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Iron ores of Southern Belgium: much more than hematite

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Résumé

En Wallonie (partie sud de la Belgique), près de 3000 gisements, gîtes et exploitations de minerai de fer ont été répertoriés sur base d'ouvrages historiques, de plans miniers, d'études géologiques mais aussi grâce à la toponymie qui a gardé plus de traces des activités minières que le paysage. Ces 3000 gîtes se rangent en trois catégories principales : (1) les gisements de fer en couches (y compris les hématites oolithiques) ; (2) les gisements d'altération (« amas couchés » des anciens), et (3) les gisements en lien avec les minéralisations de plomb et zinc. Les gisements oolithiques en couches présents en Wallonie sont interstratifiés dans les roches sédimentaires du Dévonien et du Jurassique. Les couches d'hématite ont été identifiées à la base des formations eifeliennes, frasniennes et famenniennes. La couche de goethite oolithique (« Minette de Lorraine ») se trouve à la base de la série toarcienne-aalénienne en Lorraine belge. Les minerais liés à l'altération des roches sédimentaires sont dominés par les hydroxydes de fer et se rangent en plusieurs sous-catégories. Les plus courants sont les amas couchés, des gisements formés au contact entre deux couches géologiques de lithologies différentes. Ils sont particulièrement développés dans les roches dévoniennes de l'Entre-Sambre-et-Meuse et du Condroz, dans les roches jurassiques de la Lorraine belge et dans les roches paléogènes du Hainaut et du Brabant. Les amas cryptokarstiques sont développés aux épontes de certains karsts à remplissage sableux (« abannets » de la Calestienne et de l'Entre-Sambre-et-Meuse). Les graviers ferrugineux, résultant du démantèlement des autres types de gisements, constitue une autre sous-catégorie importante en Lorraine belge. Enfin, de nombreux filons et amas de sulfures de plomb et zinc sont surmontés d'une zone superficielle altérée (« chapeau de fer ») composée en partie de limonite. Ces gisements sont connus dans les vallées de la Meuse et de la Vesdre, dans la Calestienne et dans les régions de Durbuy et de Philippeville.

