSE image) ; B – Detail of the well-preserved polished metal surface (RLOM image). A shows the areas of microanalysis reported in Table 2.

The analyses were conducted under standard operating conditions, with an accelerating voltage set at 20 kV and an acquisition time of 100 seconds for each measurement. The working distance between the sample and the detector was maintained at 15.8 mm and all observations were carried out in high vacuum mode to ensure optimal resolution. The SEM analysis was carried out in backscattered electron (BSE) mode. Three electron microanalysis measurements (area 300 x 300 microns) were conducted on these samples.

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

The semi-quantitative data were collected using an Apollo XL SDD detector and processed through the EDAX Genesis software. To ensure accurate results, the ZAF correction algorithm was applied. This method takes into account key physical effects, specifically atomic number (Z), absorption (A) and fluorescence (F), which can influence the behavior of X-rays within the sample, thus enabling a more reliable quantification of the elemental composition.

3.3 Metallographic Analysis

After mechanical polishing, metallographic etching was carried out to reveal the microstructure of the metallic sample (Figure 5). The etchant used was a 2 % Nital solution, consisting of 2 % concentrated nitric acid (HNO_3) in 98 % ethanol. The solution was freshly prepared prior to each session to ensure reactivity and reproducibility.

The polished sample surface was gently cleaned with ethanol and dried using warm air. Etching was performed by briefly immersing the sample in the Nital 2 % solution for 5 to 10 seconds, followed by immediate rinsing in ethanol to stop the chemical reaction. The sample was then air-dried.

This light etching procedure selectively attacked the grain boundaries and different microstructural phases (such as ferrite and pearlite), enhancing contrast under reflected light optical microscopy (RLOM). The exposure time was carefully controlled to avoid over-etching, which could obscure fine structural details.

Observations were performed using a Nikon Eclipse E400 polarizing light microscope, equipped for both transmitted and reflected light, to analyze the microstructural and optical properties of the polished sample.

4 Results and Discussion

Metallographic analysis performed in reflected light optical microscopy (RLOM) revealed a microstructure composed of polygonal ferritic grains, with well-defined boundaries and a homogeneous distribution, typical of low-carbon materials. The overall texture suggests the absence of post-deformation processing and is consistent with a recrystallization annealing treatment.

Within the ferritic matrix, sporadic and finely dispersed lamellae of retained austenite were observed. Their very limited presence suggests that the material underwent relatively slow cooling, sufficient to transform most of the austenite into ferrite, but not enough to eliminate it entirely. The morphology and discontinuous distribution of the austenitic lamellae may reflect local segregation phenomena or compositional variations at the microscopic scale.

The near absence of pearlite and cementite further supports the identification of a predominantly equiaxed ferritic structure, consistent with mild steel or low-carbon steel. SEM-BSE observations confirmed this interpretation, showing a homogeneous metallic matrix with the presence of oxidic and sulfidic inclusions, primarily located along grain boundaries and near the sample edges.

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

A local SEM-EDS analysis (Table 2) revealed a mean carbon content of ~0.69 wt%, which would classify the material as hypoeutectoid steel. However, the discrepancy between the microstructural observations and this carbon value, combined with the bulk chemical composition, suggests that the material is likely of ancient origin, with inhomogeneous carbon distribution across the body, possibly due to surface decarburization or micro-segregation effects.

Tab. 1 : The chemical data obtained on the tree homogeneous areas represented in Figure 4. A and their overage.

spot analysis	C	O	Si	Mn	Fe
1_1	1.5	1,0	0,0	0,1	97,4
1_2	1,6	1,0	0,0	0,1	97,3
1_3	1,5	1,0	0,1	0,2	97,3
average	1,5	1,0	0,0	0,1	97,3

Quantitative X-ray fluorescence (XRF) analysis (Table 3) provided a broader view of the bulk chemical composition (Ben-Yosef, E., 2023, Jenkins, R., 1999, Beckhoff, B, 2006, Mantler, M. E, 2022), confirming iron as the main constituent (~99.0 wt%), alongside significant trace elements such as copper (Cu), presenting up to 0.39 wt%. Although copper is known to enhance corrosion resistance, its presence in this context is likely accidental, resulting from mixed ores.

Tab. 2 : Analysis of the percentage composition (wt/wt%) of the alloy of the ingot. METALS algorithm (values are normalized to 100). The carbon value cannot be determined except in the dark matrix evaluation.

