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MINERAL DEPOSITS OF BELGIUM

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Résumé. - Dans cette note, on décrit brièvement les principaux gisements belges de plomb, zinc, barite, fluorite, fer, manganèse, phosphate, cuivre, or et kaolin. Dans chaque cas, leur genèse est précisée à la lumière des connaissances modernes.

Abstract. - In this paper, the main Belgian ore deposits of lead, zinc, barite, fluorite, iron, manganese, phosphates, copper, gold and kaolin are briefly described. In each case, their genesis is precised on the base of recent investigations.

CONTENTS.

NOTE. - This paper has been prepared for inclusion in volume 3 of "Mineral Deposits of Europe", a serie published by the Institution of Mining and Metallurgy and the Mineralogical Society. The manuscript has been submitted in March 1979. Due to the lack of certain national contributions, the publication has been delayed. In January 1983, the manuscript has been updated. As it appears to-day (August 1985) that the volume 3 will not be printed before 1987. The Société belge de Géologie has kindly accepted on the request of the author to publish the manuscript in its version 1983.

INTRODUCTION

The bedrock of Belgium has been exploited for various metals - for example, Fe, Zn, Pb, Mn, Cu and Au - as well as for several minerals - barite, fluorite, phosphates and kaolin.

Mining activities in Belgium date back to prehistoric times, as is attested by the Neolithic underground flint workings of Spiennes. Metallic mineral exploitation was also a very early activity. Iron ore deposits were being worked by the Gallic people before the Roman invasion and it is also believed that gold panning was taking place at that time in the rivers of northeastern Belgium. Lead and zinc mines were operated during the Middle Ages, La Calamine (Moresnet), the largest zinc ore deposit in Belgium, being one of the very few in the world to be actively mined for zinc during that period. In 1802 one of the later operators of this orebody (J.J. Dony) invented the first process for the industrial recovery of zinc, the process being patented by Napoléon I in 1810.

The metallic mining industry reached its apogee between 1850 and 1870, after which activity steadily declined, though a few mines survived into the early part of the twentieth century. The last sulphide mine (Vedrin) was closed in 1945 ; the last iron oxide mine in the Meuse Valley (Couthuin) was closed in 1946 ; the Toarcian "Minette" iron ore deposit of the Belgian Lorraine was mined at Musson and Halanzy up to October, 1978.

The major need for barite for oil drilling has, however, given rise to new operations on the old barite orebody of Fleurus. Production was restarted in 1979. Kaolin is also exploited on a very small scale.

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Total production of Belgian ore is estimated in Table 1.

Table 1. Total Belgian ore production (tonne)

Fe	40 000 000	hematite plus limonite ;
	1 000 000	pyrite
Zn	2 900 000	oxidized zinciferous ore plus sphalerite
Pb	450 000	galena plus lead oxides
Barite	700 000	
Phosphate	18 000 000	phosphatic crude ore
Mn	180 000	manganiferous Ore
Fluorite, kaolin and Cu	Very small	
Au	Not known	

GEOLOGICAL FRAMEWORK

The bedrock of Belgium is chiefly made up of sedimentary rocks ; igneous rock occurrences are very limited both in number and extent.

Three major groups may be distinguished (Fig. 1) :

1. A basement, made up of Cambrian, Ordovician and Silurian rocks (mainly slaty schists and quartzites) belonging to the Caledonides ;
2. An old cover, made up of Devonian and Carboniferous rocks (alternations of sandstones, shales and limestones) belonging to the Variscides ;
3. A young cover, made up of rocks of Permian and younger age (Mesozoic and Caenozoic).

Formations 1 and 2 are folded, whereas the young cover is flat-lying and sub-horizontal. The three formations are separated by angular unconformities. The Variscan orogeny is characterized by a major overthrust nappe, the Dinant synclinorium overlapping the Namur synclinorium along the Midi-Eifel thrust.

Regional metamorphism (epizone-mesozone) affects several regions of the Ardenne area and always rocks of Lower Devonian age or older.

Manganese deposits belong to the basement. Iron, zinc, lead, copper, barite, fluorite and kaolin deposits are located in the old cover, this formation supporting the major ore deposits in Belgium. The young cover contains only

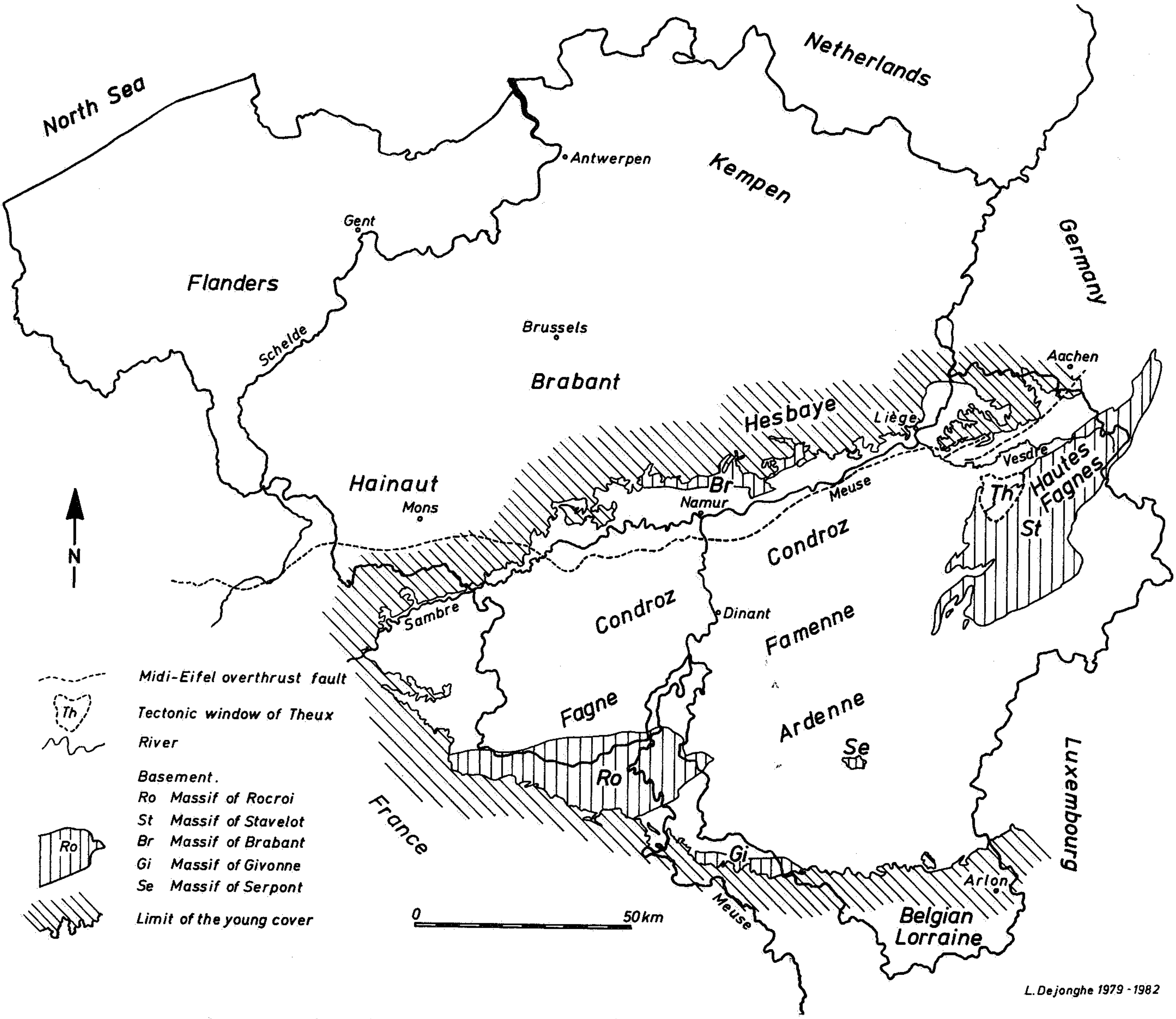

Fig. 1. Major geological formations and geographical areas of Belgium. Paleozoic rocks crop out within central parts of young cover.

