D. I2.1.1. Site specific report summarizing available historical data on Pompey site (FR)

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P. Kessouri ; J.C. Gourry

BRGM

Final Version

SUMMARY

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3 INTRODUCTION

Pompey has been chosen as one of the three test sites for REGENERATIS methodology. It is a former tailing pond. The pilot site will allow testing the methodologies developed within WPT1 and WPT2 on a site that was already remediated. EPFGE (Etablissement Public Foncier de Grand Est, Public Real-Estate Company of Grand Est region) is the owner and will retain ownership of Pompey site after the project end.

The site is chosen for two main reasons: (1) it hosted various activities for iron based alloys production; (2) it was just rehabilitated on surface, and historic documentation and investigations are done with respect of the French legislation and threshold values. The planned works on site for sampling and taking material, represent a good opportunity to build REGENERATIS methodology and compare with classic remediation methods. Site works will provide access to material to perform lab trials and also allow on-site measurements, including innovative techniques such as geophysical methods.

This site-specific report is intended to provide specific data linked to Pompey site's past industrial activities including: (1) the type of ore; (2) the processes used for the products obtained (e.g. annual quantities, description and efficiency of the process, recycling rate) (if available); (3) the geographical information of the ore; (4) the ore-products and by-products; (5) the former inventories (if available).

4 GEOGRAPHICAL, GEOLOGICAL AND HYDROLOGICAL SITUATION OF POMPEY SITE

4.1 GEOGRAPHICAL SITUATION

The Pompey site is a former tailing pond from the iron and steel complex of Pompey-Frouard-Custines, located 10 km North from Nancy. The steel complex was active from 1870 to 1986. The site was converted in the 90's to host a business park in activity today.

Located to the southwest of the island of Ban-la-Dame, at the confluence of the Moselle and the canalized Meurthe rivers, the tailing pond covers 2.6 ha. It is bounded to the west by a dike and bordered by a road; while its northern and eastern limits are materialized by the fence of the manufacturing paper plant, which settled in the business park. The southern limit of the basin is less clear and present a concrete floor area.

Over time, a forest ecosystem developed on the former tailing pond. The dike delimiting the site was planted with a curtain of black locust trees in 1997. The rest of the pond gradually got covered with diversified deciduous vegetation, more or less dense depending on the area. A floristic inventory, carried out in 2004, lists around a hundred species, including 18 woody species and around 70 herbaceous. The distribution of the trees forms small clearings, hosting different species from one clearing to the other.

