History of Metallurgy

Iulian Ripoşan and Stelian Stan

Abstract The production and use of metals and metallic materials date back to very ancient times, which are difficult to pin down and differ from one part of the world to another. It started with the use of metals in their native state, and then moved on to their production by smelting ores from the surface of the ground and easily accessible ores from underground. It is estimated that in the area that includes the territory of Romania, the processing of metals in their native state began about a millennium earlier than in the area that includes most of Europe. The new discoveries regarding the beginnings of iron metallurgy in Romania are an additional argument, besides the general historical considerations, in favor of the idea that the first iron age began in the Carpatho–Danube area before 1150 BC. The metallurgical industry in Romania has evolved over the years, being in certain periods an important player in the field. The most important metallurgical areas in our country: Călan, Hunedoara, Reşiţa, Galaţi, Slatina, Bucharest. Along with the evolution of the metallurgical industry, the Romanian metallurgical education also developed in university centers such as Timişoara, Bucharest, Iaşi, Braşov, Reşiţa, etc.

1 Genesis of Metallurgy on Romanian Territory

Due to its natural resources and geographical position at the junction between East and West, the current territory of Romania has had thorough knowledge of and an ample contribution to the emergence and development of metallurgy, having been, in some respects, ahead of many presently advanced areas. According to estimations, the processing of native metals in this region began approximately one millennium before it did in the area comprising most of Europe (Popescu and Popescu 2016; http:eurouniunea.blogspot.ro; Tylecote 1992; Hătărăscu et al. 1991, 2023, 1972; Romulus 2015; Iorga 1927; Glodariu et al. 1979; Istoria Românilor (2001–2003); Burileanu 1920; Chicoş 1925; Negrescu 1931; Stanescu 1931). The practice of metallurgy on the territory of today's Romania dates back to 2800–1900 BC for copper,

I. Ripoşan · S. Stan (✉)
Politehnica University of Bucharest, Bucharest, Romania
e-mail: constantin.stan@upb.ro

D. Banabic (ed.), *History of Romanian Technology and Industry*, History of Mechanism and Machine Science 44, https://doi.org/10.1007/978-3-031-39393-8_4

1900–1700 BC for bronze and 1150 BC for iron [iron weapons and ornaments have been discovered dating from as early as the 12th–11th century BC, but they came from outside the territory in question].

1.1 Non-ferrous Metallurgy

Copper was, practically, the first metal to be actually used by man for his everyday needs, aside from including it, alongside gold, in the making of jewellery. The alloying of copper with small amounts of As, Sb, Pb and Sn, which appeared in the Neolithic, constituted prehistoric man's first metallurgical activity.

Cu-As alloys (<8% As) emerged during the 4th millennium BC, practically at the same time in the Near East and Europe, as representative metal materials for the Early Bronze Age. In the Ocniţa-Vâlcea area in Romania, they were made from a mix of Cu and As ore with 6.7% As (Bugoi et al. 2013), using the same technique as the ones discovered in the North-Pontic region, the Caucasus, or Central Europe. The alloys in Băile Herculane—Caraş Severin (6% As) and the Lower Danube area (5–10% As) date from the late Neolithic and early Bronze Age (Bugoi et al. 2013). Cu–Sn bronze is the representative material for the second (Late) Bronze Age; it has been found in southern Romania, along the Danube, as well as in the deposits of Predeal and Sinaia, which attest to the fact that Valea Prahovei was used as one of the current routes connecting Transylvania (mining area) and Wallachia (agricultural area) (Ursulescu and Zugravu 2016).

Dacian soil was rich in ores. Dacian-Getic craftsmen worked with Au, Cu, Ag and Fe. Rich copper-ore resources allowed bronze metallurgy to begin no later than the early Neolithic and to play an important part in the dissemination and use of this metal at European level. The first to be processed was arsenious copper in surface lodes, known in Transylvania from as early as the late 5th millennium BC. The Bronze Age would reach its heyday in the 12th century BC. In the region of Banat, metallurgical ovens dating back to the 18th–17th century BC (Dognecea-Ocna de Fier) are particularly noteworthy, as are the ones in Bocşa, Giurgiova, Ciclova, Moldova Nouă, Deva, Căzăneşti. Other areas in the country were of importance as well, such as Bălan (Harghita), Baia de Aramă (Chalchis), where the Scythians and the Romans opened many copper mines. In Moşneni, near Mangalia in Dobruja, an entire agricultural inventory of items was discovered, dating back to Roman times, the possible origin of the metals used for making them being the mines of Altântepe, near Hamangia, which were rich in surface deposits of Cu (malachite) and Fe (magnetite) ores.

During the Neogene, the Baia Mare depression (Maramureş, northern Romania) saw intense volcanic activity, which led to the development of a mountain range, with eruptive rocks containing gold and silver ores such as Pb, Zn, Cu, Au as free elements and Ag. The first attested mining activities in these areas date from the 2nd and 3rd centuries BC. Baia Sprie [Mons Medius in 1329] was an important mining centre as

(a) (b) (c) (d)

Fig. 1 Dacian artefacts: Koson coins (**a**), Gold Dacian bracelets (**b**) (Constantinescu et al. 2009), Mould for casting precious-metal pieces (**c**) (https://www.dzr.org.ro/matrita-bijutierilor-daci-de-la-sarmizegetusa-regia-descoperirea-unei-unelte-unica-in-lume-utilizata-pentru-turnat-piese-decorative-din-metale-pretioase) and the treasure of Petreni-Valea Streiului (Dacian Sargeţia) (**d**) (https://www.dzr.org.ro/comoara-antica-descoperita-pe-valea-streiului-in-hunedoara-inele-podoabe-cu-forme-ciudate-si-un-topor-vechi-de-peste-doua-milenii) (courtesy of Constantinescu B.)

early as in the Bronze Age. Gold and silver exploitation is mentioned around 1141 in relation to the Transylvanian-Saxon colonisation.

Gold metallurgy has a longstanding tradition on Romanian territory. The oldest ornaments were discovered in Moigrad (Sălaj) and date from the Stone Age, thus being 6,000 years old. Romanian gold deposits, mostly found in the 'gold quadrilateral', namely the perimetre of Baia de Criş, Săcărâmb, Zlatna, and Baia de Arieş, in the Apuseni Mountains, as well as in Maramureş, were exploited for a very long time, by the Scythians, Agathyrsi, Dacians, and subsequently by the Romans. A branch of the Greek people of the 7th century BC came to the Apuseni Mountains area for the organised exploitation and use of gold deposits.