***Mots-clés** : hématite, limonite, minerai de fer, chapeau de fer, amas cryptokarstiques, Belgique.*

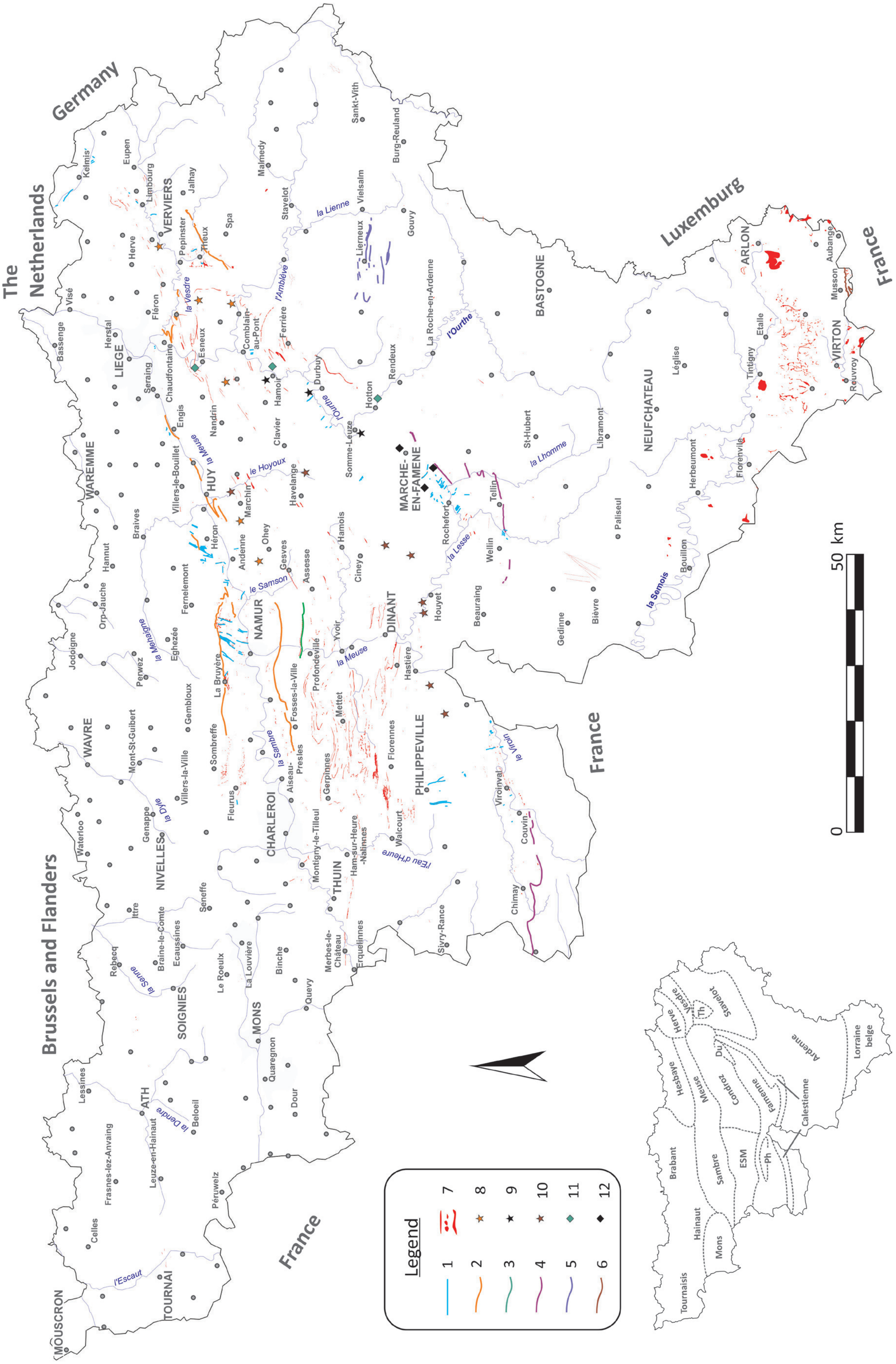
Abstract

In Wallonia (Southern Belgium), about 3000 occurrences and extraction sites of iron ores were identified after examination of historical sources, mining maps, geological studies and toponymy. These 3000 occurrences are grouped into three main categories: (1) sedimentary ores (including hematitic oolitic ironstones); (2) weathering deposists (gossans) and (3) lead-zinc sulfides-related iron ores. Oolitic ironstones are essentially known from the Devonian and Jurassic strata. Hematitic oolitic ironstone horizons are situated at the base of the Eifelian, Frasnian and Famennian stages, while the Minette ores of Lorraine (oolitic goethite) are situated at the Toarcian-Aalenian boundary. Ores related to the weathering of sedimentary rocks are grouped in several sub-categories. Gossans are developed along geological contacts between rocks of different lithologies. The latter are very common in the Devonian rocks in the Condroz and Entre-Sambre-et-Meuse areas, in the Jurassic rocks of the Belgian Lorraine area and in the Paleogene rocks of the Brabant and Hainaut areas. Cryptokarstic ore bodies, developed along the walls of sand filled-karsts (*abannets*-type ores) are known from the Calestienne and Entre-Sambre-et-Meuse areas. Ferruginous gravels resulting from the disintegration of the previous ore categories are common in the Belgian Lorraine area. A last ore type consists of weathered superficial parts of lead-zinc-iron sulfide veins (iron caps). These veins are known in the Vesdre and Meuse valleys, the Calestienne region and the Durbuy and Philippeville areas.

Keywords: haematite, limonite, iron ore, gossan, cryptokarstic ore bodies, Belgium.

1. INTRODUCTION

Wallonia is particularly rich in iron ores. About 3000 occurrences and extraction sites of iron ores were identified (Fig. 1, Denayer *et al.*, 2011) after analyzing historical sources, mining maps, geological studies and toponymy. The latter preserved more traces of mining activities than the landscapes themselves. Most of the iron ores were mined since the Antiquity. In its chronicles *De Bello Gallico*, Julius Caesar (58-50 BC) already noticed the mining skills of the Nervian and Eburons peoples. During the High Middle Age, the Entre-Sambre-et-Meuse area is thought to be one of the most important mining and iron industry center of Western Europe (Pleiner, 1964; Gillard, 1971). Legends tell that the cast iron was discovered in Liège at the beginning of the 14th century, where the blast furnace was also invented (Pasquasy, 2005). Nowadays, the blast furnace is known to have been invented in England by A. Darby who first introduced the use of coke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la Lienne
le Hoyoux
le Samson
la Sambre
la Lesse
la Lhomme
la Semois
le Viroin
l'Eau d'Heure
la Dyle
la Mehaigne
la Senne
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Calestienne
Ardenne
Lorraine belge

Kelmis
Eupen
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Jalhay
Spa
Theux
Pepinster
Herve
Visé
Fléron
Herstal
Bassenge
Seraing
Chaudfontaine
Esneux
Comblain-au-Pont
Ferrière
Hamoir
Durbuy
Hotton
Rendeux
Malmedy
Stavelot
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Tintigny
Etalle
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Rouvroy
Paliseul
Bouillon
Bièvre
Gedinne
Beauraing
Houyet
Hastière
Yvoir
Profondeville
Fosses-la-Ville
Mettet
Florennes
Walcourt
Viroinval
Couvin
Chimay
Sivry-Rance
Erquelinnes
Merbes-le-Château
Ham-sur-Heure-Nalinnes
Montigny-le-Tilleul
Gerpinnes
Aiseau-Presles
Fleurus
Sombreffe
La Bruyère
Gembloux
Eghezée
Fernelmont
Orp-Jauche
Jodoigne
Perwez
Mont-St-Guibert
Villers-la-Ville
Genappe
Waterloo
Seneffe
Ittre
Braine-le-Comte
Ecaussinnes
Rebecq
Le Roeulx
La Louvière
Binche
Quevy
Quaregnon
Dour
Lessines
Beloeil
Leuze-en-Hainaut
Frasnes-lez-Anvaing
Péruwelz
Celles