Alloy Composition

	As	As Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error
A1	0,031	0,005	0,064	0,005	0,13	0,008	0,25	0,01	98,8	1	0	0,02
A2	0,075	0,005	0,026	0,005	0,15	0,007	0,39	0,01	98,9	1	0	0,02
A3	0,032	0,004	0	0,005	0,08	0,007	0,17	0,01	99,3	0,7	0	0,02
A4	0,09	0,005	0	0,005	0,13	0,005	0,27	0,01	99	0,9	0	0,02

	As	As Error	Pb	Pb Error	Zn	Zn Error	Cu	Cu Error	Fe	Fe Error	Mn	Mn Error
A (media)	0,057	0,005	0,023	0,005	0,12	0,01	0,27	0,01	99	0,9	0	0,02

Similarly, the presence of arsenic (up to 0.09 wt%) and lead (up to 0.06 wt%) points to a complex mineralogical origin, likely involving iron ores naturally contaminated with arsenopyrite, galena, sphalerite, or tetrahedrite, all common in Alpine mining environments. The detection of minor elements such as sulfur, aluminum and calcium supports this interpretation, as they are often associated with gangue minerals and slag inclusions from pre-industrial smelting processes (Martin 2017).

The examined material was retrieved from the area of Bienno, a region with a well-documented tradition of ironworking activities dating back to the late roman period. The local metallurgical operations historically relied on the exploitation of hematitic ores (Fe_2O_3) from nearby mines such as Piazzalunga, as well as on siderite and limonite, which were occasionally associated with impurities of arsenic, lead and cop-

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

per. The lack of modern alloying elements (e.g., Cr, Ni, Mo, V), combined with the presence of As, Pb and Cu, strongly supports the interpretation of a medieval iron produced from local, unrefined ores with no advanced refining stages.

The absence of manganese (Mn) in the analyzed iron constitutes evidence of the metallurgical conditions employed during its production. Mineralogical data from the Bienno area, specifically from the Piazzalunga, Pinetto and Regina mining sites, document a significant presence of MnO in local iron ores, with concentrations ranging from 1.35% to 8.15% by weight.

Despite the abundant natural availability of manganese in the processed ores, the final metal does not contain detectable traces of Mn, either structurally or analytically. This confirms that manganese was not reduced to its metallic state during the smelting process but instead remained trapped in the slag or stabilized as manganese oxides (MnO, Mn_2O_3).

Tab. 3 : Analysis of the percentage composition (wt/wt%) of the light elements referred to the superficial patina.

	CaO	K2O	Al2O3	P2O3	SiO2	Cl	SO3
A1	6,5	1,4	3,3	0,2	4,4	0,3	3,1
A2	5,5	1,3	2,4	0,2	3,6	0,2	2,0
A3	3,2	1,2	1,7	0,1	2,0	0,5	2,8
A4	6,8	1,6	2,7	0,2	3,4	0,3	2,8

5 Conclusions

We cannot possibly know to which extent this very small fragment is representative of the whole structure and composition of the iron “disc”. It was a tiny burr at the edge of this very compact object and it formed when the clay covered wooden stick used to make the hole in the pasty metal was pulled out. It has a “large” surface if compared to its volume, this means that it could have been involuntarily decarburised or it could have been subject to micromigration.

As we have written, the hole was made in the metal when it was in a pasty state, this means that the ironworkers were able to reach high temperatures in an open hearth, or that the disc is made of cast iron cast into a round shaped mould and that the hole was made while it was cooling.

The microstructural observations revealed a predominantly ferritic matrix with occasional retained austenite lamellae, consistent with a low-carbon steel subjected to slow cooling and lacking extensive mechanical or thermal finishing. Although localised analyses suggested a higher carbon content, the absence of pearlite and cementite at the microstructural level points to compositional heterogeneity, likely caused by surface decarburization or microsegregation during solidification, phenomena typical of early iron metallurgy.

The chemical composition of the artefact, marked by the presence of trace elements commonly associated with natural mineral impurities, reflects the use of unrefined local ores. In particular, the absence of manganese in the metal, despite its documented

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

presence in the exploited ores of the Bienno area, seems to indicate that the reduction process was not sufficiently effective to incorporate this element.

Without the study of a section of this iron "disc" it is impossible to determine with any degree of certainty its structure, nor it is possible to formulate a hypothesis about its age.