The exploitation of alluvial gold in the Arieş, Mureş, Timiş, Dâmboviţa, Olt rivers appears to have been the Dacians' main source of the said metal. A few Dacian artefacts (Fig. 1) capture our attention, such as the koson coins, produced in Dacia towards the middle of the first century AD, and the Dacian gold bracelets (Fig. 1a and b) (Constantinescu et al. 2009).

Metallographic research has shown that the gold used to produce the first series of koson coins is similar to that employed by Pontic cities (the first half of the first century BC), while the gold used by the Dacians for the second series, the one without a monogram, is similar to that employed in the making of the Dacian bracelets (alluvial gold from the Apuseni Mountains area). A chemical analysis of a 'Dacian bracelet' (5–7 spirals, 682–1,196 g) made from top-quality gold in the region around Sarmizegetusa Regia, the capitalof the Dacian state in the first century BC-first century AD, showed that, aside from gold, it contained 11% Ag and 0.9% Cu, thus being different from natural gold, which contains up to 40% Ag and 1.0% Cu.

It was concluded that the material was obtained from a mixture of natural gold and primary gold from Transylvania (Constantinescu et al. 2009).

Another ancient treasure (10 ornaments and jewels, most of them made of bronze, but also an axe over 2,000 years old) (Fig. 1d) (https://www.dzr.org.ro/comoara-antica-descoperita-pe-valea-streiului-in-hunedoara-inele-podoabe-cu-forme-ciudate-si-un-topor-vechi-de-peste-doua-milenii), was discovered in the forest at the edge of Petreni village, on Valea Streiului (Dacian Sargeţia, known as 'the Dacian Path'), along the river where the Dacian king Decebalus is said to have hidden his treasures. It is important to mention that Decebalus's treasures, found on the bank of the river Sargeţia, following Bacilis's betrayal, was evaluated by Jerome Carcopino to contain approximately 165 tons of gold and 331 tons of silver (Romulus VI 2023, Ursulescu and Zugravu 2016).

Once Dacia had been occupied by the Romans, miners were brought from Dalmatia, Asia Minor, and other regions and they perfected the methods for the exploitation and preparation of gold ores during the 166 years of Roman dominion. In Roşia Montană, Bucium, Zlatna, Almaş, Stanija, Ruda, and Caraci approximately 3,000 kg of pure gold/year and almost double the amount of silver were produced.

During the period immediately following the Roman withdrawal from Dacia, for over 100 years (272–395 AD), the production of gold dropped radically to a mere 100 kg/year. Mining began to be revived at the dawn of the 2nd millennium and registered great progress in Europe from 1320 onwards, when the exploitation of gold mines started in earnest in Transylvania. It is estimated that, during the long period of the Middle Ages (396–1492 AD), the gold production amounted to an average of approximately 450 kg/year. The year 1500 marks the debut of a sustained development of gold mining, thus reaching over 1000 kg per year (2012).

From the 7th–6th century onwards, the Greeks founded a string of colonies on the shore of the Black Sea, into which Scythians influences found their way. The city of Histria minted its own coin (the first one to be issued on Romanian territory). The treasure in a tumulus in Agighiol—Tulcea dates from around 400 BC and contains pieces made of silver, gilded silver, and gold.

1.2 Ferrous Metallurgy

N. Ursulescu and N. Zugravu, in their work (2016), provide a summarised presentation of the prehistoric and ancient civilisations on Romanian territory associated with the Iron Age, particularly its first (ca 1200/1150-450/300 BC—Hallstatt) and second period (450/300 BC-106/271 AD—La Tène).

The first people to base their development on their knowledge of iron were the Hittites of Asia Minor, starting from around 1400 BC (the zenith of the Hittite Empire). There are several paths via which ferrous metallurgy could have entered Romanian territory: *(a) the South path.* Several Balkan Thracian tribes set out on expeditions into Asia Minor, where they could have borrowed ferrous metallurgy and then spread it among the north-Danubian Thracians. It is also possible that it may have been developed by the south-Balkan Thracians under Greek influence. *(b) The north-western Balkan and Italic path* was active in the western part of the country. The influences stemmed from the Illyrian metallurgical centres, as well as from the pre-Etruscan ones (the *Villanova*-type culture) and subsequently from the Etruscan centres in northern Italy. *(c) the North (or Cimmerian) path.* The Cimmerians (an Indo-European population of the North-Iranian branch, related to the Scythians), found north of the Black Sea, would attack the eastern part of Asia Minor in particular, which is where they borrowed, among other things, the knowledge about ferrous metallurgy, which they went on to spread, during their warlike raids, towards East-Central Europe and, thus, into Romanian territory as well. The various paths of access were convergent and sometimes even synchronous.

On the territory of today's Romania, the Iron Age began with the arrival of the Scythians, in the 7th–4th century. Later on, the Celts introduced an improved version of the craft, which the Dacians learned as well. The oldest whole iron object discovered on Romanian territory up to the present appears to be a *Celtic*-type axe found in the tumular necropolis of Lăpuş-Maramureş, probably dating from the very end of the 13th century BC (Bugoi et al. 2013). Traces of iron exploitation and processing were also found in Almaşul Mare and Ghelari. Iron objects began to be produced locally, in various areas, important findings in that sense being the pieces of iron slag in Susani (Timiş County) and the iron ore-reduction workshops in Baia de Fier (in Oltenia), Cernatu de Sus and Sâmpetru (in Transylvania), and Babadag and Dervent (in Dobrogea).

Aeschylus (525–456 BC) remarked on the fact that the land of the Scythians, which were tribes that had come into Dacian territory and been assimilated by the locals, was also called 'the motherland of iron', with one of its largest centres in the Paranx (Parâng) Mountains, in the vicinity of 'the violent river that is difficult to cross' (Olt), namely in today's Baia de Fier (Popescu and Popescu 2016).

Ferrous metallurgy was predominant in the mountains of Banat (having begun at the end of the 2nd millennium BC), as vestiges of such activities were found in various places, such as Ocna de Fier, Bocşa, Berzovia, Broşteni, Brebu, Ezeris, Sosdea, Fizeş, Ramna, etc. (Popescu and Popescu 2016). The number of such centres increased radically, particularly after the introduction of the procedure for obtaining iron through the melting of ores on open hearths or in ovens. The continuity of metallurgy in this area and of activities in this field, which have also evolved technologically, is highlighted. Mined iron was processed either at the extraction site or elsewhere.