to replace the charcoal in 1709, whilst the cast iron was already used in Sweden at least in the 12th century (Den Ouden, 1985; Isaksson *et al.*, 1995). However, the modern steel industries of Belgium are not legendary: they reached a peak in production and technology in the 1820-1860's, when Cockerill's engineer Montefiore finally used the hematite ores in blast furnace working with coke in 1852 (Pasquasy, 2005). The past industrial history of Wallonia is almost entirely relying on the richness and quality of the local iron ores, the availability of coal and the traditional skills of the miners and steelworkers, and this, long before Darby or Cockerill. As early as the Neolithic, men already used oolitic hematite as a pigment, as proved by several archeological discoveries (e.g. Bosquet *et al.*, 2013). Neolithic ochres industries are less well documented in Belgium but archaeological materials – limonite and goethite – are known from the beginning of the 20th century (e.g. Van den Broeck *et al.*, 1910)

2. Geology of the iron ores

The Walloon iron ores can be grouped into three categories: (1) sedimentary ores, (2) weathering deposits and (3) lead-zinc sulfides-related iron ores. With a few exceptions, all of the irons ores are hosted in Palaeozoic sedimentary rocks (Devonian and Carboniferous) and, to a lesser extent, in Jurassic and Paleogene rocks (Fig. 2). The iron oxides and hydroxides are the dominant components of the ores. The iron oxide (hematite, Fe_2O_3) is a dense, black, grey or red mineral occurring in massive or granular (oolitic) form or, more rarely in Belgium, as crystals. Theoretically, it contains up to 70 % of iron but due to frequent impurities, the iron contain of the ore is usually less than 50 %. The goethite (FeO(OH)) is an iron hydroxide occurring in dark or yellowish massive, concretionary or pulverulent forms. Goethite is often associated with limonite, a general term used for minerals composed of hydrated iron hydroxides ($FeO(OH).nH_2O$). Limonite results often from the weathering of other iron minerals, such as pyrite. Pyrite and marcasite are two common iron sulfides (FeS_2) not used as an iron ore but mined for the production of vitriol (iron sulfates) and sulfur. Iron silicates (glauconite, chlorite, berthierine) are common iron minerals occurring as grains (ooids) within sedimentary rocks but of no industrial utility if not weathered into limonite.

Fig. 1 – (left page) Map of Wallonia (Southern Belgium) with position of the iron ores. Legend: 1: iron cap upon lead-zinc sulfide veins; 2:hematitic oolitic iron horizon in the basal Famennian; 3: hematitic oolitic iron horizon in the basal Frasnian; 4: hematitic oolitic ironstone horizon in the basal 'Couvinian' (Emsian-Eifelian); 5: ferro-manganesiferous ore horizons of the Lienne valley; 6: Minette-type goethitic oolitic ironstone horizon; 7: weathering deposits (cryptokarstic ores, gossans, etc.); 8: isolated outcrop of hematitic oolitic ironstone horizon in the basal Famennian, red facies; 9: isolated outcrop of hematitic oolitic ironstone horizon in the basal Famennian, green facies; 10: isolated outcrop of hematitic oolitic ironstone horizon in the lower and middle Famennian; 11: isolated outcrop of hematitic oolitic ironstone horizon in the basal Frasnian, red facies; 12: isolated outcrop of hematitic oolitic ironstone horizon in the basal Frasnian, green facies. The small map indicates the main geological and geomorphological areas of Southern Belgium. Abbreviations: Ph: Philippeville Massif; Du: Durbuy Massif; Th: Theux Tectonic Window.

2.1. Sedimentary iron ores

Because the overall geological characteristics and the petrographical description of the Belgian hematitic oolitic ironstones aim the papers of Goemaere *et al.,* 2016: volume 1 and Dreesen *et al.*, 2016: volume 1), we will rather focus on the other sedimentary iron deposits. Nevertheless, a short description of these hematitic oolitic sedimentary iron ores is given below, because of their geological and industrial importance and their large spatial distribution within Southern Belgium and surroundings areas. They are described in an ascending stratigraphical order.