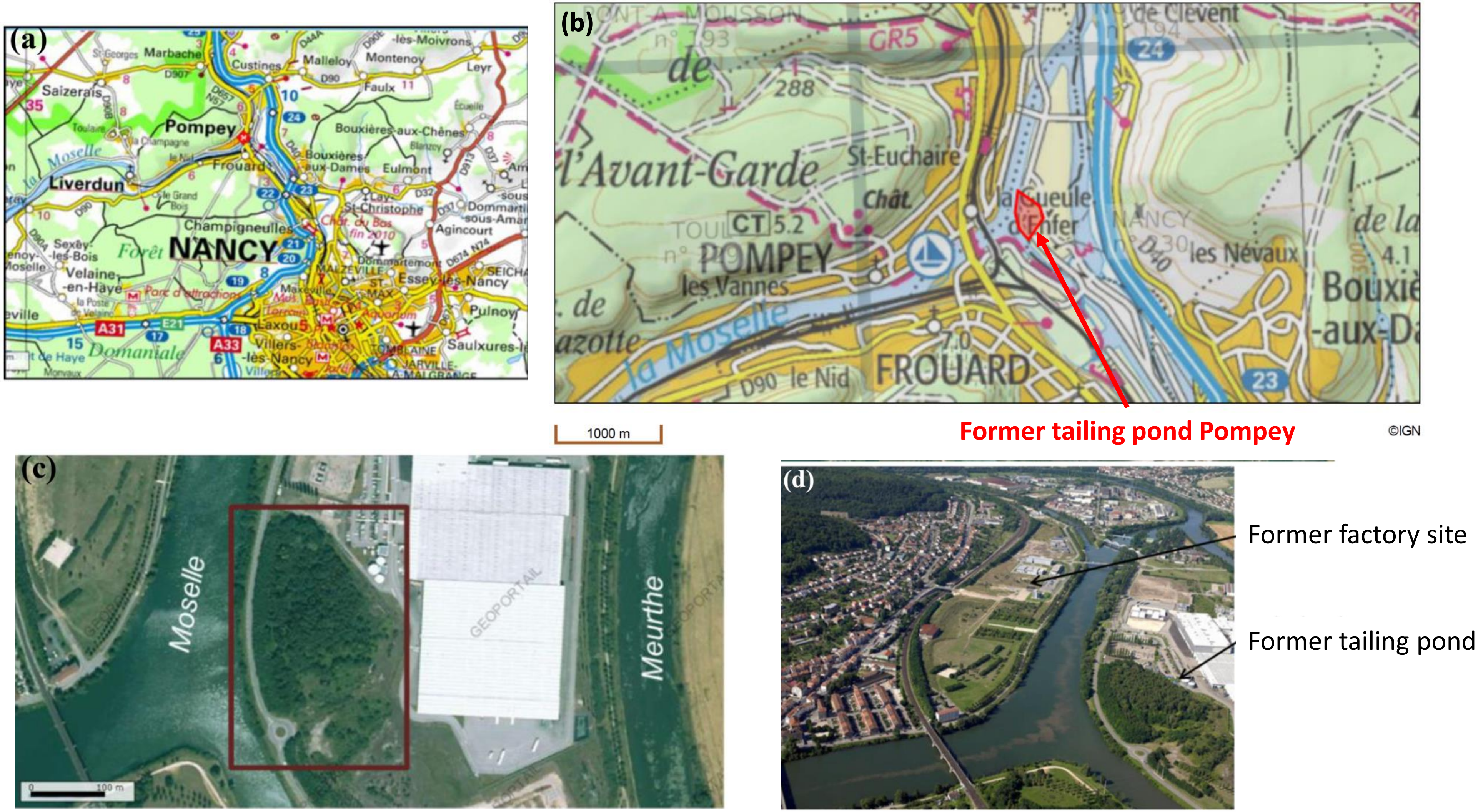


Figure 1: Localization of Pompey former tailing pond on (a and b) geographical maps and (c and d) aerial images (from Huot phD thesis, 2013 and Infoterre, 2020).

4.2 GEOLOGICAL AND HYDROLOGICAL SITUATIONS

4.2.1 Geological situation

The geological substratum consists of the Lias marl formations (at 181 m NGF), which are covered by alluvium from the two rivers, composed of coarse siliceous materials (sands, gravel and pebbles) at the base over 3 to 6 m surmounted by finer materials (sands, silts and clays) on 1 to 3 m. These alluvial formations were locally exploited and backfilled with waste rock and iron and steel by-products. The depth of the deposits in the basin is estimated at around ten meters.

4.2.2 Hydrological situation

The waters of the alluvial table would circulate from the channeled Moselle towards the Meurthe, whose level is lower. The piezometric levels measured in 2002 are 187.5 m NGF upstream (South-West of the island) and 184 m downstream (East of the island), the basin surface being 195 m NGF (ANTEA, 2002).