A significant part of the iron used by the Geto-Dacians came from the area of the Orăştiei Mountains, more exactly from around the capital of the Dacian state. It is thought that the largest workshops for the extraction and processing of iron in South-Eastern Europe in the La Tène age operated at Sarmizegetusa. Some of the items from the said workshops are specific to the Dacians, among which the massive iron pieces ending in two wings bent in the form of a conical sleeve, which protected the mouth of the bellows, massive unclogging tools which served to remove the deposits of slag and impurities (Popescu and Popescu 2016).

In the Transylvanian part of Dacia, the Celts would have a beneficial influence on metallurgy, as they added to an existing autochthonous form of it, which had already reached a certain level of development, new elements which were disseminated over a large Dacian territory. One might say that the Celts brought a boost of civilisation to the Geto-Dacian region. After the occupation of Dacia (106 AD), the Romans introduced their own administration (conductores ferrariarum), which materialised, among other things, into a new manner of organising metallurgy. The result was an intensification of the exploitation of metalliferous mines and of metallurgical activities. As they were interested in the mining and metallurgy conducted on these territories, the Romans focused on the metalliferous areas in Transylvania and Banat, which, at the time, were deemed to be 'inexhaustible'.

In the Medieşu Aurit—Şuculeu area, there were several hundred ovens (associated with the ceramic ones), which are certain to have operated in the 2nd–3rd century AD. Consequently, this area must have played a very important part in the lives of the free Dacians, as it is unique in Central Europe (http:www.cunoastelumea.ro). Ferrous metallurgy registered a fairly large-scale expansion in Scythia Minor as well, namely in Roman Dobruja, as traces of ovens carved in rock were identified in the area, in Teliţa (Wollman 2010).

Iron extraction, both worldwide and on Romanian territory, evolved in parallel with the development of related systems, especially those which ensured the introduction of air (oxygen), as well as with the quality improvement of the fuel used to supply the necessary energy. From that point of view, one can identify two main periods, namely one when (a) open hearths and ovens were used to reduce iron ores and one characterised by the use of (b) furnaces.

2 Open Hearths and Ovens for the Reduction of Iron Ores

Early procedures of metal-ore melting relied on the use of open hearths (Fig. 2a) (Popescu and Popescu 2016), with charcoal as fuel, which was added in consecutive layers [charcoal—iron ores—unslaked lime], and forcefully inserted air as a source of oxygen. The resulting 'ball lumps' (iron clumps that included slag) were reheated and submitted to processing through beating, which led to the removal of the slag to obtain the desired metal items.

The oven's limited thermal regime, together with the restrictive iron-carbiding conditions caused the resulting ferrous product to be low in carbon, classifiable as steel, malleable, yet with limited strength.

Towards the end of the Hallstatt period, open hearths were replaced by **metallurgical ovens**, which constituted a particularly important step in iron extraction: the burning was carried out in a closed space and the air was blown in at the bottom of the burden (as opposed to the top, as in the case of open hearths). Thus, the temperature in the space where the iron ores were reduced grew, which brought a series of notable advantages: the increase of the percentage of iron extracted from the ores, the reduction of the duration of a burden and the rise in the carbon content dissolved into the iron—in other words, the production of what we, today, call steel. In European countries, the shift from open hearths to vertical ovens took place during the transition from the first period of the Iron Age (Hallstatt) to the second (La Tène), namely at the end of the 1st millennium BC.

The items which are representative for Romania are the ovens discovered and reconstructed in Doboşeni-MiercureaCiuc (Fig. 2b, 2nd–1st century BC) and Șercaia-Făgăraş (Fig. 2c, 1st century AD) (Popescu and Popescu 2016). The Orăştiei

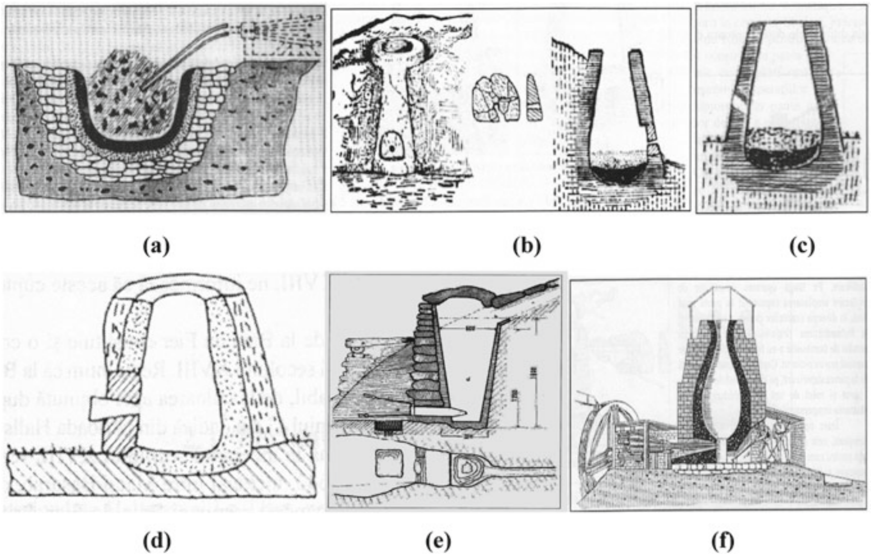


Fig. 2 Iron-ore reduction systems along the centuries, with an open hearth (**a**) and oven-based (**b**–**f**): **b** Doboşeni, 2nd–1st century BC; **c** Șercaia, 1st century AD; **d** Fizeş, 4th century AD; **e** Ghelari, 9th–10th century AD; **f** representative for the 16th century AD (Popescu and Popescu 2016) (courtesy of Popescu C)

Mountains area comprised several iron extraction and processing centres, such as the ones in Sarmizegetusa, Grădiştea Muncelului, Dosul Vârtoapelor, Valea Tâmpului, Căprăreaţa, etc., which continued to operate into the Roman period (Popescu and Popescu 2016). Vestiges from the 2nd–3rd century AD were found in other metalliferous areas in Transylvania (Ghelari-Teliuc, Hunedoara), as well as in the Bocşa-Reşiţa region, in Ocna de Fier and Dognecea, Berzovia, Şoşdea, Fizeş (Fig. 2d), etc. In the late 1st millennium AD, larger metallurgical ovens appeared (Ghelari, 9th–10th century AD, Fig. 2e). The extraction of iron remained important during the period of advanced feudalism and in hill and plain areas as well, such as in Moldavia, where it was carried out in Dacian-style ovens.

As they possessed significant iron and fuel (wood/coal) resources, Transylvania and Banat maintained a significant level of activity throughout the known duration of iron metallurgy, that is, namely from the late 2nd millennium BC to this day. The representative areas in these regions are the Poiana Ruscă mountain area (Ghelari and Teliuc, from the late 1st millennium BC to the mid 20th century AD), Harghita and Ciuc in Transylvania, and Dognecea and Anina in Banat. Less important were the areas of Baia de Fier, Birtin, Halmagiu, Vaşcău, Baia-Fălticeni, Iacobeni, Rimetea, in Transylvania, Oltenia, and Moldavia.