2.1.1. The Middle Devonian (Eifelian) hematitic oolitic ironstone ('couche d'oligiste oolithique du Couvinien')

This first hematitic oolitic ironstone is composed of 2 to 6 individual centimetric oolitic ore layers separated by shales and dolomitic sandstones. The ferruginous ooids are rare but hematitized bioclasts are frequent ('fossil ore facies' according to Dreesen *et al.*, 2016: volume 1). Red-coloured facies are dominant but some layers richer in siderite (iron carbonate) are grey to green in colour (Cayeux, 1911). The mean iron content varies from 35 to 42 % (Delmer, 1913). The oolitic ironstone horizon stratigraphicaly forms the top of the Emsian Hierges Formation (formerly called the

'*Assise de Bure*') but locally it grades into younger strata (Eifelian, Saint-Joseph Formation). It extends from the Wignehies (France) to Couvin areas and reaches a maximum development south of Chimay. A second outcrop area is situated eastward, between Wellin and Champlon-Famenne (Fig. 1).

2.1.2. The Frasnian hematitic oolitic ironstone ('couche d'oligiste oolithique du Frasnien')

A hematitic oolitic ironstone horizon occurs at the extreme base of the Frasnian: it is a 0.2-1 m-

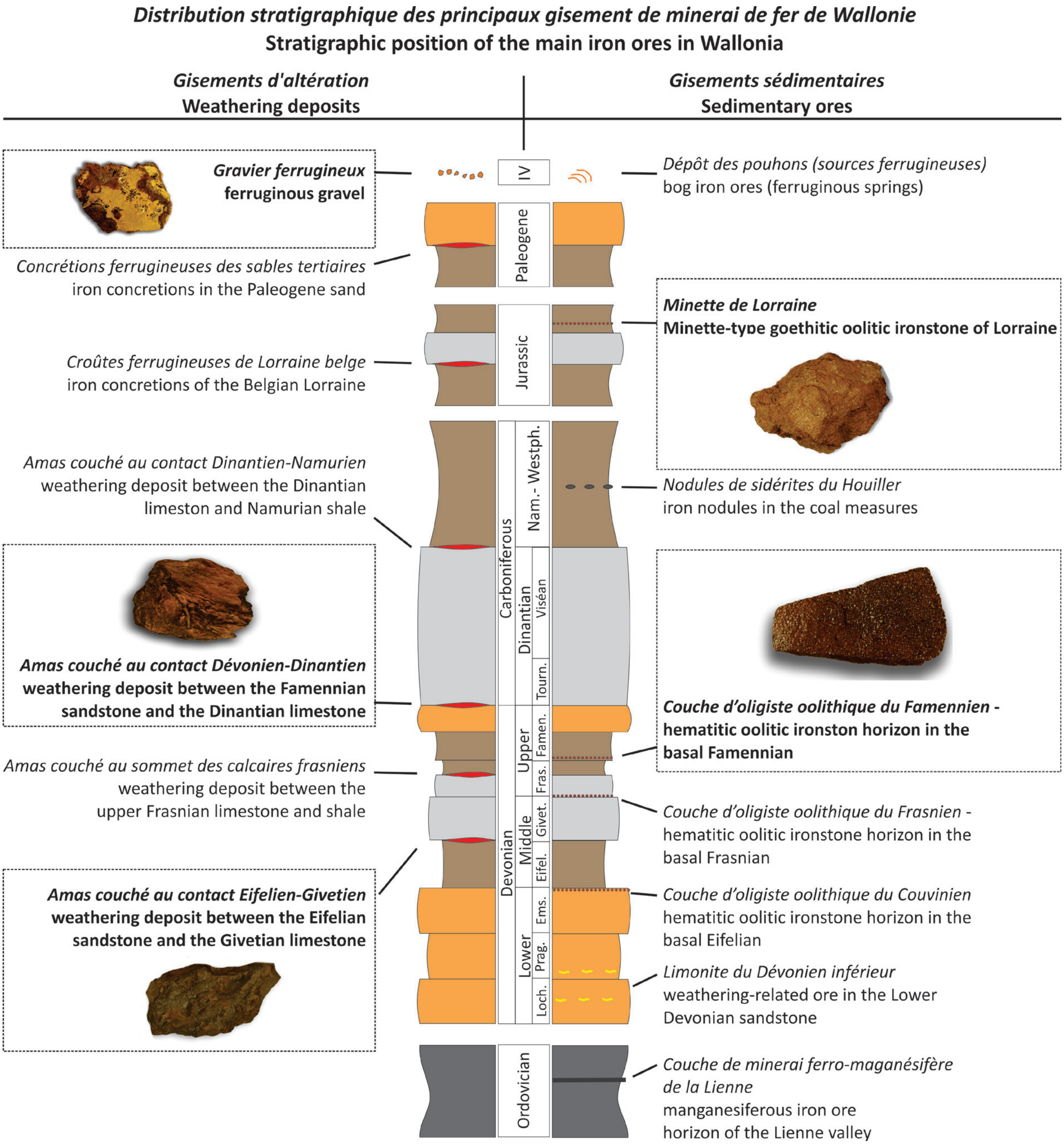

Fig. 2 – Stratigraphic position of the main sedimentary rocks-related iron ores of Wallonia. Illustrated ores (boxes) were the most important from an industrial and economical point of view. Fragments of ores c. 10 cm. Abbreviations: Loch. Lochkovian, Prag.: Pragian, Ems.: Emsian, Eifel.: Eifelian, Givet.: Givetian, Fras.: Frasnian, Famen.: Famennian, Tourn.: Tournaisian, IV: Quaternary.