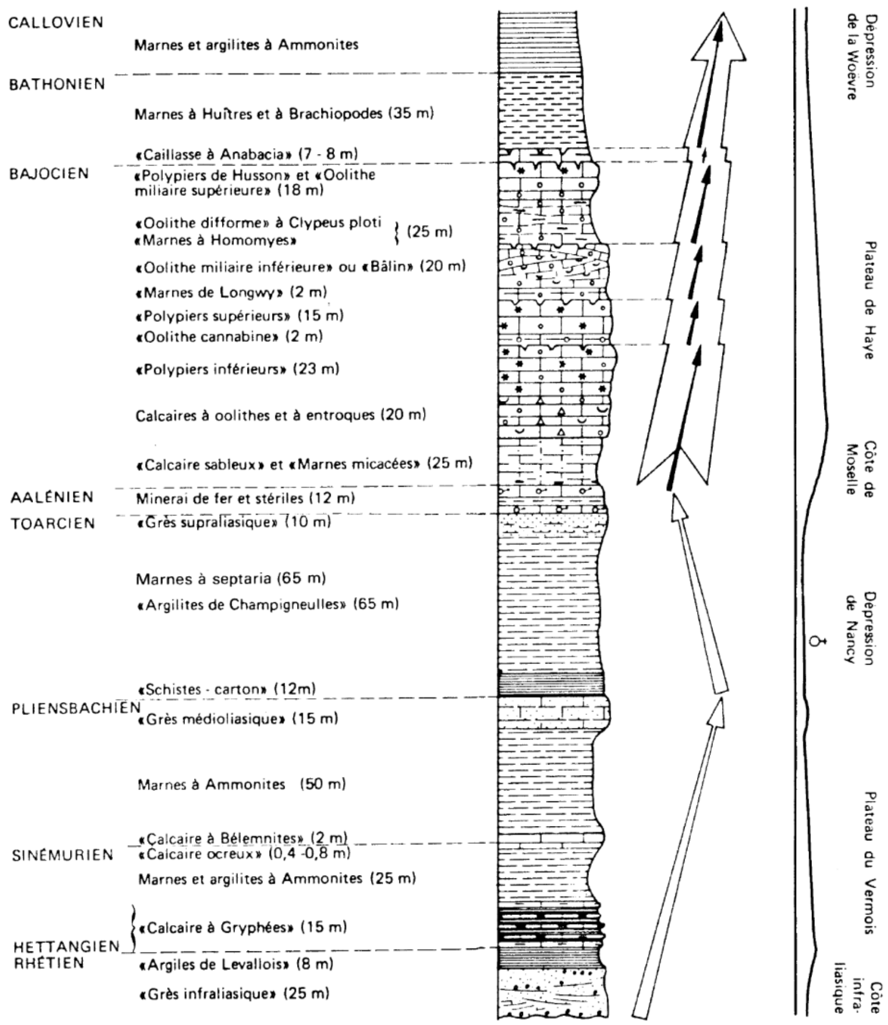
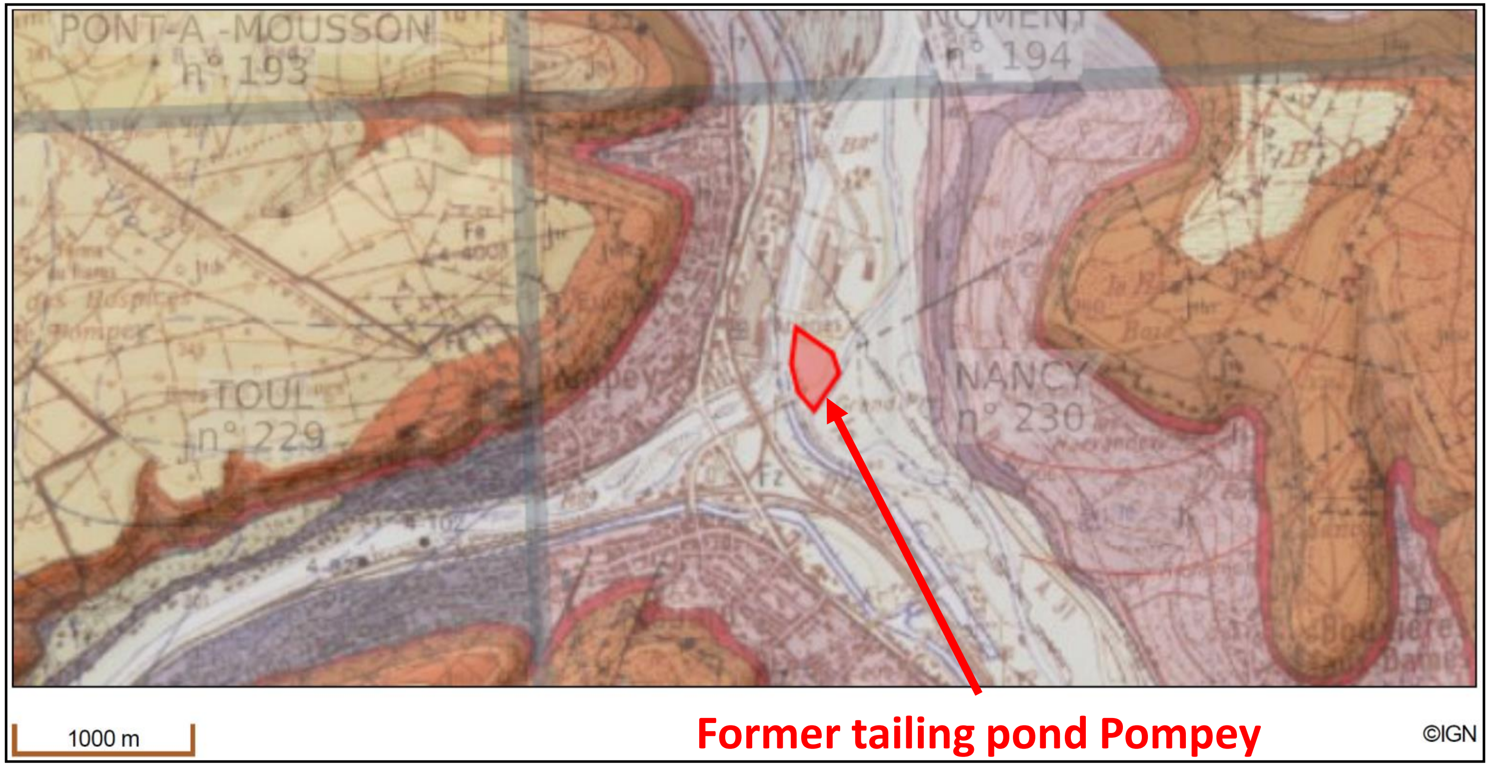