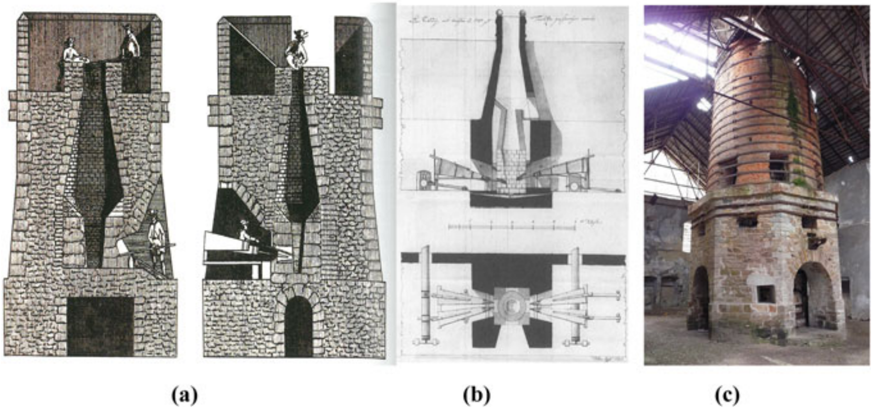


Fig. 3 Furnaces in the first period of their construction (**a** Bocşa, 1725; **b** Topliţa, 1787; **c** Govăjdie-Hunedoara, 1813) (private collection)

3 Iron Extraction Using Furnaces (18th–21st Century AD)

Iron ore-reduction ovens were abandoned in favour of furnaces. On the territory of Romania, they began to be used in the mountain area of Banat, which fulfilled the three simultaneous prerequisites: metal ores (Fe), forests to produce charcoal (fuel), and running water featuring sufficient level differences to enable hydraulic operations (supplying the air, or, more exactly, the oxygen required for the fuel to burn).

Thus, from 1718 (Oraviţa) until 1884, circa 60 furnaces were built in 45 locations. The efficient volume of these furnaces increased gradually, from circa 7 m^3 for the first ones found in Oraviţa, Bocşa (Fig. 3a), Dognecea, Topliţa (Fig. 3b), Govăjdie-Hunedoara (Fig. 3c) to 10–50 m^3 in 1800–1850, then to over 80 m^3 after 1850, culminating at 350 m^3 for the furnace in Călan, in 1871.

4 The Representative Metallurgical Areas on Romanian Territory

4.1 Ferrous Metallurgy

The reorganisation of mining and metallurgy sites constituted a priority for the region of **Banat** immediately after the Austrian–Hungarian Empire took over the area from the Turks (the Peace of Passarowitz,1718) and was carried out by colonising it with German workers. In 1719, the first tall oven that used charcoal for fuel was built in **Bocşa**, followed by furnaces in various locations in Banat, which remained functional for a long time (Fig. 4) (Wollman 2016).

(a) (b) (c) (d)

Fig. 4 Views of the furnaces: Bocşa (**a**), Dognecea (**b**), Anina (**c**) and Reşiţa (**d**) (Wollman 2016), (courtesy of Dr. V. Wollmann)

The expansion of ferrous metallurgy within the region of Banat occurred in **Reşiţa** (Cimponeriu 1930; http://www.csr.ro.50megs.com/istoricr.htm; Jurma 1996; Perianu 1996; Malinschi 1964; Haşeganu 1957; Nicolescu 1940; Ministere de l'industrie, La Roumanie Economique 1921). The construction of the furnaces there began in 1769 and was completed in 1771. The place became known for its cannonball exports (to Napoleon and the royal court of Naples).

Part of the production was supplied to other, neighbouring centres to be processed, such as to Bocşa, Ciclova, Rusca and Văliug.

Puddling furnaces were introduced (replacing refining fires) and the first rolling mill in today's Romania appeared here in 1846, thus providing the rails for the country's first railway (Oraviţa-Buziaş, 1854). The steel produced in Reşiţa was used in the building of the Eiffel Tower in Paris.

Then Bessemer converters appeared (1868), followed by Siemens-Martin furnaces (1876), crucible furnaces (1889) and electric furnaces (1894). Production continued to grow until 1913, then dropped upon the outbreak of the First World War, after which it registered a revival until 1918, followed by another drop until 1920. In the years that followed, there was a general ascending trend, which turned into a linear one in 1948–1980, then started dropping in 1980–1989 (by 43% for cast iron, 30% for steel, 12% for rolled steel). The post-1989 restructuration and retechnologisation programme aimed to eliminate the use of furnaces, reduce steel production to half (electric furnaces), implement continuous casting and the development of secondary-metallurgy technologies.

Hunedoara and its surroundings constituted a remarkable hub for ferrous metallurgy, which has been practiced there from the middle of the 1st millennium BC to this day. In the seventeenth century, the Corvin Castle, a wonderful piece of medieval architecture, became the administrative seat of the smithies on the Hunedoara domain. The castle yard was organised as a market for iron trading, hence the German name for Hunedoara, which is **Eisenmarkt**.

Cast-iron production began in **Topliţa** (1754), expanded into **Govăjdia** (1837) and eventually reached **Hunedoara** (1884), due to its proximity to the iron-ore sources of Ghelari and Teliuc. In a relatively short period of time (1884–1903), 5 furnaces were put into operation, the cast iron being intended to be turned into steel, as well as used as such by casting it into various pieces, either directly in its liquid state or after it has been remelted in foundry-specific furnaces (initially cupolas), either their own or belonging to other beneficiaries. The melting of steel began in 1892. There was an expansion of production operations based on plastic deformation, namely those categorised as forging or lamination. Cast-iron production grew constantly during the early part of the period during which the ferrous-metallurgy platform in Hunedoara was operational, reaching its peak around 1900. The interval between 1949 and 1989 can be divided into three subperiods: (a) 1948–1960, significant increases in production; (b) 1960–1980, a surge in production, for cast iron, as well as steel and rolled steel; (c) 1980–1989, a drop in production below its rated capacities. After 1990, activities were carried out for the restructuring of production, so that, after the privatisation of 2003, only one electric steel plant, a continuous-casting one, remained in operation.