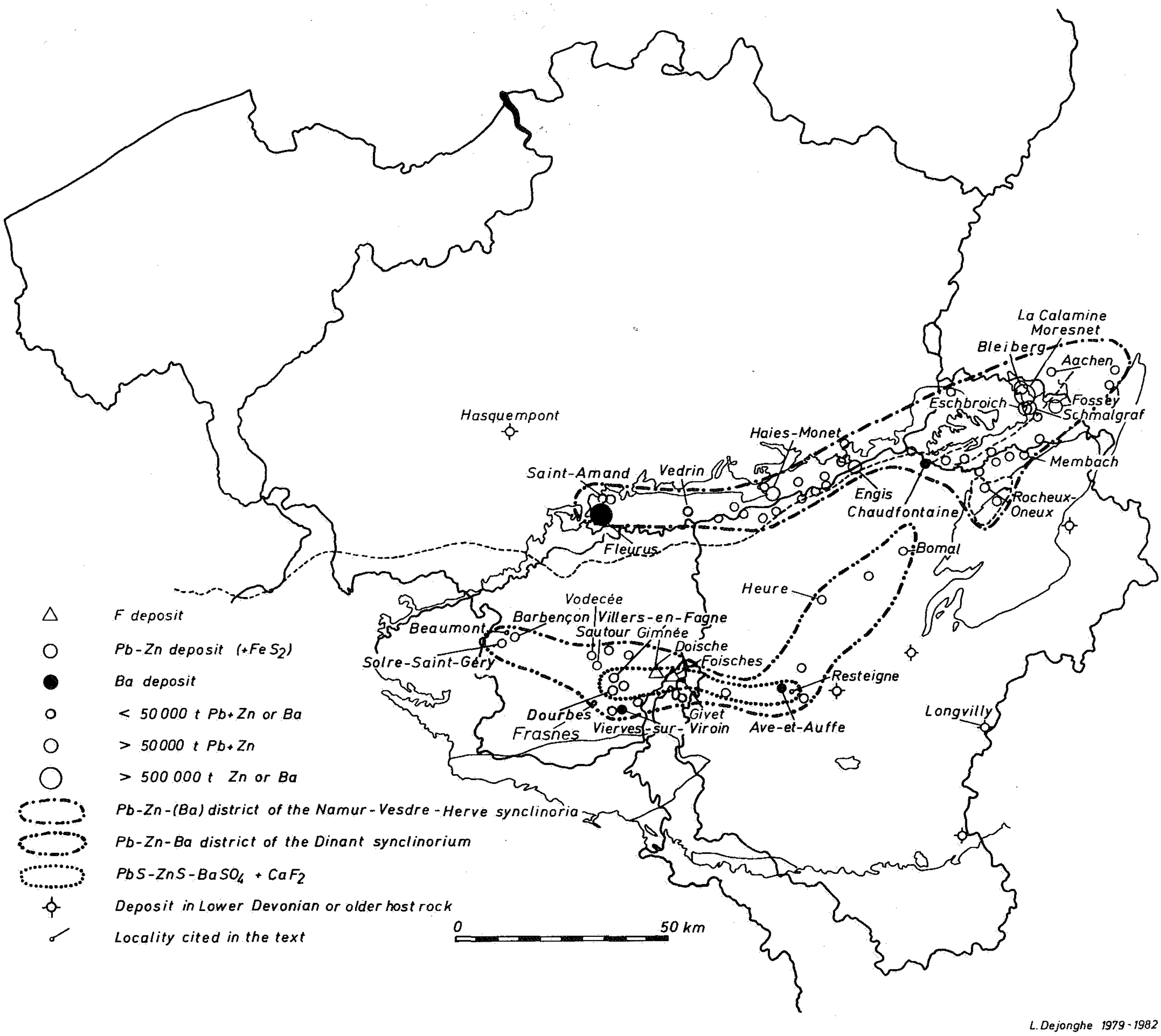

Fig. 2. Location map of main lead-zinc, barite and fluorite deposits of Belgium.

phosphate and some small iron and kaolin deposits. Gold has been exploited in alluvial deposits.

In this review, deposits are dealt with element by element or mineral by mineral. A selection of relevant publications is noted.

LEAD AND ZINC DEPOSITS[4,26,31,35,36,38,44,46,55,70]

Lead and zinc exploitation has been recorded from more than 200 localities. The main ore deposits are indicated in Fig. 2. The largest deposit was that of La Calamine* with around 600 000 tonne of zinc metal. Six other high-grade deposits have produced more than 50 000 tonne of combined metals - Schmalgraf, Bleiberg (in French, Plombières), Fossey, Eschbroich, Engis and Haies-Monet.

Pyrite and marcasite were subordinate by-products of lead and zinc ores in most mines, but at Vedrin and Rocheux-Oneux pyrite and marcasite were the dominant sulphides. Gossans capped most of these ore deposits.

Productions is given in Table 2 (figures taken from Dejonghe and Jans, [26]). The production of the district of the Herve-Vesdre-Theux Massifs (the main

* This ore deposit is also known under several other names : "Altenberg", "La Vieille Montagne", "La Grande Montagne" and "Moresnet". It is situated in the territory of La Calamine, but before 1919 it belonged to the "Territoire neutre de Moresnet".

Table 2. Production (tonne) of ore of Belgian lead-zinc deposits for 1837 - 1936[26]

	Herve-Vesdre Theux Massifs	Belgium	Grade, %
Calamine	1 872 693	1 979 962	29 - 37
Sphalerite	674 780	813 960	45 - 57
Lead ore (including oxides)	197 742	265 499	55 - 75
Pyrite	324 534	961 240	35

metallogenic district and the only one for which a study of all lead-zinc deposits has been done[26]) is compared with that of Belgium as a whole. These ore deposits belong to the category of "Mississippi Valley type deposits". They may be divided into two classes.

Vein-type deposits and associated irregular bodies (so-called "amas")

Economic mineralization of this type is mainly restricted to the intersections of faults with limestones and dolomites of the Devonian (mainly Givetian and Frasnian) and of the Dinantian. Ore deposits hosted in the detrital rocks of the Lower Devonian and the basement are very rare.

Most of these deposits, and especially those with the largest tonnages, are hosted in the Dinantian carbonate formations of the Namur synclinorium (to the west) and the Herve-Vesdre-Theux massifs (to the east). They lie along a belt 10-25 km wide, extending for 120 km from Saint-Amand to east of Aachen (first lead-zinc district, Fig. 2). These Dinantian limestones bear lead and zinc mineralizations only where their lower part is dolomitized. The deposits consist of irregular lens-like masses(in French, "amas") connected to fissure-filling veins. These "amas" concordantly rest at the very top of the Dinantian limestones immediately below the base of the pyritic Namurian shales (the so-called "ampélites"). Ore from the "amas" as well as from the veins often exhibits a brecciated fabric. In comparison with the veins, the overlying "amas" have yielded by far the largest tonnages.

Another lead-zinc district is located in the Dinant synclinorium along a knee-like belt 10-15 km wide that extends for 125 km from Beaumont to Bomal via Givet (second lead-zinc district, Fig. 2). There some small fissure-filling veins, never capped by any "amas", were mined, yielding only a small production (usually only a few thousand tonnes of metal and seldom more than 10 000 tonne). These veins are hosted in the carbonate formations of the Devonian, mainly in the axial zone of anticlines and often with trends transverse to the axial plane.