thick level of hematitic oids and hematitized bioclasts ('fossil ore') incorporated in the so-called Presles Formation (Delmer, 1913). It crops out in the Meuse valley (Tailfer) and occurs in the Samson valley eastward (Fig. 1). Several punctual outcrops are also known in the Ourthe valley (near Esneux and Hotton, Fourmarier, 1908). Southward, the horizon displays a green facies (black squares on Fig. 1), due to the reduced state of the iron in the minerals composing the ferruginous ooids. The hematite (red ore) is replaced by berthierine and chamosite (green ore, complex iron silicates) in the Marche-en-Famenne and Rochefort area (de Magnée, 1933). The latter Fe- chlorite-rich oolitic facies corresponds to a more distal setting of the oolitic level, according to Dreesen (1982b). In Tailfer the ironstone has an iron content of about 25 % (Delmer, 1913).

2.1.3. Hematitic oolitic ironstones from the basal Famennian ('couche d'oligiste oolithique du Famennien')

The Clinton-type hematitic oolitic ironstone horizon in the basal Famennian is the most important of all Walloon oolitic ironstones (Fig. 2). It is composed of true ooids and pisoids (micro-oncoids), enclosed in a hematitic, sideritic or carbonated cement. The ooids are usually ellipsoidal and flattened (forming the so-called 'flaxseed ore', Dreesen *et al.*, 2016: volume 1). This points to the fact that the original material was not entirely hardened when deposited (Dreesen, 1982a-b). The iron content varies from locality to locality and from layer to layer, but a mean value of 35 % is acceptable, the richest layer reaching up to 55 % of iron (Delmer, 1912). The horizon crops out along two inliers parallel to the Sambre and Meuse valleys (Fig. 1). The southern limb ranges from Aisemont to Haltinne and eastward from Ben-Ahin to Engis. The ore is here composed of one to four layers, the thickest reaching 45 cm and the beds are almost vertically disposed in all these localities. The northern limb forms three segments separated by faults, the westernmost ranging from Les Isnes to Marche-les-Dames, the middle one occurring between Houssoy and Vezin and the easternmost occurrence located near Couthuin (Fig. 1). The ore is also present in the Theux area (*'la Heid de Fer'* outcrop, Marion *et al.*, 2013) and in the Vesdre valley (Vaux-sous-Chevremont, Chaudfontaine, Fraipont) but it rapidly thins eastwards, showing ferruginous ooids scattered in shales only, in the Verviers area (Macar & Calembert, 1938). The ore is composed of two to ten individual layers of oolitic ironstones, the thickness of each layer varying from several centimetres to 125 cm (in the Couthuin mine, Delmer, 1912). More to the South, in the Hamoir, Durbuy and Somme-Leuze areas (yellow stars on Fig. 1), the horizon crops out discontinuously and presents a green facies (distal facies), with scarce ooids composed of berthierine, chamosite and chlorites (Anthoine, 1912).

2.1.4. Other hematitic oolitic ironstone horizons within the Famennian succession

Dreesen (1982) recognized five stratigraphically distinct layers of hematitic oolitic ironstones in the Famennian strata. The lower one, identified as level I, is the main ore deposit as described above. The other stratigraphical levels, labeled II, IIIa, IIIb and IV are rather lenticular and scattered within the lower and middle Famennian rocks. They crop out punctually, e.g. in the Hoyoux, Lesse and Hermeton valleys (orange stars on Fig. 1). These ironstones are very thin (a few centimetres at the most). The composition of these horizons is highly variable, mostly composed of hematitized bioclasts ('fossil ore facies'; mainly crinoids). These horizons were rarely mined because of their lesser geographical extent, thickness and quality.

2.1.6. Other sedimentary iron ores within the Palaeozoic rocks

The *'couche d'oligiste oolithique du Gedinnien'* - a hematitic oolitic ironstone horizon in the Lochkhovien and the *'couche d'oligiste oolithique du Givetien'* – a hematitic oolitic ironstone horizon in the Givetien - are cited in the literature but only poorly described (Ancion & van Leckwijck, 1947; Fourmarier, 1954). Both probably represent rocks that are locally enriched in hematite but they do not represent true sedimentary ores (Dimanche & Toussaints, 1977). The manganesiferous iron ore of the Lienne valley is a sedimentary deposit transformed and enriched by low-grade metamorphism, but does not display any oolitic facies. It comprises two to six layers of dark or reddish iron and manganese oxides, often laminated (Libert, 1906). The ores have a mean iron content of 20 % and about 5-25 % of manganese (Firket, 1884) and were mined to produce a high-manganese cast iron in the first half of the last century (Dusart & Dusart, 1991). Several sideritic horizons (nodular iron carbonates) are known throughout the thick sequence of coal measures in the Mons and Liège areas (Kaisin, 1943) and in the Lower Devonian of the eastern Ardenne (Legrand, 1965). Once weathered, these rocks yielded an ore of bad quality, siliceous and argillaceous, that was locally extracted only.