Situated near Hunedoara and practically capitalising on the same resources, **Călan** lies on ValeaStreiului (the Dacian Sargeţia, possibly the location of Decebalus's treasure). Its charcoal furnaces became operational in 1871 and 1875 (82 m^3 of efficient volume, 10,000 tons/year each). In 1990, annual production capacities amounted to 1,170,000 tons of first-fusion cast iron for foundries (practically the sole significant producer of this material in Romania) and circa 100,000 tons of second-fusion cast iron (cast pieces).

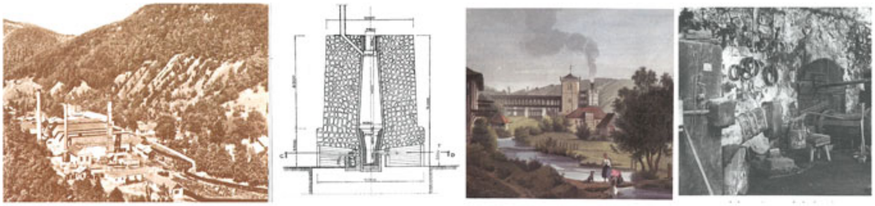
Călan also saw the development of the manufacturing of cast pieces made of cast iron (1877), general-use pieces, ingot moulds and moulding beds, rolling mill cylinders for machine tools. Thus, in the second half of the 19th century, Călan produced over 350 types/versions of heating and cooking stoves, some of which were veritable artworks (Fig. 5a) (Wollman 2016).

Cast pieces of the same category were also produced in Anina, Vulcan, Ruşchita, Vlăhiţa, Nădrag, some of which are hosted by museums around the country, such as the ones in Hazsmann Pal, Cernatu de Sus (Fig. 5b–e) (Wollman 2016).

Located in Banat, near Lugoj, **Nădrag** (Fig. 6a) has had a metallurgical industry since 1845, including iron-ore reduction ovens and heating ovens, as well as hydraulic lift hammers. Charcoal furnaces were to follow (1846, functional until 1916), accompanied by refining fires for the production of steel [in 1848 even puddling furnaces]

(a) (b) (c) (d) (e)

Fig. 5 Cast stoves made of cast iron in the 19th and 20th century: [**a** Călan (Wollman 2016); **b** Nădrag (Wollman 2016); **c** Ruşchiţa (Wollman 2016); **d** Vlăhiţa (Wollman 2016); **e** Anina (Wollman 2016) (courtesy of Dr. V. Wollmann)



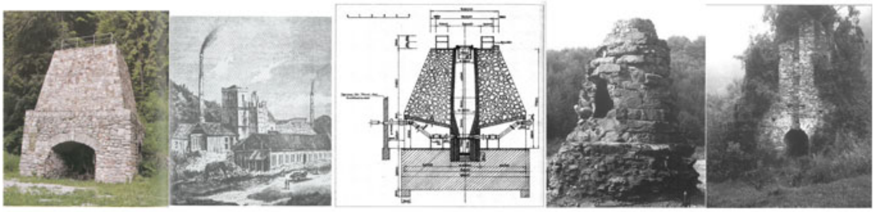
(a) (b) (c) (d)

Fig. 6 The Nădrag plant, early 20th century: (**a**) (Wollman 2010); furnace built in 1860 (**b**), view of the plant in 1864 (**c**) and the hydraulic hammer (**d**) of the Vlăhiţa Iron Plant (Wollman 2010) (courtesy of Dr. V. Wollmann)

and a rolling mill for the processing of steel. The 1924 merger and creation of the Titan [Galaţi]—Nădrag [Banat]—Călan [Hunedoara] concern, which operated until 1948, relaunched metallurgical production (Wollman 2010). After nationalisation (1948), the cast-iron, steel and non-ferrous-material foundry is re-established and new departments are created, such as the ones for various chains. The concern ceased its activities in 1999.

In a different geographical region, yet still in Transylvania, lies another hub of ferrous metallurgy, namely **Vlăhiţa**—Harghita (Fig. 6b–d) (the village of the ancient Vlachs), which has the iron ores in the area at its disposal (abundantly used ever since antiquity by the Dacians and Romans), as well as the deciduous forests and the force of the Homorodul Mic river. The first furnace that became operational in 1825 (21 m^3, open crucible, charcoal) functioned without any essential modifications for over 100 years. The supplying of iron ores, charcoal, and flux was performed by means of carriages, which ran on wooden tracks (a procedure used in this country ever since the fourteenth century, with a series of technical improvements) on a platform situated at the level of the furnace mouth. A classic foundry appeared in 1950 (cupolas, electric ovens), next to which a foundry for rolling mill cylinders (electric ovens) was built. The year 1977 came with a new foundry, very modern for its time (Disamatic automatic casting line), mainly intended for cast-iron pieces for the electrical engineering industry.

Other operational furnaces, located south of Vlăhiţa, were found in **Herculian** (Fig. 7a, from the beginning of the second half of the 19th century to 1950), **Filia** (Fig. 7b, 1854), **Doboşeni** (Fig. 7c), **Zălan**, all in Covasna County. A centre of renown which used locally extracted iron ore (oolitic ore, 40% Fe) was found in **Rimetea,** in the Trascău Mountains; it employed miners who had come from Austria even before the Tartar invasion (1241). Ferrous metallurgy was present in **Maramureş and Bucovina** as well, in the 18th–19th century AD, in places such as **Lăpuşul Românesc—Păduroi—Strâmbul**. The same can be said about **Borşa**, which hosted two operating furnaces in 1866. In **Iacobeni**, Suceava County, 3 furnaces and a foundry were in operation in 1784, using iron ores from Mestecăniş and Valea Fierului, and manganese ore from Arşiţa. In the same area, on the Bistriţa Aurie river, iron was processed in a two-hammer forge which was hydraulically operated (by means of



(a) (b) (c) (d) (e)

Fig. 7 The reconstructed furnace of Herculian: (**a**), the appearance of the Filia plant in 1868 (**b**), the Doboşeni furnace (**c**), the ruins of the furnaces of Răşchirata (**d**) and Zimbru (**e**) (Wollman 2010) (courtesy of Dr. V. Wollmann)

its own sluice). **In western Romania (Bihor, Arad)** (Wollman 2010, 2016) where sources of iron of the oolitic-ore type were found, in the 18th–19th century, iron metallurgy developed in centres such as **Vaşcău** and **Pietroasa** in Bihor, as well as **Moneasa** (1853–1855), **Dezna-Răşchirata** (1849, Fig. 7d), and **Zimbru** (1844–1865, Fig. 7e) in Arad. Iron-processing workshops operated in Donceni, Zugau, Brezeşti, Sebiş.