Lastly, some rare small veins (without "amas") also exist in the detrital formations of the Lower Devonian. The largest deposit is that of Longvilly, near the Belgian-Luxemburg border (production, < 10 000 tonne of ore). Veins that cut the pre-Devonian basement are even rarer and smaller. The latter are only known in the Brabant Massif - for example, at Hasquempont (Ittre).

Water problems, combined with the fact that the lodes were thinning out in depth, were the two main factors that were responsible for the closure of the mines.

According to de Magnée[31], the genesis of these ore deposits is linked with the deep circulation of connate and/or meteoric waters dissolving metals contained within the sediments. The precipitation of the sulphides occurred in the ascending parts of deep channelways under reducing conditions and by liberation of CO_2. It is related to the near-surface portions of the sub-vertical faults transverse tot the axial plane of the folds. These faults are post-Variscan in age. This hydrothermal theory was confirmed by Bartholomé and Gérard[5] on the basis of a detailed study of the Engis ore deposit. In general, the northeast longitudinal thrust faults, linked with the Variscan orogeny, are not mineralized. Only the post-Variscan faults, which trend northwest transversely to the folds, are mineralized. These tectonic traps seem to have various origins.

In the Herve-Vesdre-Theux Massifs most of the mineralized fractures belong to the fault network of the Rhine Graben. These faults seem to have started in the Permian and to have been reactived at various periods of the Caenozoic and the Mesozoic. This tectonic pattern is more and more pronounced in the northeast direction. Such faults may sometimes be traced for several kilometres. Mineralization is present where carbonate formations are intersected (mainly the Dinantian, and to a lesser extent the Frasnian and Givetian). Lodes usually dissappear in the shale and sandstone country rocks. Some small lodes are, however, known within the detrital Famennian (for example, at Fossey). But no lode is hosted within the Silesian, the basal shales of which have acted as an impervious screen (this circumstance also explains the setting of the "amas"). Bleiberg, the third largest lead-zinc deposit in Belgium, is a unique and major exception. There, a lode cuts the Silesian over a distance of more than 100 m. Bleiberg is also the most northeasterly of the Belgian deposits, in which direction the block-faulting tectonics is assumed to be at its most intense.

In the Namur and Dinant synclinoria metals have been trapped mainly by a set of transverse fractures and to a lesser degree by a conjugate set of longitudinal fractures. Displacements of the walls are negligible.

In every case, lodes seem to occur where the country rocks have been slightly domed - a circumstance leading to the opening of tectonic traps.

Most of the lodes are characterized by the following features : (1) the main fracture is accompanied by minor parallel satellite fractures ; (2) in the vicinity of the pre-Triassic palaeo-surface the main trap fracture is well formed and the mineralization is concentrated in one or several planes, the mineralized thickness of which may sometimes reach several metres ; (3) the lode pinches out at depth ; and (4) at still greater depths, the main fracture grades into a complex network of small fractures, the mineralization becoming a true stockwork.

The mechanical behaviour of the rocks is that of a flexed beam with, on each side of the neutral core, a body in tension (single open fracture) and a body in compression (crushed rock material without important voids).

The brecciated structure of the lodes is related to the reactivation of the faults. The cement is dominantly carbonate (mainly calcite) with subordinate quartz. It seems that the period of hydrothermal sulphide activity has been relatively short in comparison with the subsequent period of hydrothermal carbonate and quartz activity (mineralized veins are intersected by barren veins, as, for example, at Heure,[23]; the lode metals would have been deposited between the end of the Variscan orogeny and the beginning of the Cretaceous[31]).

Other types of deposit

Into this category fall all those ore deposits to which the perascendent hydrothermal model described by de Magnée[31] and Barthomé and Gérard[5] does not apply. This section refers to the strata-bound (peneconcordant) and stratiform (concordant) deposits. It includes those of karstic affinities (insofar as the karst is not linked with hydrothermal activity) and those of sedimentary affinities (syn- and/or early diagenetic), the latter very often in a shale and carbonate reef environment.

Ore deposits of karstic affinities

This category of ore deposit is poorly recognized in Belgium and also controversial. The metallogenetic interest of the palaeo-karst has been underlined by Pirlet[62] in relation to the Viséan and by Dejonghe [20] in a broader sense, but Balcon[4] has made the most substantial contribution to this topic. According to Balcon[4], the Dinantian should be particulary rich in mineralizations as a result of the circulation of meteoric groundwaters. He distinguished three levels of emersions to which metalliferous concentrations are linked : the system of intra-Viséan emersions, the system of infra-Namurian emersions and that of a post-Variscan to present-day emersions. In fact, it is likely that the largest Belgian deposit, La Calamine, is genetically related to the Palaeozoic-Mesozoic unconformity through karstic processes [26].

La Calamine, already, quoted by Lindgren [56] as an ore deposit without any relationship with magmatic activity, was exploited for centuries by the "Vieille" Montagne" company. The German name of this society appears for the first time in a letter, written in German, dated 4 January, 1421, in which ten nobles of the "Duché de Limbourg" recognized that the city of Aachen had, from the earliest times, exploited in association with them and their ancestors the mine of calamine ("Kailmijnberg") situated at La Calamine ("Kelmijs").

Before 1825 no statistics of productions are available, but it is estimated that at least 100 000 tonne of zinc metal had already been extracted by then ; 473 800 further tonne of zinc metal was produced prior to the exhaustion of the orebody and the closure of the mine in 1884.

La Calamine orebody extends over a length of 500 m and a width of 100 m, its deepest part reaching 110 m. It is located in the nose of a plunging syncline. The orebody forms part of an enormous pocket that rests on Famennian detrital rocks. This pocket is filled with silicified dolomite, predominant at the bottom, and enormous irregular bodies made up of red clay and "calaminar"* ore (Zn grade, 30-37 %).

The reasons for distinguishing the ore deposit of La Calamine from vein-type deposits have been set out by Dejonghe and Jans[26].

Ore deposits of sedimentary affinities

In the Dinant synclinorium numerous occurrences of low-grade disseminated mineralization occur in the reefal Frasnian dolomitized limestones. In some localities (Barbençon, Solre-Saint-Géry, Sautour, Vodecée) concentrations at the junction of the dolomitic and calcareous facies have been of economic interest, though these deposits never yielded large tonnages. Pel and Monseur [61] described in the peripheral part of a bioherm of Frasnian age (F2h) and its enveloping sediments, at Frasnes, mineralization of galena and pyrite. The tendency of lead to concentrate in the outer zone of reefs was underlinde.

In the other districts ore deposits of sedimentary affinities are very rare. Although some (for example, Membach) are clearly controlled by the stratification, their sedimentary origin has not been demonstrated.

Nevertheless, a sedimentary barite orebody, with accessory pyrite, sphalerite and galena, was discovered at Chaudfontaine by boreholes drilled between 1964 and 1973. This ore deposit is described under Barite, but we can say that it is situated at the top of a biostromal formation of Upper Frasnian age. The fact that sulphides, mainly sphalerite, are relatively abundant

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* In the ancient literature oxidized zinciferous ore is called "calamine" : it is a mixture of hemimorphite, smithsonite and willemite (the latter mineral was discovered at La Calamine).

suggests that a sulphide-dominant zone is probably adjacent to the barite zone[25]. Furthermore, this discovery underlines the metallogenic importance of the Upper Frasnian (Aisemont Formation, sensu Coen-Aubert and Lacroix [18]) for the prospecting of concealed stratiform deposits situated at the margin of the Brabant Massif. As several Devono-Dinantian anhydrite formations have been discovered during the last thirty years by drilling, and because of the link that many geologists see between evaporites and lead-zinc mineralization, in Belgium [6,9,22,31,38,65] as elsewhere, new hopes for the discovery of sedimentary deposits arise.