2.1.5. The Minette ore of Lorraine ('Minette de Lorraine')

The goethitic oolitic ironstone horizon of Lorraine, in the southernmost part of Wallonia, corresponds to the northern edge of the large iron ore basin of the Grand Duchy of Luxemburg and Eastern France. In our region, the ore is composed of two thick individual layers (50 cm and 110 cm respectively) interstratified with shales and marls, forming the Toarcian-Aalenian boundary succession (Cayeux, 1922). The ferruginous are composed of goethite – not of hematite – and are enclosed within a carbonate matrix or cement ('Minette-type' oolitic ironstone). Its phosphorous content long restricted its use in blast furnaces. The so-called Thomas-Gilchrist de-phosphorization process that allowed the use of minette in furnaces was finalized only in 1878, but mining activities are recorded at least from the beginning of the 17th century (Delhez, 2004). In Southern Belgium, the Musson-Halanzy mine was the last active iron mine in Belgium that finally closed down in 1978.

2.2. Weathering deposits

The weathering-related ores – secondary ores, replacement ores or impregnation ores after Routhier's classification (1963) – are the dominant ones, both in term of quantity and variety in Southern Belgium. All these weathering ores originated through the same three-step process:

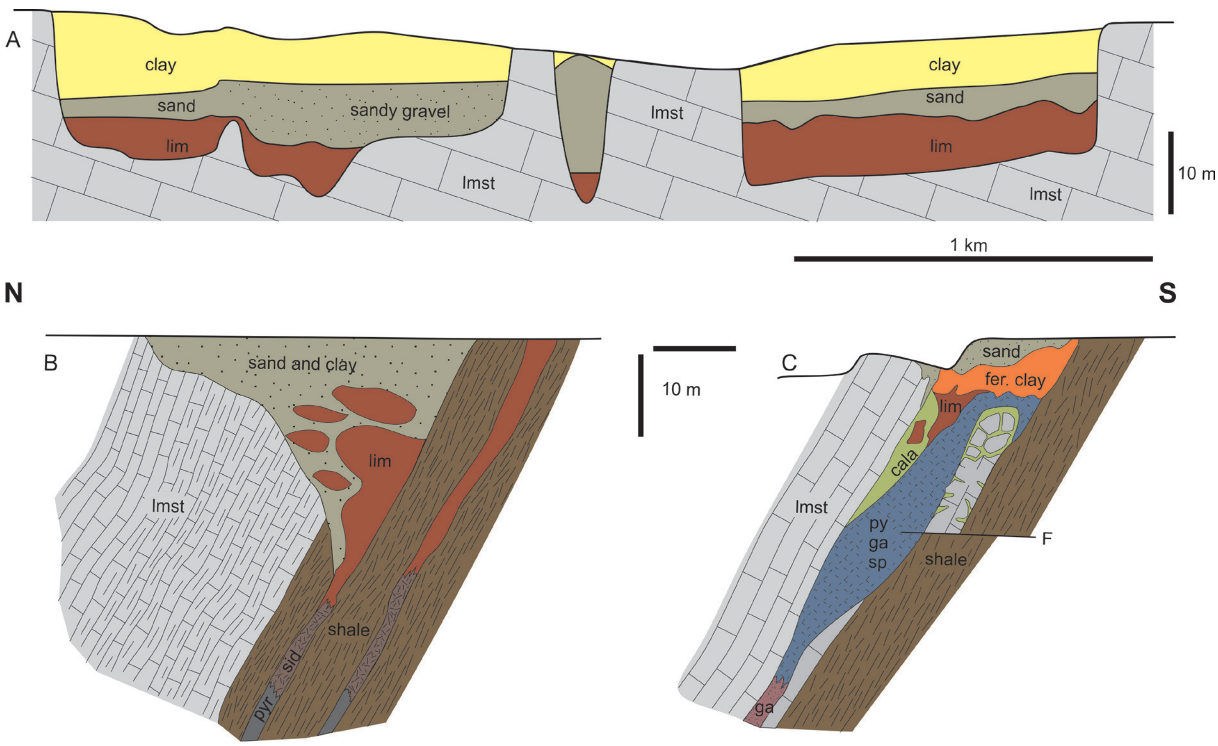

Fig. 3 – Geological section through different ores and deposits. A: Cryptokarstic deposits (exemplified by the Saint-Aubin mine, redrawn after 1/20000 mining plans – 1848 – stored in the Walloon Administration mine service, Namur). B: Weathered deposit between Givetian limestone and Eifelian shale (exemplified by the Berzée mine, redrawn after Bouhy, 1856). C: Iron cap in a sulfide vein (exemplified by the Dos mine in Engis, redrawn after 1/1000 mining section – 1875 – stored in the Walloon Administration mine service, Namur). Abbreviations: lmst: limestone; lim: limonite; py: pyrite (iron sulfide), sid: siderite (iron carbonate); ga: galena (lead sulfide); sp: sphalerite (zinc sulfide), cala: calamine (zinc hydroxide and carbonate). Fer. clay: ferruginous clay; F: fault.