Starting its activity in 1966, on the bank of the Danube, the **Galaţi Steelworks** was designed to produce 10,000,000 tons of liquid steel per year and began with the heavy-plate rolling mill (1.2 mil. tons/year). The first furnace (1,700 m^3) began production in 1968, followed by another three until 1975. Larger furnaces would follow in 1975 (2,700 m^3) and 1981 (3,500 m^3). Thus, the production capacity for first-fusion cast iron reaches over 7.5 million tons per year, using furnaces built at the latest technological standards of the time. For the direct processing of furnace liquid cast iron into steel, several LD converters are built [1968–1979], and, for special-property steels, arc furnaces (50 t/burden) are constructed in 1974.

In 1970–1987, other rolling mills are added, amounting to a total capacity of 10 mil tons/year. In 1968–1989, production practically registers constant growth, reaching 6.5 mil. tons of cast iron and 7.5 mil. tons of steel in 1989, making it the largest steel producer in Romania.

The 1990 restructuration aimed to reduce production capacities and conduct retechnologisation and modernisation operations, including the intensification of furnace use, the introduction of new, high-performance installations for liquid-steel processing, the modernisation of the carbonisation plant and rolling mill departments, etc. Three furnaces, along with the steelworks with three LD converters and continuous casting, and the lamination departments for heavy plate, hot and cold-rolled strips (including zinc-plated ones) remained operational.

Located on the banks of the Danube, the **Călăraşi Steelworks** was designed as an integrated flow, with a production of 4 million tons a year for medium and heavy profiles, including rails weighing between 49 and 75 kg/LM. It became operational in 1980, when its electric steelworks started to be used (400,000 tons/year, continuous casting), followed by the light-profile rolling mill (350,000 tons/year) two years later. In 1986, it produced the coke furnace block, with its associated chemical sector.

In 1991 it became a company, SC SIDERCA SA Călăraşi, with the electric steelworks and medium-profile rolling mill running, while the other departments were in various phases of execution, some already in the technological-testing phase. The restructuration programme envisaged discontinuing the production of furnace cast iron, coke, sintered iron ore, and converter-made steel.

The accentuated growth of metallurgical production in Romania, especially after 1965, led to an increasing need for ferro-alloys, all imported. The first burden of Romanian ferrosilicon was produced in 1976, at the **Tulcea Ferro-alloy Plant Complex**, which reached 80,000 tons/year in capacity four years later. Maximum production is registered in 1988, amounting to 250,000 tons of ferro-alloys with silicon, manganese, chromium, and complex ferro-alloys such as FeW, FeSiMg, FeSi TE (electrotechnic sheet) (www.feralrom.ro).

4.2 Non-Ferrous Metallurgy

In the **Baia Mare area** in northern Romania, significant metallurgical activities have been conducted ever since the Bronze Age, as its rich non-ferrous metal resources including Cu, Pb, Zn, Au, Ag, etc. have been known and exploited by all the populations which passed through it along the centuries. The Phoenix Baia Mare Plant Complex was founded in 1907 as a sulfuric acid factory, then it was expanded in 1925 to include the neighbouring glass factory, after which it entered the market for non-ferrous metal metallurgy (copper wire, gold and silver ingots, of the raw materials on the Romanian market). During the interwar period, Romania was one of the main producers of precious metals in Europe. Moreover, the copper produced in Baia Mare was traded on the markets in Romania, Czechoslovakia, Poland, or Germany. The plant was nationalised in 1948 and became a private company once again after 1989. Every year, it produced 40,000 tons of refined electrolytic Cu (99,99% Cu), 120 tons of Ag and 12 tons of Au. Gold was extracted from the mining concentrates coming from the county mines and from other places, such as Satu Mare, Alba, Harghita, Mehedinţi (Pantea 2017; https://ro.wikipedia.org/wiki/Cuprom; www.cuprom.ro). Pb was produced in Baia Mare ever since the mid 19th century, out of selective Pb concentrates, through the dry-metallurgical processing of concentrates in a vertical flowing furnace of the Watter Jacket type.

The **ALRO Slatina Company** (Fig. 8a and b) was founded in 1963 through the building in Slatina of the first and only Romanian aluminium plant, with a capacity of 50,000 tons/year Al, which gradually went up to 263,500 tons a year. In 1996, ALRO was turned into a joint-stock company and subsequently privatised, undergoing significant investments in the way of environmental protection. It is the only producer of primary aluminium and aluminium alloys in Romania and the largest aluminium producer in Central and Eastern Europe (except for Russia). Its production capacity makes it possible to obtain 265,000 tons of electrolytic Al, 300,000 tons of primary-Al castings, and 120,000 tons of processed Al products every year. In 2006, ALRO merged with **ALPROM Slatina**, a company in Slatina

(a) (b) (c) (d)

Fig. 8 ALRO Slatina (a and b) (www.alro.ro) and ALTUR Slatina (c and d) (www.altursa.ro) (courtesy of ALRO and ALTUR)

which produced Al alloys, and with **ALUM Tulcea** (founded in 1973, the largest producer in Romania and South-East Europe of calcined alumina, which is used to obtain Al) (www.alro.ro).

Slatina is host to another metallurgical company which is emblematic for the efficient use of Al, namely **ALTUR Slatina** (Fig. 8c and d), which was founded in 1979 and turned into a joint-stock company with private Romanian capital called SC ALTUR SA in 1991 (www.altursa.ro. xxxx). It is an important supplier for several industrial sectors, such as the auto sector (on-road and off-road automobiles, freight and passenger automobiles), tractors and agricultural machinery, the electrotechnical industry, natural-gas heating systems, etc., items made through gravitational casting (74%), die casting (19%), and machine-work (finite) items (7%).

Another area with longstanding activity in the field of non-ferrous metallurgy, particularly that of Pb, was **Copşa Mică**, where the company SOMETRA Copşa Mică (abbreviation of Societatea Metalurgică Transilvană) was active, producing Pb, Zn; and other non-ferrous metals. The ingots made here were used in the automobile industry, in electronics, electrotechnics, electroplating, car batteries, etc. (www.sometra.ro) Founded in 1939 (metallurgical-zinc production, 4,000 tons/year), it was nationalised in 1948 and, in 1950–1960, produced up to 28,000 tons of Zn a year. Complex installations for the simultaneous extraction of Zn and Pb from mining concentrates [30,000 tons/year of metallurgical Zn and 20,000 tons/year of decopperised Pb] were set up, thus diversifying production. Along the years, the plant bore different names: SONEMIN, U.C.M., 21 DECEMBRIE, I.M.M.N, and, from 1991 onwards, SC SOMETRA SA. Its production included: electrolytic Pb—ingots, Ag-Au alloy (D'ore alloy), Zn oxides (Waelz oxides—powder), clinker Waelz (Waelz slag—granules).