Lastly, it should be pointed out that, in the Dinant synclinorium, disseminated-type mineralization and concentrated vein-type mineralization often occur very close together. As Dejonghe and de Walque[23] have indicated for the Heure ore-deposit, this veins were probably derived by leaching of the sedimentary country rocks. This hypothesis is supported by lead isotope studies [15].

Hypotheses concerning source of metals

The source of the metals remains conjectural. Following Fourmarier[46], all later authors have classified the lead-zinc deposits of Belgium in the category of hydrothermal ore deposits, genetically connected with hypothetical magmatic intrusion (telethermal ore deposits). That connexion was questioned by Van Wambeke[72] but it was de Magnée[31] who radically broke with tradition by searching for the source of the metals elsewhere than in a hypothetical pluton. de Magnée[31] has said : "la minéralisation apparaît comme une conséquence de l'érosion post-orogénique. Son intensité dépend de la vitesse de cette érosion et de la teneur géochimique en Pb, Zn, Ba des sédiments érodés".

On the basis of detailed studies of individual ore deposits or of metalliferous districts other authors[4,22,23,24,38,61] have come to the conclusion that the metals were embodied in carbonate-shale sediments during the Devono-Dinantian sedimentation, with eventual early remobilization during diagenesis. Studies on the lead isotopic geochemistry of Belgian galenas and pyrites have, however, led Cauet and co-workers[14] to exclude the Dinantian as the main source of the metals.

Lithogeochemical studies[68,71] do not confirm or refute the sedimentary capture of the metals. They are unable to conclude whether the Pb-Zn strata-bound anomalies eventually encountered are contemporaneous with the sedimentation or if they are due to epigenetic metasomatism of particular stratigraphical horizons.

Finally, the model that actually fits best with the available data is the following outlined below.
During the Middle Devonian, the Frasnian, and the Dinantian the sea is considered to be the vector of transportation of the metals, the initial source of which remains hypothetical. Under the appropriate palaeogegraphical, sedimentological and physico-chemical conditions (e.g. within confined environments) enrichment of the environment in metal takes place and, locally, sedimentary ore deposition. Diagenetic mobilizations take place as a result, inter alia, of the early dolomitization of the limestones.
During the Permo-Trias after folding and overthrusting during the Variscan orogeny, development of transverse faults (in most cases linked with the block-faulting tectonics of the Rhine graben) occurs. Opening of these fractures in their superficial parts owing to local upwarping (induced, for example, by the movement or by the solution of underlying evaporites) takes place. Filling of the tectonic traps by leaching of the surrounding rocks (mainly the dolomites) follows, the metals being transported by groundwaters, the chemistry of which has probably been conditioned by the leaching of evaporites. Precipitation occurs in the fissures and in associatied solution cavities by modification of the hydrodynamic conditions (necking-down effects) as well as the physico-chemical conditions (liberation of CO_2 and H_2S).
During the various periods of emersion there is superficial reworking of the ore deposits and karstic reconcentration.

In this model the metals in all types of deposit have not only a common source (consanguinity) but also a complex history : the same metalliferous stock has been remobilized and reconcentrated several times.

BARITE DEPOSITS [30,32]

The only barite ore deposits that have been mined are those of Fleurus, Vierves-sur-Viroin and Ave-et-Auffe. They differ from one another in shape, geological habit, associated minerals and tonnage. In other deposits barite was an accessory mineral - generally not recovered. For example, at Villers-en-Fagne, nine lodes (two of them important) that cut Frasnian carbonate rocks have yielded galena, pyrite and barite, but the latter was discarded, not having found any industrial use at the time of exploitation.

On the basis of tonnage the Fleurus ore deposit is certainly the most important of the Belgian barite deposits. It is mainly made up of unconsolidated barite, varying from a very fine powder to debris a few centimetres in length and, exceptionally, of decimetre length. In a very few places are found irregular barite bodies, relatively coherent, though easily breakable with the hammer. The fine-grained barite is dusted with iron oxides, clay minerals and siliceous material. At the bottom of the mineralized body black shale preponderates. It forms, at the contact with the underlying limestone, a relatively continuous though irregular layer, which may reach several metres in thickness. This layer contains quartz pebbles and, locally, sandstone cobbles and boulders. In some places black shales also rest on barite bodies. Galena is extremely rare and only known as small disseminated spots in the eastern part of the orebody. The ore fills a karstic depression in Visean limestones (V2b). This pocket extends for 450 m in length and 125 m in width. At the centre the base is located 40 m below the palaeo-surface of the Palaeozoic formations. The overlying Caenozoic formations have a thickness of 10-25 m and are made up of glauconitic sands, argillaceous at the base. Above the baritic body is a conglomerate with quartz and chert (phtanite) pebbles. de Magnée and Doyen [32] assumed that the barite was precipitated in a karstic depression under lacustrine or palustrine conditions. The Fleurus deposit has been exploited sporadically from 1890 to 1928. Total production reached 694 500 tonne of commercial barite. Reserves under the water-table have been assessed by drilling and have been estimated at 833 000 tonne of pure barite, which has justified new exploitation by Baroid Mineral, Inc. ; open-pit mining operations (Fig. 3) commenced in 1979.

At Vierves-sur-Viroin the orebody is a lode located in a north-south fault cutting limestone and shale of the Middle and Upper Devonian for a distance of more than 2 km perpendicular to the folding. Barite and calcite with disseminated sulphides are typical of the infilling of the southern part of the lode (extending for 460 m), whereas the adjacent northern prolongation is richer in marcasite, sphalerite and galena. The lode is lenticular in shape with a maximum thickness of 14 m, which is exceptional in Belgium : at that place the lode is built of three layers of barite, with a useful thickness of 4.5 m, and calcite intercalations. Exploitation has been episodic and was abandoned finally in 1962. Total production reached about 19 000 tonne.

The Ave-et-Auffe ore deposit, which extends into the communes of Villers-sur-Lesse and Lavaux-Ste-Anne, is also a vein-type deposit, but with a pattern different from that of Vierves-sur-Viroin. Here the limestones of the Fromelennes Formation (Upper Givetian)