1 Infiltration of meteoric waters through siliciclastic sedimentary rocks (sand, sandstones, siltstones);
2 Leaching of the iron ions (Fe^{2+}) released by the weathering of iron-rich minerals (glauconite, chlorite, pyrite, etc.);
3 Deposition of the iron ions by modification of the pH-Eh values of the water where it touches carbonate rocks (limestones), as iron oxides and hydroxides.

This category of ores is rather restricted to the geological contact between carbonate and siliciclastic sedimentary rocks. In Southern Belgium, such contacts are frequent throughout the lithostratigraphic column (see below and Fig. 2), and iron ores are also well developed. The subsequent subcategories are detailed below in ascending stratigraphic order.

2.2.1. Replacement ores along geological contact ('amas couchés')

This old denomination designates stratiform ore bodies chiefly composed of goethite and limonite, occurring along the contact of two different lithologies of sedimentary rocks (e.g. between limestones and shales or between limestones and shales; Fig. 3A). The contact between Eifelian shale and Givetian limestone bears iron mineralization in the Entre-Sambre-et-Meuse area (e.g. Erquelinnes, Merbes-le-Chateau, Berzée, Gourdinne, Gerpinne and near Fosse-la-Ville; Fig. 1) and in the Condroz area (around Esneux, Plainevaux, Dolembreux, Trooz, Sougné, Aywaille, Harzé, Ferrière and Weris). The ores form long (up to several hundreds of meters) and narrow (no more than 40 m) bodies stretched parallel to the strata, funnel-like in section and up to 80 m thick (Fig. 3B). This type of ore yields limonite and goethite concretions often carbonated or siliceous, that reach a content of 25-50 % of iron. The deepest parts of the ores are usually made of siderite and/or pyrite. In the Entre-Sambre-et-Meuse area, the contact between the middle Frasnian limestone and upper Frasnian shale occasionally contains such ores (e.g. Gerpinnes and Saint-Gérard areas). They form ore bodies similar to the previous ones but smaller in dimension. The most important *'amas couché'* in Southern Belgium occurs along the contact between the Famennian sandstone and the Tournaisian limestone (Fig. 1, Fig. 2). These ore bodies reach several hundred metres in length and reach up to 100 m in width and thickness. The mineralization is dominated by limonite and goethite, siderite and rare hematite and pyrite (Delmer, 1913). The Famennian-Tournaisian ore is omnipresent in the central part of the Entre-Sambre-et-Meuse area: Saint-Gérard, Biesmes, Scry, Mettet, Furnaux, Oret, Denée, Graux, Ermeton-sur-Biert, Sosoye, Biesmerée, Stave, Hanzinelle, Yves-Gomezée, Jamiolle, Falaën, Serville, Onhaye, etc. The ores were mined discontinuously between the Antiquity and the 19th or 20th century in all these localities (Gillard, 1971) sometimes at a true industrial scale. In the Condroz area, the same geological contact is less mineralized and this for unclear reasons (hydrological context? enhanced erosion?). Some mines also operated in the Dinant, Hamois, Gesves, Anthisnes and Comblain-au-Pont vicinities and in the Vesdre area. Several ores, mainly those of the Vesdre valley, are developed along the contact between Viséan limestone and overlying Namurian shale. Some rare ores are known to occur between the Jurassic marl and sandstone in the Belgian Lorraine (Souchez-Lemmens, 1968) but they were not mined *in situ*. The same phenomenon is observed if the two lithologies are in tectonic contact (e.g. along the Theux Fault in eastern Belgium). This first subcategory of ores was abundantly mined in Southern Belgium and is at the origin of the Gallic, Roman and medieval industries and lately of Walloon cast iron and steel industry (Denayer *et al.*, 2011).

2.2.2. Cryptokarstic ores

The *abannets*-type or cryptokarstic ores formed in open karsts (developed in Devonian and Carboniferous limestone, Quinif, 1993) filled with Paleogene glauconitic sand. The glauconite being unstable under atmospheric conditions, it released its iron, subsequently leached through the sand by infiltrated meteoric waters and precipitated along the contact with the basement limestone. This category forms irregular bulks of limonite that are usually sandy (Van den Broeck *et al.*, 1910) and contain up to 45 % of iron (Delmer, 1913). The renowned 'Abannets' and 'Fondry des Chiens' sites in the Calestienne area, are the most emblematic of this category of ores. They were mined since the late Antiquity and the sand initially filling the pockets was excavated. The large ore deposits of Fraire, Saint-Aubain and Morialmé in the Entre-Sambre-et-Meuse area, also belong to this cryptokarstic category (Fig. 3A), together with the smaller ore deposits of the Fleurus and Oret vicinities (Rucloux, 1849; Dejaer, 1970).