SC ZIROM SA Giurgiu is a company in Romania which produces strategic metals. Its main activity is the production and commercialisation of Ti, Zr, and their alloys, as well as the microproduction of non-ferrous and ferrous metals. It was founded before 1989, as a division of the Giurgiu Chemical Plant Complex. SC ZIROM S.A. appeared as a result of the reorgnaisation of Regia AutonomăZirom, which was created in 1990. At present, the company produces titanium ingots and alloys (www.zirom.ro).

5 Metallurgical and Mechano-Metallurgical Plants and Companies

Aside from the traditional metallurgical centres with a long track record (Reşiţa, Hunedoara, Călan, Vlăhiţa, Nădrag, Baia Mare) or more recent ones (Galaţi, Slatina, Călăraşi, Tulcea, Giurgiu, Copşa Mică), many other companies used to make or are still making 'metallurgical history', thus providing vital support for various fields of metal-item manufacturing, for various purposes.

Among the representative **metallurgical plants and companies** we can include the following (with their year of founding): the Oţelul Roşu Plants (1795), Industria Sârmei Câmpia Turzii (wire industry) (1920), the Titan Galaţi Plant (192)], the Griviţa Bucureşti Plant (1921), Întreprinderile Metalurgice Dunărene (the Danubian Metallurgical Companies) (1923), Întreprinderea Industria Sârmei Brăila (wire industry) (1930), the Malaxa Tubes and Steel Plant of Bucharest (1938), Uzina de Țevi Roman (pipe plant) (1957), Combinatul de Oţeluri Speciale Târgovişte (special-steel plant) (1973), Uzina Oţel Inox Târgovişte (stainless steel plant) (1974), Întreprinderea de Țevi Zalău (pipe company) (1980).

The representative **mechano-metallurgical plants and companies** would be: the Lemaitre Plant (Timpuri Noi) in Bucharest (1874), the Aversa company of Bucharest (1882), the Aiud Metallurgical Plant (1884), the Vulcan company of Bucharest (1904), the Fabrica de Locomotive Malaxa (Malaxa 23 August / FAUR) Locomotive Factory) of Bucharest (1921), the Progresul company of Brăila (1921), the MaşiniGrele (Heavy Machinery) company of Bucharest (1966), Combinatul de Utilaj Greu Iaşi (Heavy Machinery Plant Complex) (1977), Combinatul de Utilaj Greu Cluj-Napoca (Heavy Machinery Plant Complex) (1979).

Another category of metallurgical companies includes **producers of cast metal pieces** for other users, namely cast iron, steel, and non-ferrous-alloy foundries other than those which are part of metallurgical and mechano-metallurgical plants and plant complexes, which put to use the cast pieces produced mainly for internal processing. Examples of companies which can be included in this category are the ones in **Alba Iulia** (1972—MECANICA/SATURN), **Câmpina** (1971—Întreprinderea de PieseTurnate (the Cast Piece Company) / ORION), **Olteniţa** (1978—Întreprinderea de Construcţii de Nave şi Piese Turnate Olteniţa (the Olteniţa Ship-Building and Cast-Piece Company) / TUROL), **Băileşti** (1975—Întreprinderea de Piese Turnate (the Cast-Piece Company) / FONTANEF).

6 Metallurgical Education in Romania

The tradition of metallurgical education in Romania goes back a long way, having originated in the development of ferrous and non-ferrous metallurgy on the territory of this country (Universităţi cu învăţământ Superior Metalurgic in Romania). After the occupation of Dacia, within the framework of the Roman organising structure, an important part was played by the craftsmen's 'colleges', which had their own schools for the training of specialists in the field. 'Schola fabrorum' was the blacksmithing school, organised by the Romans at the same time as the 'college', and contributed greatly to the development of the field. After the appearance of the first metallurgical industrial units in Banat, in the 18th century, on January 23rd, 1729, the Mining and Ferrous Metallurgy School of Oraviţa was founded, to be subsequently transferred to Reşiţa 60 years later (1771).

The first notions of metallurgy are introduced by Gheorghe Asachi into the engineering classes of the Greek School of Iaşi in 1813; in 1842, a metallurgy course is introduced in the 3rd-year curriculum in the Exploitation Engineers' section of the same school. In 1867, the School for Bridges, Roads, and Mines is founded by decree in Bucharest, with a five-year course of study, the 4th year of which includes metallurgy courses for the Mining section. From 1881 onwards, the school grants engineering diplomas in the field of metallurgy as well.

In June 1920, the Polytechnic School of Bucharest is created out of the former National Bridge and Road School, including the Mechanics and Metallurgy section and the Mining and Metallurgy section. In the same year, the Polytechnic School of Timişoara is founded. Both establishments train metallurgy engineers for the country's ferrous and non-ferrous industry. In 1928, an Iron Metallurgy Conference is born, which turns into Iron Metallurgy and Metallurgical Machines, which, in 1933, becomes a department in itself, to be merged with the Metallurgy Department led by Traian Negrescu in 1939. It is noteworthy that the first engineering PhD of the Polytechnic School of Bucharest was granted to the American engineer Welton Crook from Stanford University in California in 1936, having Traian Negrescu as dissertation supervisor.

In 1948, the Mining and Metallurgy faculty sections were dissolved and replaced by the Iron Metallurgy Institute of Timişoara. During the academic year of 1949–1950, the 3rd and 4th years of study in the field of metallurgy are created, pertaining to the Mechanics Faculty, yet administratively part of the Iron Metallurgy Institute of Timişoara. During the academic year of 1952–1953, the 1st and 2nd years of study which used to be carried out in Timişoara were transferred to Bucharest and, in combination with the Non-Ferrous Metallurgy section of the Industrial Chemistry Faculty, formed the Metallurgy Faculty, the 6th faculty of the Polytechnic Institute of Bucharest.

The academic year of 1990–1991 marked the beginning of a complex process of reformation in the field of metallurgical education in the way of the modernisation of education technology and the broadening of the scope of knowledge in the field of metallic, ceramic, carbonaceous materials, high-performance materials (composites, intermetallic compounds, amorphous materials, etc.). As a result of these considerations, in 1990, the Metallurgy Faculty of the Polytechnic Institute of Bucharest became the Materials Sciences and Engineering Faculty, a change which was registered in other academic centres in the country, where faculties with this specialisation were founded (Braşov, Cluj Napoca, Iaşi, Galaţi) in 1990. Sub-engineers' institutes were created, such as the ones in Reşiţa (1971—a sub-engineers institute;

1990—an engineers institute; 1992—the 'EftimieMurgu' University) and Hunedoara (1970—a sub-engineers institute; 1990—an engineers institute, the POLITEHNICA University of Timişoara).