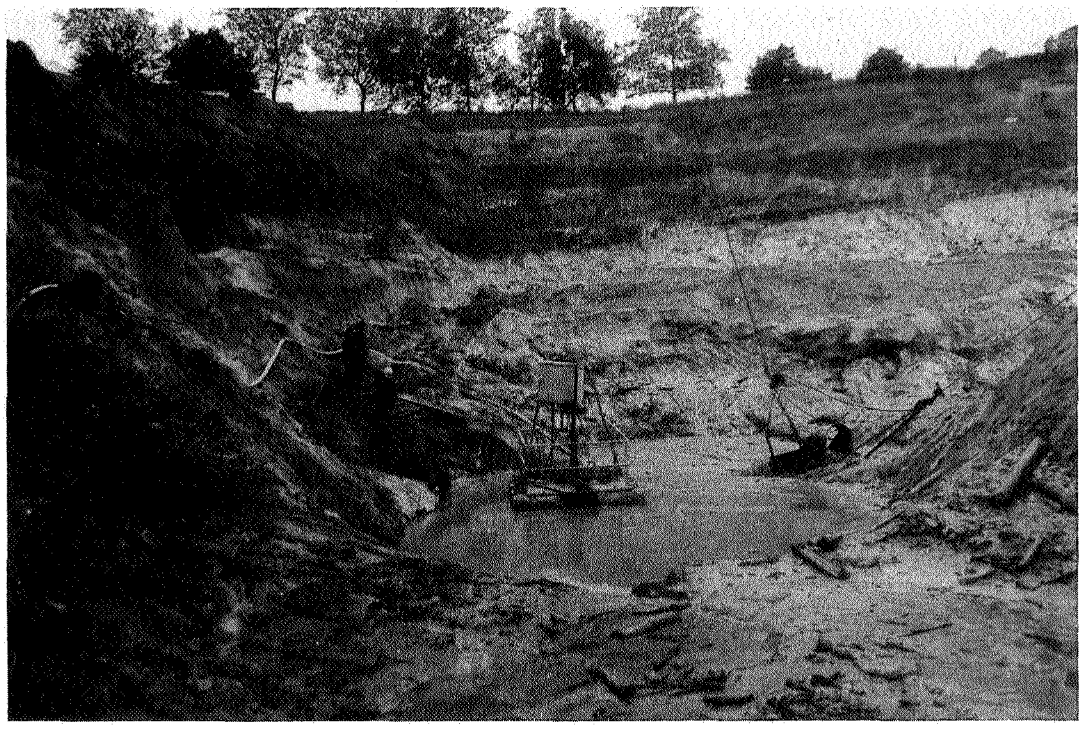

Fig. 3. View of Fleurus open-pit exploitation (June, 1980). Contact between the baritic body (light grey) and the overlying Caenozoic formations (dark grey).

form a large anticline cut by two sets of lodes, longitudinal and transverse. Their thickness vary from 0.20 m to 1.50 m. Barite constitutes the main infilling of the veins. Calcite, fluorite (mainly disposed near the walls) and galena (very scarce spots located at the eastern and western extremities of the orebody) are accessory minerals. The walls are slightly silicified. The first mine working dates back to the nineteenth century and the latest to 1949. Statistics for the period 1864-1948 mention a total production of 8191 tonne.

This section would be incomplete without further information on the Chaudfontaine deposit, which has already been mentioned. It is a new type of deposit in Belgium. It was discovered by three boreholes drilled between 1964 and 1973. The mineralization lies on the two flanks of a faulted anticline at depths between 80 and 210 m. In one of the drill-holes the stratigraphical thickness of the mineralized zone reaches 10.75 m. The ore is mainly made up of barite, with accessory pyrite, sphalerite and galena (chalcopyrite and bravoite are very scarce and only visible under the microscope). The rhythmic pattern of layering of barite and sphalerite ore is sometimes well marked. Alternations of massive barite layers, more or less mineralized layers, and barren beds are of centimetre, decimetre and metre amplitudes. Also present are sedimentary fabrics involving barite crystals such as slumpings, load-casts, intraformational breccias and small sedimentary faults. According to Dejonghe[22], this deposit is of sedimentary origin and was deposited in a reef shaly and carbonate environment of Upper Frasnian age (Aisemont Formation sensu Coen-Aubert and Lacroix[18]). This conclusion has been confirmed by the study of sulphur isotopes of barite [24]and fluid inclusions of barite[25]. It may be noted that 1 km farther east of the drill-hole area, at a place called La Rochette, a small lead-zinc lode has been exploited in the past. Barite and quartz were abundant as gangue minerals, which is very unusual in this district. Furthermore, bravoite has been found in both deposits. This indication of similar mineral assemblage supports the idea of derivation of the veins from the leaching of the surrounding rocks or, eventually, from pre-existing sedimentary concentration.

FLUORITE DEPOSITS[12]

Fluorite has been noted in many localities, but the major occurrences occupy a narrow band (around 50 km length and 5 km wide) that extends from Dourbes to Resteigne, which coincides with the central part of the lead-zinc district of the Dinant synclinorium (Fig. 2). There temporary small exploitations are recorded - principally those of Gimnée, Doische and Foisches (France).

Givetian and Frasnian carbonate rocks are the host rocks of most occurrences.

The usual habit of the fluorite is isolated cubes or easy cleavable aggregates. Crystals, generaly purple, may also be colourless, yellow or greenish. Fluorite appears as dispersed spots and infillings of fractures in carbonate rocks and as isolated crystals in calcite veins. The richer concentrations are hosted by the Fromelennes Formation (Upper Givetian) within a silicified level described as "à rogneux" by the local miners. Fluorite is sometimes concentrated in residual clay filling solution cavities. Lastly, fluorite is also associated with pyrite, galena and barite in some crosscutting veins (at Villers-en-Fagne, Ave-et-Auffe and Resteigne).

Fluid inclusion and trace element data[65] confirm that Belgian fluorite and, by implication, the associated Pb-Zn-Ba-Fe mineralization, may be classed with deposits of the Mississippi Valley type. Homogenization temperatures fall in a range below 150°C. The salinity varies from 10.2 up to 18.2 % equivalent NaCl (in weight). Na/K ratios are, however, unusually low with high K concentration in the inclusion brines. These mineral deposits could result from movement of connate brines from thick sedimentary sequences in sedimentary basins adjacent to the mineralized areas. The brines would possibly have been modified by contact with evaporites at some stage of their evolution.

IRON DEPOSITS[1.3.16.20.21.27.28.63.]

The Belgian iron deposits, already worked by the Gallic people before the Roman invasion, have contributed greatly to the industrial development of the country. Until about 1860 the iron industry was wholled fed by production from Belgian orebodies, part of which was exported. The mining industry had its most prosperous period between 1850 and 1870, but after the discovery of the Thomas dephosphoration process in 1878 activity declined quickly with the consequent access to the ore deposits of Lorraine and Luxembourg.

The parcelling of the exploitations as a result of the mining regulations applicable to iron deposits and the shape of the orebodies (often followed for long distances at outcrop) did not allow large mines to develop. A vast number of small workings is recorded ; in the Vezin area, however, iron ore exploitation was very intense, some mines employing several hundred men.

Belgian iron ore deposits may be divided into two genetic groups - those of sedimentary origin and those formed by weathering.

Sedimentary deposits

The marine sedimentary iron ore deposits are distributed throughout the Palaeozoic (mineralized horizons are encountered within the Gedinnian, the Couvinian, the Givetian, the Frasnian, the Famennian, the Tournaisian and the Silesian) and in the Mesozoic (the Toarcian) (Fig. 4).

The sedimentary ore consists of hematite, sometimes with chamosite and/or siderite. Oolitic fabric is a constant feature. The iron orebodies occur as lenticular layers (average thickness, approximately 1 m ; maximum thickness 5 m) that outcrop over long distances. Average analysis of the most important orebodies are shown in Table 3.

Table 3. Average analyses (%) of iron ore deposit of Belgium[26]

Formation	Fe	P	S	SiO_2	CaO	MgO	Al_2O_3	Mn
Gedinnian	43	1.03-1.17		17.25-21				
Couvinian	34.86-42.02	Up to 0.42		18.24-18.50	0.49-7.59	Up to 0.85	2.15-18.70	
Famennian	25-52 (exceptionally 56)	Up to 0.48	Up to 0.68	Up to 17.1	2.65-10.61	0.3-5.71	6.13-13.63	Up to 0.63
Tournaisian	30-35	Up to 0.22	Up to 0.644	4.10-5.15	13.00-13.62	4.32-5.71		
Silesian	25-30	Up to 0.128						
Toarcian	35-39	0.5 -0.6	0.070-0.074	14-23	2-11	0.45-0.80	5.70-5.80	0.32-0.35
Diestian	18.0 -28.0 (exceptionally 38)	0.077-0.247	0.082-0.116	51.03-60.67	Up to 13	0.36-0.82	0.77-4.90	Up to 0.16
Holocene	35-48	0.4-3.0		7.45-11.40	1.15-1.50	Tr.	0.91-1.03	
Gossans	25-35 (exceptionally 50)							

In the Couthuin area intensively pyritized parts are linked with the existence of crosscutting mineralized veins with marcasite and galena. Pyrite decreases and disspears away from the veins.