Fig. 3 - Le Lias et le Dogger de Lorraine centrale : modalités de la transgression jurassique

(Extrait du Guide géologique régional : Lorraine - Champagne (Masson))

Figure 2: Stratigraphic column of Lias and Dogger formations in central Lorraine region (from Geological map of Nancy 1/50 000, BRGM).



Feuille N°230 - NANCY (Notice) (Commander la carte)

B(3.1)
Couvertures sur "terra fusca" (épaisseur supérieure à 0,80 m)

Fz
Alluvions des fonds de vallées : matériaux fins, argiles, limons, sables reposant ou non sur des matériaux grossiers, sables, graviers, galets

j1c
Jurassique : dogger-bajocien : "bâlin" : calcaires blancs finement oolithiques à débris coquillers, 23 mètres. "Marnes de Longwy" : calcaires argileux à pseudo-oolithes difformes, 2 à 5 mètres

j1b2
Jurassique Dogger Bajocien : "polypiers supérieurs" : calcaires récifaux variés, 13 mètres environ

j1b1
Jurassique Dogger Bajocien : "polypiers inférieurs" : calcaires récifaux variés

j1a
Jurassique Dogger Bajocien : "oolithe blanche" : calcaire finement oolithique, "roche rouge" : calcaire à entroques, "calcaires sableux" : marno-calcaire gréseux, "marnes micacées" : marne et argile à intercalations de calcaire à entroques ou gréseux

l9
Jurassique Dogger Aalénien : minerai de fer, "minette" : "calcaires" oolithiques ferrugineux, 8 à 13 mètres

l8
Jurassique Lias Toarcien : "grès supraliasiques" : grès argileux micacés (5 à 10 mètres) "marnes gris-bleu micacées" à sapteria (75 à 90 mètres)

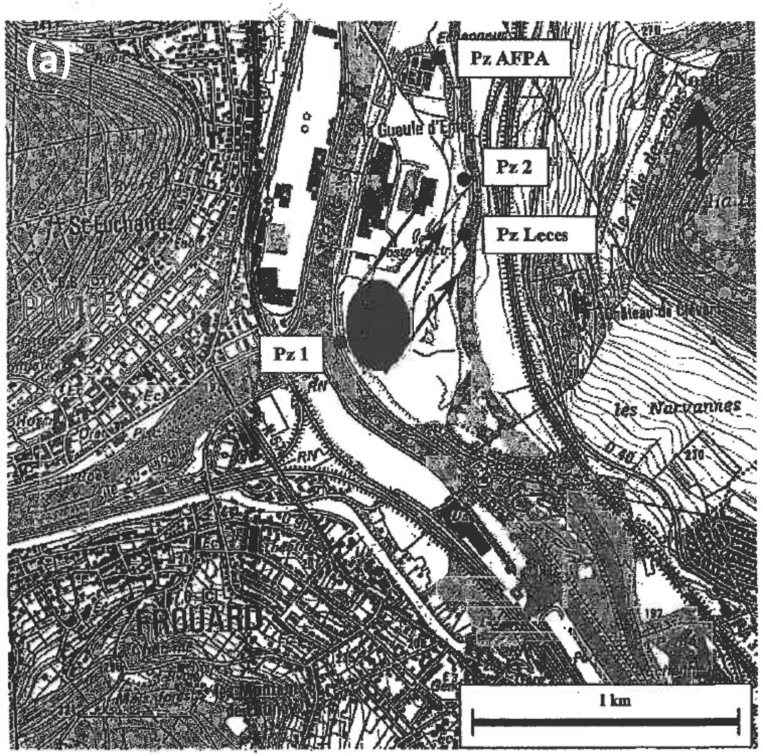
l7
Jurassique Lias Toarcien : "schistes carton" : calcaires argileux à la base et argile calcaires bitumineuses ensuite, 12 à 18 mètres