2.2.3. Ferruginous gravels

Ferruginous gravels in the Belgian Lorraine area, consist of reworked fragments of goethitic and limonitic crusts. These crusts occur along lithological contacts within Jurassic rocks (see paragraph 2.2.1). The dismantling of the ferruginous crusts by superficial erosion and the sedimentation of the fragments in the valley, produced superficial deposits (so-called *'fer d'alluvion'*, alluvial iron ore) mined in the Tintigny and Châtillon areas (Delhez, 2004). This ore is mainly composed of dark goethite, reaching up to 25-50 % of iron (Delmer, 1913). Similar ores are observed in the Hainaut Province, where the Paleogene sands contain iron concretions reworked as gravel in some valleys (e.g. in the Quevy area, Delmer, 1913).

2.3. Lead-zinc sulfides-related iron ores

The lead-zinc ores are usually developed as sulfide veins composed of galena (lead sulfide) and sphalerite (zinc sulfide) associated with pyrite/marcasite (iron sulfide). The latter being unstable, it often degrades into iron oxides and hydroxides. The uppermost part of the vein, the so-called *'chapeau de fer'* (iron cap or *'gossan'*) corresponds to the weathered, iron-enriched ore, capping the underlying lead-zinc ore (Fig. 3C). The lead-zinc veins are developed inside the Lower Carboniferous limestone and dolostone in the eastern part of Wallonia (Moresnet, Plombière, Kelmis), the Verviers and Theux areas (Dejonghe *et al.*, 1993). In the Sambre and Meuse valleys, from Rhisnes (west of Namur) to Liège, several iron cap ores were mined for iron long before the discovery of zinc and lead in the deeper parts of the veins. The best example is the Vedrin mine, where the iron cap was mined at least since the 14th century, while the galena was discovered only in 1612 (Évrard, 1943). In other deposits (e.g. Haies Monets, Héron, Engis, etc.) the iron cap is less developed and the limonite was less exploited (Balcon, 1981; Dargent, 1949). The same veins are observed throughout the Devonian limestone and dolostone along the Calestienne area (from Chimay to Hotton) and in the Philippeville and Durbuy areas. Occasionally, barite, fluorite and copper minerals are associated with the lead-zinc veins (Dejonghe, 1985).

Remarkable hematite-rich veins occur near Porcheresse (Bièvre) in the Ardenne (Denayer *et al.*, 2011). It is poorly known, but consists obviously of quartz-hematite veins set in Lower Devonian sandstone.

3. CONCLUSIONS

The hematitic oolitic ironstones (*'oligiste oolithique'*) is probably the most renowned iron ore of Southern Belgium and it is the most studied both from an archaeological and historical point of view (see Dreesen *et al.*, 2016: volume 1; Goemaere *et al.*, 2016: volume 1). Nevertheless, it represents only a small part of the total volume of Southern Belgium iron ores, the first place being occupied by iron hydroxides (limonite and goethite) extracted from weathering deposits. Contrary to the hematitic oolitic ironstones, the weathering ores are very poorly documented, both from a geological point of view (except Delmer, 1913a) or from a historical and archeological point of view (e.g. Bonenfant *et al.*, 1986). Iron hydroxides initially produced the source materials for prehistoric ochre industries. Occurrence of iron ochre associated with burial has been documented in Mesolithic and Neolithic sites throughout Belgium (e.g. Van den Broeck *et al.*, 1910; Cauwe, 2001; Polet & Cauwe, 2002; Steevens *et al.*, 2009; Miller *et al.*, 2011 and references within). Nevertheless, the origin of the material (geographical and geological) has not been answered. The source of iron hydroxide ochre may be local considering the wide distribution of ore bodies in Southern Belgium, but long-distance dispersion cannot be excluded since such dispersal patterns are documented for hematitic oolitic pigment (Roebroeks *et al.*, 2012). Analytic methods – such as Raman spectroscopy, Froment *et al.* (2008) – are interesting for the characterization of pigments but a database of natural ores is yet to be established for comparison purpose.

The iron hydroxides were the source of an important steel industry in Belgium reaching acmes during the Middle Ages and in the 19th century. The palaeometallurgy is an important human activity of our history but the source and process of ores are still poorly understood in Belgium. Again, analytic methods (e.g. Blakelock *et al.,* 2009; Fluzin *et al.*, 2000) applied to iron artifact or slags are promising but require a prerequisite knowledge of the iron ores.

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