The origin of the pre-Silesian sedimentary iron ore deposits is to be found in the denudation of the Caledonian belt, on the remnants of which the Devono-Dinantian seas successively transgressed from south to north. Indeed, these iron

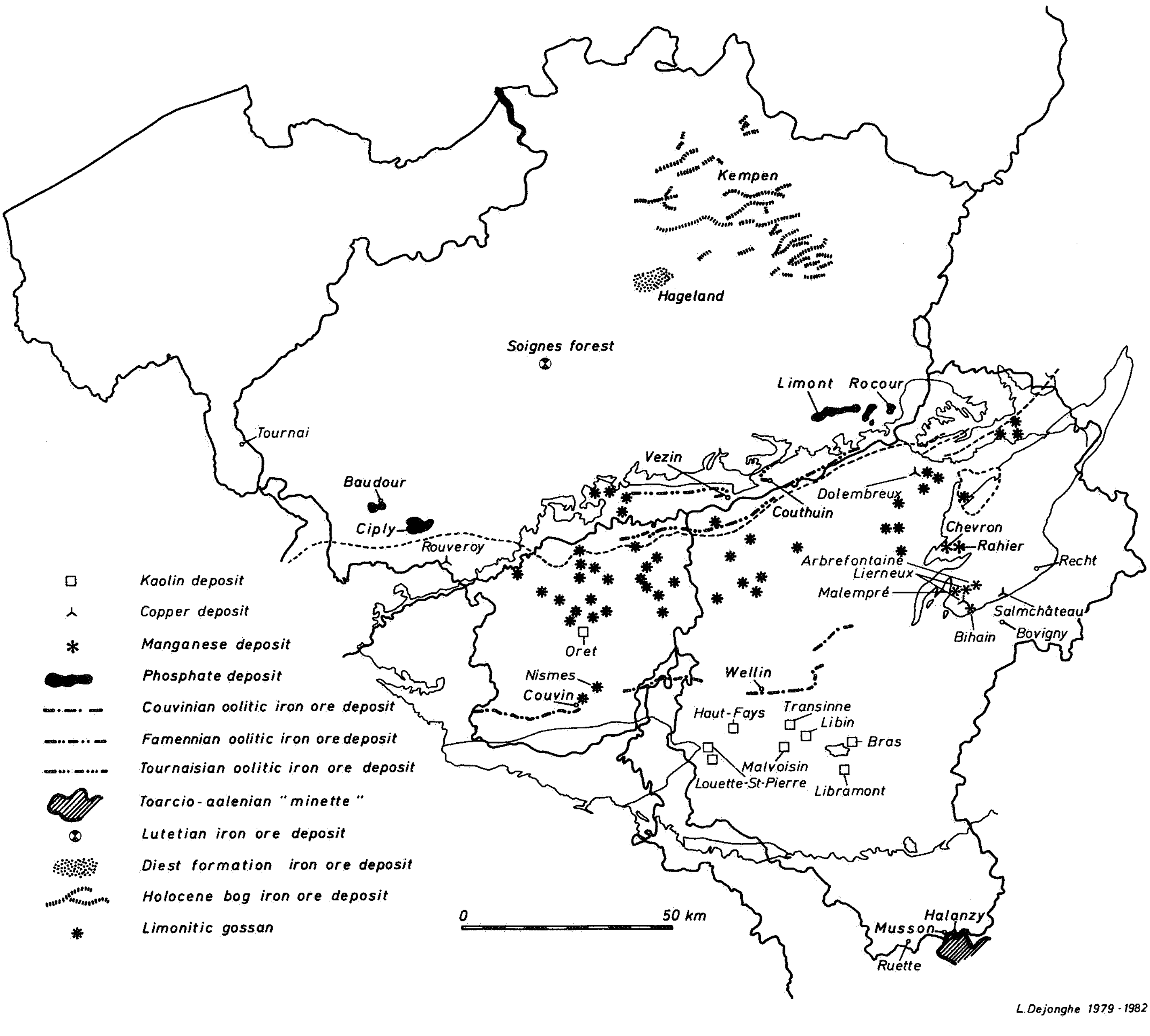

Fig. 4. Location map of main iron, phosphate, manganese, copper and kaolin deposits.

ore deposits are of a more recent age the farther north they lie. Their coastal marine genesis, shown by their oolitic and fossiliferous features, accords with the direction of transgression.

A relationship between the Frasnian and Famennian ironstones and the volcanic activity of the Rhenish Massif has been proposed by Dressen[41], who has also indicated their allochthonous character within subtidal offshore sediments, probably associated with small-scale epeirogenic movements at the border of the sedimentary basin[40]. These ironstones would have been transported by storm wave events (turbid surficial clouds) to the open shelf [42].

The Silesian iron ore deposits also have a sedimentary origin, but they belong to a continental subaqueous facies. Lastly, the Toarcian iron ore deposit was formed by leaching, under wet and hot climatic conditions, of the emergent Lower Liassic rocks, followed by transport to the sea in temporary regression and then sedimentation in the gulf of Luxembourg.

Weathering deposits

Weathering deposits may be,in individual cases, qualified by the terms "secondary", "substitution", "replacement" or "impregnation" in conformity with the terminology of Routhier[64]. Indeed, they may be divided into various types - for example, ore deposits formed by the weathering of sediments, gossans of the sulphide lodes and karstic deposits.

Ore deposits due to weathering of sediments

All these deposits reflect oxidation processes accompanied by either residual concentration or leaching, transport and deposition of iron under the predominant control of climatic conditions.

In general, during the Caenozoic, and particularly during the Miocene and the Pliocene, climatic variations were responsible for the creation of iron duricrusts. The latter have been well studied in the Belgian Lorraine.

Deposits due to the weathering of sediments are reviewed according to the age of the host rock.
Palaeozoic - A number of iron ore deposits are controlled by the lithostratigraphy, as in the case of numerous limonitic orebodies of the northern limb of the Dinant synclinorium (Condroz area, Figs 1 and 4). They follow the contact between carbonate and detrital formations, and preferentially follow the base of the carbonate unit rather than the top. In depth, limonite grades to siderite, which itself grades to pyrite. A comparable strata-bound iron ore deposit of hematite and goethite has been described by Dimanche and Toussain[37] at Esneux in a bed of sandstone that separates calcareous rocks of the lowest Givetian from conglomerates and red rocks of the uppermost Couvinian. According to these authors, the precipitation of iron is due to contact between a reducing aqueous medium and an oxidizing medium that was responsible for the reddening of the underlying rocks.
Lias - The so-called "minerai de fer des prés", also named "Wascherz" or "minerai de fer tendre" (Fe, maximum 57 % ; P_2O_5, 0.55-3.32 %) covers vast areas in Luxembourg and also extends into the Belgian Lorraine. It takes the form of concretions (crusts or nodules) included within lenses made up of yellow or greyish clay that are spread over the irregular erosional surface of the Middle and Upper Lias. This ore contains oolitic debris reworked from the Toarcio-Aalenian "minette" ore[49]. The weathering processes, the mobilization and the concentration of iron have occured under temperate humid climatic conditions during the Upper Oligocene[50] or the Lower Miocene[57].
Eocene - Lenses of limonitic sandstones enclosed within Lutetian (Bruxellian) sands have been the subject of ancient exploitation in the area of Groenendael in the Soignes forest (Fig. 4).
Mio-Pliocene - Within the sands of the Diest Formation (Upper Miocene or Lower Pliocene) lenses of ferruginous sandstone are encountered (Fe, average 18-28 %, exceptionally 38 % ; P,~ 0.07 %). They have been exploited in various localities of the Hageland area, especially in the vicinity of Rotselaar, Wesemaal and Gelrode (Fig. 4).
Pliocene - Ferruginous sands grading to limonitic sandstones of Pliocene age (Scaldisian-Poerderlian) have been exploited in the past on the hills of Poederlee and Lichtaart.
Holocene - The main ore deposits take the form of lenticular lenses (maximum thickness, 1.5 m) and are located in the swampy valleys of the Limburg and Antwerp Kempen in the regions where the glauconiferous sands of the Diest Formation crop out (Fig. 4). This so-called "limonite des prairies" (Fe, 35-48 % ; P, 0.4-3 %) was actively exploited between 1845 and 1914. The richer parts are now exhausted. Their genesis was explained by de Magnée [29] as follows : during the oxidizing leaching of the glauconitic sands by recent meteoric waters the iron derived from the glauconite is dissolved and carried away by the phreatic groundwaters. These solutions feed the peat of low-lying bogs, which are spongy and continuously drained. Ferric hydrates precipitate near the surface by the action of micro-organisms, replacing almost completely (90 %) the vegetable matter. de Magnée[29] estimated that such a deposit could be reformed within a period of 50 years.