Aknowledgment : The authors wish to express their sincere gratitude to Mr. Giacomo Comensoli, owner of the disc ; Mr. Nicola Pedretti, former Mayor of Bienno ; and Mr. Uberto and Mr. Tomaso Morandini of Ferramenta Gnaro s.r.l., Bienno, for their invaluable support and for facilitating access to the object under study.

We extend our deep appreciation to the CISRiC – Arvedi Laboratory, Pavia Campus, University of Pavia, for performing the SEM investigations and offering expert technical support, as well as to the Project CH4.0 under the MUR programme 'Dipartimenti di Eccellenza 2023–2027' (CUP : D13C22003520001) of the Department of Chemistry, University of Turin.

We wish to dedicate this study to Philippe Fluzin, with deep appreciation and affection. Philippe played a central role in our shared research on Lombard ironmaking and his contribution to the archaeometallurgical analysis of numerous finds from our excavations in the territory of Bienno and at Piani d'Erna (Lecco) remains of enduring value.

Bibliographie

Beckhoff, B., Kanngiesser, B., Langhoff, N., Wedell, R. E Wolff, H. (a cura di), 2006. *Handbook of Practical X-Ray Fluorescence Analysis*. Handbook, Springer, Berlin.

Belhoste, J.-F., 1991. L'Italie du Nord et le procédé indirect : un chainon manquant (remarques de conclusion). *In* N. Cuomo Di Caprio, C. Simoni (eds). *Dal Basso fuoco all'altoforno. Atti del 1 Simposio Valle Camonica 1988 'La siderurgia nell'antichità'*. Brescia : 327-336.

Ben-Yosef, E. E Levy, T.E., 2023. *Using X-Ray Fluorescence to Examine Ancient Extractive Metallurgy Practices : A Case Study from Iron Age Khirbat al-Jariya, Jordan*. Scientific article, *Journal of Powder Metallurgy & Mining*, 5(1) : 140.

Boisseuil, D., Rico, Ch., 2021. Conclusions. Le 'marché' des matières premières en question(s). *In* D. Boisseuil, Ch. Rico, (eds.). *Le marché des matières premières dans l'Antiquité et au Moyen Âge*. Rome, École Française de Rome, OpenEditionBooks : 463-473.

Braunstein, Ph., 1966. Le commerce du fer à Venise au XV^{e} siècle. *Studi Veneziani*, VIII : 267-302.

Braunstein, Ph., 2001. L'acier de Brescia à la fin du XIV^{e} siècle : l'apport d'une correspondance d'affaires. *In* Ph. Braunstein (ed.). *La sidérurgie alpine en Italie (XII^{e}-XVII^{e} siècle)*. Rome, École Française de Rome : 455-479.

Claerr Roussel Chr., Philippe M. 2001. La saline de Salins (Jura, région de Franche-Comté, France) et le Val Camonica entre le XIV^{e} siècle et le milieu di XV^{e} siècle. *In* C. Cucini Tizzoni, M. Tizzoni (eds.). *Il ferro nelle Alpi. Iron in the Alps. Deposits, mines and metallurgy from antiquity to the XVI century*. Proceedings of the conference, Bienno, 2-4 Octobre 1998. Breno : 100-101.

Cornacchia, G., Faccoli, M. and Roberti, R. 2014. Metallurgical investigation of a steel Miner's Chisel from Ponte di Val Gabbia III site. *The Minerals, Metals & Materials Society*, 6 : 260-271.

Cucini, C., Tizzoni, M., 1999. (eds.). *La miniera perduta. Cinque anni di ricerche archeometallurgiche nel territorio di Bienno*. Tipografia Camuna, Breno.

Cucini, C., Riccardi, M. P., Tizzoni, M., 2019. From the bloomery furnace to the blast furnace : The iron working complex of Valle delle Forme at Bienno, Brescia, northern Italy (mid-13th to mid-15th century). *Historical Metallurgy*, 53, 1 : 10-18.

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984

Da Lezze, G., 1609-1619. *Il Catastico bresciano di Giovanni da Lezze (1609-1619)*. Con prefazione di C. Pasero. Brescia, F. Apollonio editore.

Fluzin, Ph., 1999. Ponte di Val Gabbia III : i reperti metallici della forgia. Primi risultati dello studio metallografico. *In* C. Cucini Tizzoni, M. Tizzoni 1999, (esd.). *La miniera perduta. Cinque anni di ricerche archeometallurgiche nel territorio di Bienno*. Breno : 189-194.