References

Budapest Foundry Museum, https://whichmuseum.com/hungary/budapest/foundry-museum

Bugoi R, Constantinescu B, Popescu AD, Munnik F (2013) Archaeometallurgical studies of bronze age objects from the Romanian cultural heritage. Romanian Rep Phys 65:1234–1245

Burileanu S (1920) Istoria metalurgică a Banatului şi Transilvaniei(The metallurgical history of Banat and Transilvania). The Romanian Regal Society Bulletin of Geography, Tome XXXIX

Chicoş Ş (1925) Industria siderurgico-metalurgică în România (The steel and metallurgical industry in Romania). Publishing House of Statistical and Economic Annals, Bucharest

Cimponeriu G (1930) Din istoricul Reşiţei (From Reşiţa history). U.D.R. Bulletin

Constantinescu B et al (2009) Dacian bracelets and Transylvanian gold: ancient history and modern analyses. ArcheoSciences, Revue D'archéométrie 33:221–225

Fodor D, Vedinaş IC (2012). Univers Ingineresc (Engineering universe), No. 20

Glodariu I et al (1979) Civilizatia fierului la daci (The Dacian iron civilization). Dacia Publishing House, Cluj Napoca

Haş M (1957) Geografia economică a RPR—Industria Metalurgică (Economical geography of RPR—Metallurgical Industry). Scientific Publishing House, Bucharest, pp 92–116

Hătărăscu O et al (1991) Din trecutul metalelor (From the metal's past). Tehnical Publishing House, Bucharest

http://www.cunoastelumea.ro/cuptoarele-metalurgice-ale-dacilor-de-la-mediesul-aurit-unice-in-europa-centrala/ (http://www.cunoastelumea.ro/the metallurgical-furnaces-of-the-Dacians-from-the-gilded-medieval-unique-in-central-europe/)

http://www.csr.ro.50megs.com/istoricr.htm

http://eurouniunea.blogspot.ro/2011/05/istoria-metalurgiei-in-orient-levant

http://www.cuprom.ro/lang_ro/cuprom.html

https://www.dzr.org.ro/comoara-antica-descoperita-pe-valea-streiului-in-hunedoara-inele-pod oabe-cu-forme-ciudate-si-un-topor-vechi-de-peste-doua-milenii/ (https://www.dzr.org.ro/anc ient-treasure-discovered-in-the-streiului-valley-in-hunedoara-ornamental-rings-with-strange-shapes-and-an-axe-old-over-two-millennia/)

https://www.dzr.org.ro/matrita-bijutierilor-daci-de-la-sarmizegetusa-regia-descoperirea-unei-une lte-unica-in-lume-utilizata-pentru-turnat-piese-decorative-din-metale-pretioase (https://www.dzr.org.ro/the Dacian jeweler's mold from Sarmizegetusa-Regia directed the discovery of a unique tool in the world used for casting decorative pieces from precious metals)

Iorga N (1927) Istoria industriilor la români (The history of Romanian industries). The National Industrial Credit Society, Bucharest

Jurma G (1996) 225 de ani de siderurgie la Reşiţa (225 years of steelmaking in Reşita). Timpul Publishing House, Reşiţa

Malinschi V (1964) Industria României 1944–1964. Cap. X (The Romanian industry 1944–1996 Chapt. X). Publishing House of the Academy, Bucharest, pp. 391–444

*** (1921) Ministere de l'industrie, La Roumanie Economique 1921, Impremerie de la Cour Royale, (Ministry of Industry, Economic Romania 1921, Royal Court Printing Office), Bucharest

Negrescu T (1931) Istoricul dezvoltării şi starea actuală a metalurgiei în România (The development history and the actual state of metallurgy in Romania). Bull Polytech Soc 45

Nicolescu N (1940) Industria Românească 1930–1940. Industria metalurgică (Romanian Industry 1930–1940. Metallurgical Industry). The Ministry of Economy, Bucharest, pp. 269–291

Niţulescu I. (1972) Baia de Fier. Monografie (Baia de fier. Monograph). Litera Publishing House, Bucharest

Pantea A (2017) Mineritul românesc va renaşte! (Romanian mining will be reborn!). Graiul Maramureşului (published in Dec. 21, 2017)

Perianu D (1996) Istoria Uzinelor din Reşiţa 1771–1996 (The plant's history from Reşiţa 1771–1996). Time Publishing House, Reşiţa

Popescu V, Popescu C (2016) Geneza şi evoluţia metalurgiei feroase în România. Ediţia a II-a revizuită (The genesis and evolution of the ferrous metallurgy in Romania, Second edition reviewed). Semne Publish House, Bucharest

*** (2001–2003) Istoria Românilor Vol. I-VIII (The Romanian history, Vol. I–VIII). Encyclopeding Publishing House, Bucharest

Romulus VI (2015) Istoria Uzinei de Fier Hunedoara (The history of the iron plant Hunedoara). Graph Publishing House, Reşiţa

Romulus VI (2023) Istoria producerii fierului la Hunedoara (The history of iron production in Hunedoara). http://romulusioan.blogspot.ro/

Stanescu N (1931) Industria metalurgică, turnătoriile şi instalaţiile mecanice în România (The metallurgic industry, foundries and mechanical installations in Romania). Bull Polytech Soc 45

Tylecote R (1992) Istoria metalurgiei, ediţia a II-a (A History of Metallurgy, 2nd edn. Maney Publishing, London

Universităţi cu învăţământ superior metalurgic in Romania (Universities with metallurgical higher education in Romania). www.upb.ro, www.upt.ro, www.unitbv.ro, www.tuiasi.ro, www.ugal.ro, www.utccluj.ro

Ursulescu N, Zugravu N (2016) Civilizatii preistorice şi antice pe teritoriul României (Prehistorycal and acients civilizations from Romanian Land). University "Alexandru Ioan Cuza" Iaşi

Wollman V (2010) Patrimoniu preindustrial şi industrial în România. Vol 1 (Pre-industrial and industrial heritage in Romania. Vol 1). Honterus Publishing House, Sibiu

Wollman V (2016) Patrimoniu preindustrial şi industrial în România. Vol VI (Pre-industrial and industrial heritage in Romania. Vol. VI). Honterus Publishing House, Sibiu

www.alro.ro

www.altursa.ro

www.feralrom.ro

www.sometra.ro

www.zirom.ro