It may also be noted that bog ore in Holocene alluvia has been worked in the Belgian Lorraine. It would have been reworked from the underlying Liassic iron ore ("minerai de fer métis").

Gossans of sulphide lodes

The lead and zinc lodes were very often accompanied by pyrite or/and marcasite. In some deposits the sulphides of iron were even predominant (e.g. Vedrin, Rocheux-Oneux, Heure (Fig.2)). At Rocheux-Oneux, for example, the following production figures (tonne) may be noted for the period 1859-80, after which the mine was closed : calamine, 70 000 ; lead ore (including oxides), 32 000 ; pyrites, 220 000 ; and limonite, 132 500.

Iron oxide and sulphide productions are, however, very often mixed in the statistics. The oxidation of these sulphides has yielded many gossans with limonite (goethite, hydrohematite, lepidocrocite), calamine (hemimorphite, smithsonite, willemite) and cerussite. Even in the very weakly mineralized Tournai area (northern limb of the Namur synclinorium on the western side of the lead-zinc district) it has been shown that the small limonitic bodies (the so-called "amas") that occur there were inherited from small pyritic veins[13,19]. But it is on the basis of petrological and geochemical studies on drill-hole core from the pyritic vein of Heure that the relationships between the hypogene and supergene assemblages have been most clearly described. There a model for oxidation and hydrolysis of the primary ore mineral has been presented and an attempt has been made to establish a geochemical balance sheet[23].

In Belgium these gossans, which have been exploited from olden times, were intensively worked in the nineteenth century. Until 1870 they supplied the main part of the Belgian iron ore production. The average annual extraction exceeded 500 000 tonne between 1850 and 1865. Then it decreased quickly, yielding first place to the Famennian and Tournaisian oolitic hematites, and ceased altogether around 1890.

Karstic deposits

Karstic iron ore deposits are well known in the Grand Duchy of Luxembourg. They are made up of brown to black iron concretions, mixed with a kind of laterite (the so-called "bolus"), which fill up karstic cavities in the Bajocian limestone. Such deposits also exist in Belgium in the limestone of Longwy southwest of Ruette (Fig. 4). As the ore was of excellent quality and the orebody easy to exploit, the deposit was quickly exhausted. These ore deposits would have been emplaced in the Oligocene in two stages : first, solution of the limestones and marls of the Upper Jurassic and, eventually, of the Lower Cretaceous, giving a residual argillaceous material that would have undergone lateritization under dry and hot climatic conditions, followed by mobilization of the iron-bearing laterites and deposition in a concretionary form.[49,57]

On the other hand, some ferriferous bodies seem to have been trapped in palaeo-karstic structures (the so-called "Abannets") in the area of Nismes and Couvin[67] (Fig. 4). Limonite and Caenozoic sands fill up these karstic cavities, sometimes of large size (cavities 100 m in length and 50 m in width and depth are reported). They have been worked in Devonian limestones. Delmer[28] mentioned that a lode is very often found at the very bottom of these "abannets".

MANGANESE DEPOSITS[2,8,11,53]

Belgian manganiferous occurrences are all located on the southern and south-western limbs of the Cambro-Silurian Massif of Stavelot (Fig. 4). They are of small size, the only manganese ore deposit of any extent being located in the Lienne Valley, at Bierleux (Chevron) and Meuville (Rahier). This is a sedimentary ore deposit interbedded in Tremadocian (Salmian, Sm2) slaty schists and quartzites forming a syncline complicated by transverse folds and minor faults. Kramm[51] interpreted the high manganiferous content of the Salmian 2 as consequence of volcanic activity.

The orebody consists of two mineralized layers separated from each other by 30-55 m of barren sediments. In fact, each layer is made up of several interbedded mineralized and barren thin layers. The useful thickness of the lower layer reaches 0.70 m. The upper layer is very lenticular and limited in extent (useful thickness, up to 1.10m).

The ore is a ferromanganiferous arenite with quartz, hematite, rhodochrosite, kutnahorite, spessartine, siderite, pyrolusite, chlorite and muscovite. The grades (%) are distributed as follows :

	Mn	Fe	P
Upper layer	7-16	17-26	0.23
Lower layer	9-12	24-25	0.27

The orebody was discovered in 1845 and exploited periodically between 1856 and 1934. Total production amounted to 180 000 tonne of ore, underground workings reaching a depth of 116 m.

In the same area there are similar orebodies of lesser extent (not worked at Werbomont, but worked at Lierneux and Arbrefontaine). Also present are secondary enrichments (nodules, lenses, crustifications, etc..) in altered schists, which have been worked at Bihain and Malempré.

Finally, mention should also be made of the famous "coticule" beds in the area of Bihain, Salmchâteau (Vielsalm) and Recht. Coticule is chiefly made up of microscopic garnets (spessartine) and contains 28 % MnO and 4.5 % FeO. Exploited for centuries, not for its manganese content but as stone to sharpen razors (whetstone), it has been exported throughout the world. Bastin' reported that the coticule from Vielsalm was known in Rome from very early times. Coticule is a metamorphic rock for which Kramm[51] considered a volcano-clastic sediment the primary source material.

PHOSPHATE DEPOSITS[10,58]

Belgian phosphatic deposits are chiefly linked to Cretaceous formations. They are distributed in two areas - the Hainaut to the west and the Hesbaye to the east (Figs 1 and 4).

In the Hainaut area the richest phosphatic formation is the Ciply chalk - a lenticular formation of Maastrichtian age that contains numerous disseminated phosphatic granules, pebbles and fossils remnants. The thickness of this phosphatic chalk increases with the subsidence of the Cretaceous basin of Mons. Its maximum thickness is 58 m, where the base of the Ciply chalk is at a depth of 150 m. Grades vary greatly (average P_2O_5 composition, 8-10 % ; between extremes of 5 and 16 %). Close to the outcrop of the Ciply chalk phosphate with P_2O_5 grades as high as 65 % was naturally concentrated in solution pockets. The Ciply chalk was exploited in the Ciply and Baudour areas from 1874 until the second world war, after which mining activities declined continuously. Total production of crude ore amounted to about 14 000 000 tonne.

In the Hesbaye area the phosphatic deposits are residual accumulations formed by solution of the Maastrichtian chalk. The phosphatic formation is made up of two to five layers, each around 10 cm in thickness, alternating with barren layers. The ore consists of granules, nodules and fossil remains crowded together in an earthy sandy-clayey groundmass. The deposits were chiefly exploited around 1900. Total production of crude ore amounted to about 4 000 000 tonne.