l6b
Jurassique Lias Pliensbachien ("charmouthien") Domérien : "grès médioliasiques" : marnes calcaires et gréseuses, 8 à 15 mètres

l6a
Jurassique Lias Pliensbachien ("charmouthien") Domérien : "marnes à Amalthées" : marnes à Amaltheus margaritatus, 85 à 90 mètres

hydro
Hydro

Figure 3: Geological map of the Pompey area (from infoterre, 2020).



(b)	Cote estimée sol (m NGF)	Hauteur Tube/sol (m)	Cote sommet Tube (m NGF)	Niveau Eau/tube (m)	Cote eau (m NGF)
Pz1 (amont)	191,2	0	191,2	3,69	187,51
Pz2 (aval)	187,9	0,53	187,37	3,47	183,9
PzAFPA (aval)	187,4	0,7	186,75	2,81	183,9

Figure 4: (a) Localization of piezometers around the Pompey site; (b) water levels measured in April 2002 by Antea (from Antea, 2004)

5 HISTORICAL INDUSTRIAL USE OF THE POMPEY SITE

5.1 HISTORY OF POMPEY-FROUARD-CUSTINES IRON AND STEEL COMPLEX

The iron and steel complex was in use from 1872 to 1986. It is well known for its production of the 7 000 tons of metal needed to build the Eiffel tower. It is also renowned for producing cast iron and special steels. The history of the complex is detailed in the following table.

Tableau 1: History of the Pompey-Frouard-Custines iron and steel complex

Starting dates	*Events*
1872	*Moselle becomes part of Germany* Installation of the Ars-sur-Moselle factory in Pompey by M. Dupond and M. Dreyfus, near the Moselle river and the train track
1874-1875	Ignition of the first 2 blast furnaces
1888	Building of the Martin steel mill
1895	Building of the Thomas steel mill, allowing the use of phosphorous iron-ore from Lorraine
1900-1906	Ignition of 2 new blast furnaces
1918 **1922**	*End of 1st world war – Moselle is part of France again* Building of the second Martin steel mill, that can produce special cast iron, especially ferromanganese (ferro-alloy rich in manganese)
1932	Creation of a research and development unit to produce various special steels
1939 *1940*	Building of an electrical oven allowing production of special steels *Moselle becomes part of Germany (the IIIrd Reich)*
1945 **1963**	*End of 2nd world war – Moselle is part of France again* Installation of an oxygen steel mill
end of 1960's	**Steel industry crisis**
1973	No more supply of iron-ore from Lorraine Import of foreign iron-ores
1980's	Plant installations are progressively closing
1986	Stop of the last blast furnace EPFL (Etablissement Publique Foncier Lorrain, now called EPFGE) buys the plant and start rehabilitating the different locations, that are now hosting more than 150 companies