Fluzin, Ph., 2000. Ponte di Val Gabbia III (Bienno). Les premiers résultats des études métallographiques. *In* C. Cucini Tizzoni, M. Tizzoni (eds). *Il ferro nelle Alpi. Giacimenti, miniere e metallurgia dall'antichità al XVI secolo – Iron in the Alps. Deposits, mines and metallurgy from antiquity to the XVI century*. Proceedings of the conference, Bienno, 2-4 Octobre 1998. Breno : 24-31.

Fluzin, Ph., 2003. Synthesis of metallographic studies of samples of the site of Ponte di Val Gabbia III (Bienno V-VI AD century) : obvious facts of pig iron decarburization. *In* L. C. Norbach (ed.). *Prehistoric and medieval direct iron smelting in Scandinavia and Europe. Aspects of technology and society*, CSA-UISPP International Conference, 16-20 September 1999. Acta Jutlandica, LXXVI : 2, 75, Aarhus University Press, 139-146 : 285-287.

Fluzin, Ph., 2005. Nouvelles études métallographiques concernant le site de Ponte di Val Gabbia III. *Notizie Archeologiche Bergomensi*, 13 : 287-294.

Fluzin, Ph., 2006. Premiers résultats des études métallographiques concernant les masses de métal brutes. *In* M. Tizzoni, C. Cucini, M. Ruffa (eds). *Alle origini della siderurgia lecchese. Ricerche archeometallurgiche ai Piani d'Erna*. Materiali. Periodico dei Musei Civici di Lecco, n.s., Lecco : 129-146.

Gregorio, di Valcamonica (Pietro Brunelli), 1698. *Curiosj trattenimenti contenenti raguagli sacri e profani de' popoli camuni*. Venezia, G. Tramontin.

Jenkins, R., 1999. *X-ray Fluorescence Spectrometry*. Monograph, Wiley, New York.

Leroy, S., 2010. Circulation au Moyen Âge des matériaux ferreux issus des Pyrénées ariégeoises et de la Lombardie. Apport du couplage des analyses en éléments traces et multivariées. Thèse de doctorat, Université de Technologie de Belfort-Montbéliard.

Mainoni, P., 1997. *Le radici della discordia. Ricerche sulla fiscalità a Bergamo tra XIII e XV secolo*. Edizioni Unicopli, Milano.

Mainoni, P., 2012. Note sulla gestione politica della produzione mineraria nell'Italia settentrionale. *In* C. Cucini (ed.), Acta mineraria et metallurgica. Studi in onore di Marco Tizzoni. *Notizie Archeologiche Bergomensi*, 20 : 255-261.

Mantler, M. E Schreiner, M. (a cura di), 2022. *X-ray Fluorescence Spectrometry (XRF)* in Geoarchaeology. Handbook, Springer, Cham.

Martin, S., 2017, *Siderite deposits in northern Italy : Early Permian to Early Triassic hydrothermalism in the Southern Alps*, Lithos, 284–285, 276–295.

Menant, F., 1987. Pour une histoire médiévale de l'entreprise minière en Lombardie. *Annales Economie, Société, Civilisation*, 42, 4 : 779-795.

Menant, F., 1999. Bergamo comunale : storia, economia e società. *In* G. Chittolini (ed.). *Storia economica e sociale di Bergamo. I primi millenni : il comune e la signoria*. Bergamo, Bolis edizioni : 15-181.

Morin, D., 1999, La miniera di ferro di Piazzalunga. *In* Cucini Tizzoni C., Tizzoni M. (eds), *La miniera perduta. Cinque anni di ricerche archeometallurgiche nel territorio di Bienno* (Breno) : 49-60.

Serneels V. 1999, Analisi di scorie da Ponte di Val Gabbia II e III e del minerale di Piazzalunga. In Cucini Tizzoni C., Tizzoni M., 1999. (esd.). *La miniera perduta. Cinque anni di ricerche archeometallurgiche nel territorio di Bienno*. Breno : 114.

Uda, I., 2015-2016. *The archaeological site of Valle delle Forme : archaeometric study of the iron making process between Middle Ages and modern period in northern Italy*. PhD Thesis, Pavia University.

Published in : BERRANGER, Marion ; SARAH, Guillaume ; TÉREYGEOL, Florian (dir.), *Paléométallurgie, archéométrie et archéologie. Recueil en hommage à Philippe Fluzin*, Editions des archives contemporaines, ISBN : 9782813005984, doi : 10.17184/eac.9782813005984