COPPER DEPOSITS

The main copper occurrences are indicated in Fig. 4. Copper has been exploited on a very small scale (preliminary exploration) at Rouveroy. There malachite and azurite fill fissures and sedimentary partings of the Burnot Formation (Lower Devonian) made up of shaly sandstones and conglomerates with predominant red colours. Production dates back to the nineteenth century and is estimated at about 5 000 tonne of copper. Oxidized copper minerals are also encountered in the Burnot Formation throughout Belgian territory, but only in very low amounts.

At Salmchâteau (Vielsalm) and Lierneux exploratory work was undertaken on small mineral occurences with chalcopyrite, bornite and oxidized copper minerals that fill quartz-bearing fissures cutting Tremadocian schists.

Except for occurrences of academic interest, no economic copper mineralization is associated with the lead, zinc, barite and fluorite ore deposits hosted in the Devono-Dinantian limestones. Dolembreux is an exception : this very small occurrence is hosted in Givetian limestones. Its production has been negligible.

No magmatic rock has ever been mined in Belgium for its mineral content, but special interest has been aroused by an igneous intrusion (the composition of which varies from monzodiorite to tonalite) located in the Hautes Fagnes area (Fig. 1) along the La Helle River at place named "Herzogenhügel". This sill-like intrusion and the associated stockwork of quartz veins carry chalcopyrite and molybdenite. According to Van Wambeke[72] and Weis and co-workers[74] the mineralization is of the porphyry copper type. A drilling programme in 1976-77 by the Union Minière Company indicated 20 000 000 tonne of provern reserves. Cu and Mo grades vary from place to place, but a general trend is to higher grades close to the contacts of the sill where quartz veins are much more abundant.

Analysis of this intrusion has given an average of 0.17 % Cu (extremes 0.01-0.45 %) and 0.02 % Mo (extremes 0.001-0.097 %).

The other copper mineral occurences, though abundant (see Mélon and co-workers[59]), have only a mineralogical interest.

GOLD DEPOSITS[7,33,34,43,48,73]

According to Bastin[7], alluvial gold exploitation in Belgium dates back to Celtic or Gallo-Roman times. He put forward the hypothesis that the gold that Caesar brought back to Rome came partly from Gaul. Some workings were still operating during the nineteenth century in the high Amblève River area.

Gold has been found around the Massifs of Stavelot and Serpont and north of the Rocroi Massif, where Cambrian, Silurian and Ordovician formations outcrop (Fig. 1). In general, it was found in ancient colluvia and alluvia that fill the bottom of the valleys and, occasionally, in recent alluvia. In most cases these gold occurrences are spread over underlying Gedinnian rocks. This observation led de Rauw[33] to put two questions on the source of the gold : Does the gold come from sedimentary formations or from crosscutting veins ? - If the gold is sedimentary, are the host rocks of pre-Devonian or of Gedinnian age ?

The discovery by Lepersonne[54] of gold lamellae in a quartz vein at Bovigny partly answers the first question. But Hanssen and Viaene[48], after a study of the morphology of the alluvial gold grains of the southern and southeastern margins of the Stavelot Massif, as well as their silver content, concluded that event if the gold originated initially from veins, it was incorporated in the Gedinnian and Siegenian sediments as a detrital mineral. Indeed, the high roundness index of some gold particles and their low silver content indicate, on the one hand, a transportation of several tens of kilometres and, on the other, a leaching compatible with a long transport.

Again, in the case of gold, the notions of inheritance and permanency from Cambrian to Holocene periods are well illustrated around the Caledonian Massifs.

KAOLIN DEPOSITS[17,39,45,69]

Kaolin (china clay) deposits are classified into two categories on the basis of their geological features and their geographical location (Fig. 4). Both types of deposit provide very modest supplies of ore.

Weathering deposits

These have arisen from the weathering of arkoses, feldspathic sandstones and slaty schists of Palaeozoic age during the peneplenation of the Ardenne Massif at the end of the Caenozoic. At Malvoisin drilling has shown that weathering effects extended down to at least 35 m. All kaolin deposits of industrial interest are located in the Ardenne, in a location of wet plateaus, within an elongated band 20 km long from Haut-Fays to Libin. All of the deposits of this type are inherited from Gedinnian rocks. Water problems usually limit the depth of exploitation to around 20 m. Small occurrences are also located along a more southerly band 40 km long from Louette-St-Pierre to Bras and Libramont, and including the Cambrian of the Serpont Massif.

Sedimentary deposits

These are associated with argillaceous sands or fine-grained sands that fill karstic holes in Dinantian limestones of the Condroz area. They are hosted in a local marine formation, of Upper Oligocene or Lower Miocene age, preserved from further erosion in karstic cavities. The kaolinite content decreases from the botton to the top of the deposits whereas illite, smectite and various interstratified clay minerals increase. The argillaceous-sandy sediments that overlie these kaolin deposits are sometimes intercalated with lignite layers that testify to the lacustrine conditions prevalent at the end of infilling of the karstic depressions. The most representative kaolin deposit of this type is the Oret deposit.

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IN DE HERFST 1987, ZAL DE BELGISCHE VERENIGING VOOR GEOLOGIE DE HONDERSTE VERJAARDAG VAN HAAR OPRICHTING VIEREN.
TEN EINDE ENKELE MANIFESTATIES TE KUNNEN HOUDEN, DOET HET COMITE EEN OPROEP AAN HAAR LEDEN EN SYMPATHISANTEN OM EEN FINANCIËLE BIJDRAGE TE STORTEN OP HET REKENINGNUMMER : 000-0145219-10 (VERMELDING : EEUWFEEST).

EN AUTOMNE 1987, LA SOCIETE BELGE DE GEOLOGIE FETERA LE CENTIEME ANNIVERSAIRE DE SA CREATION.
AFIN DE POUVOIR ORGANISER DES MANIFESTATIONS DIGNES DE CET EVENEMENT, LE COMITE FAIT APPEL A LA GENEROSITE DE SES MEMBRES ET DE SES SYMPATHISANTS EN LEUR SIGNALANT SON NUMERO DE COMPTE : 000-0145219-10 (MENTION : CENTENAIRE).

COMPTE RENDU

JOURNEE SUR LE GRANITE - Orléans-la-Source, 26 juin 1984 organisée par le Bureau de Recherches Géologiques et Minières, les Laboratoires de l'Ecole Polytechnique et de l'Ecole Nationale Supérieure des Mines de Paris. Communications. Documents du B.R.G.M. n° 84.

Depuis une dizaine d'années déjà de nombreuses et importantes études appliquées au Granite ont été réalisées à la demande de l'IPSN et plus récemment de l'ANDRA dans le cadre de leurs programmes de recherche sur la gestion et le stockage des déchets radioactifs. Ces travaux ont conduit à des résultats techniques et scientifiques de grand intérêt et il est apparu opportun d'en faire part à la communauté scientifique française.

Le BRGM, l'Ecole des Mines de Paris et l'Ecole Polytechnique qui ont assuré une part de ces activités pour le compte du CEA ont organisé après la "Journée sur le Sel" qui s'était tenue le 1er mars 1984 à l'Ecole Polytechnique, une journée spécialement consacrée au Granite. Cette manifestation n'avait pas pour but de présenter tous les travaux réalisés dans ce domaine par ces trois organismes ou d'autres, une seule journée n'aurait pas suffi, même en se limitant aux plus récents et aux plus saillants de ces travaux. Cependant les principaux thèmes ont été abordés (à la seule exception des études sur les interactions physico-chimiques entre les radionucléides et le milieu granitique). Et l'occasion a ainsi été donnée de préciser, pour chacun d'eux, l'état actuel des connaissances.

Le document rassemble les textes des exposés de cette "Journée sur le Granite".

(doc. B.R.G.M. n° 84)

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