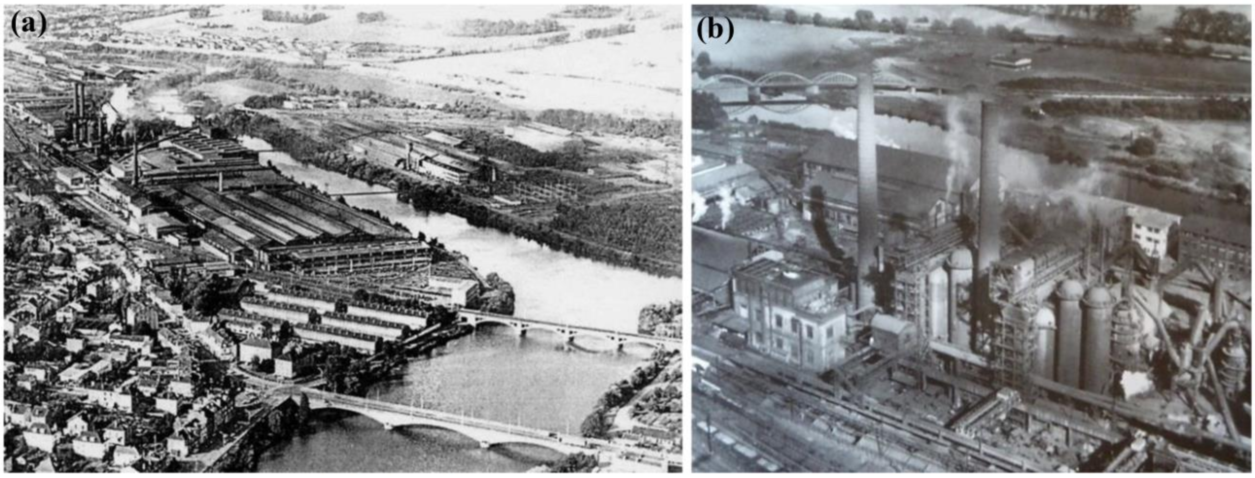


Figure 5: Aerial views of (a) the steel plant in 1963 and (b) the blast furnaces in the 50's (from Gerber, 2005)

5.2 HISTORY OF STEEL SUPPLY

The blast furnace charge was composed of: (1) iron ores; (2) manganese ores in the case of ferromanganese production; (3) agglomerates; (4) coke as fuel; (5) "fondant" (smelting) added in to improve the melting of gangue; (6) ashes; and possibly other unidentified additives.

5.2.1 Iron-ore

The Pompey plant was supplied with iron ore from Lorraine until 1972.

The iron basin of Lorraine, formed in the Jurassic geological period (Aalenian), extends from Belgium to the South of Nancy. A discontinuity separates the basin into two parts: (1) the Briey basin to the North; and (2) the Nancy basin to the South, which is less important. Of sedimentary origin, the deposit has about ten layers of ore, from one to a few meters thick, alternating with marl beds over more than 60 m in the Briey basin and over 12 m only in the Nancy basin (Rideau, 1956; Rogé, 1982; Atelier Mémoire Ouvrière).

Several concessions in the Nancy basin supplied the Pompey factory (Geindre, 1966; Berrar, 2011):

- from 1873 to 1932: Ludres concession
- from 1896 to ? : Giraumont concession
- from 1900 to 1938: Faulx concession
- from 1910 to ? : La Mourière concession
- from 1957 to 1973: Saizerais concession

Lorraine iron-ore is characterized by its relatively low iron (Fe) contents (30-35%), hence its denomination of "minette" and its high phosphorous (P) contents, which implied the development of adapted steel processes (Thomas process) so that it can be used. It comes under oolith-shaped, ovoid grains of 200 to 500 µm made up of fine successive concretions of goethite around a core composed of iron grain, oolith fragment, quartz grain, shell fragment or test fragment. Inter-oolith cement is mainly composed of limestone and silica, their proportion varying according to the layers (Rideau, 1956; Rogé, 1982; Atelier Mémoire Ouvrière).

After 1972, the Pompey plant was supplied by iron-ores from Brazil, Australia and Mauritania that are richer in iron and hematite, and not phosphorous (Geindre, 1966)

5.2.2 Manganese-ore

The manufacture of ferromanganese (after 1922) requires the use of manganese-ores (40% and more) and iron-ores, in case the Mn-ore does not contain enough iron. The Mn-ores consumed by the French steel industry were imported from various countries (Russia, India, West Africa, Brazil, South Africa, Australia, Morocco) according to market trends international (Truffaut, 2004).

5.2.3 Agglomerates

Agglomerates are the material constituting the load of the blast furnace. The Pompey plant was not fully integrated and did not have an “agglomeration”, which is an installation that makes it possible to manufacture agglomerates from mineral fines and various steel by-products (rich in iron) by mixing and by cooking. However, in 1963, a charge preparation facility including a crushing-screening workshop and an agglomeration line was created in Saizerais (SNAP, 1963). Imported hematite ores were agglomerated there. Furthermore, ferrous materials to recycle (scale, LD steelmaking slag, dust, foundry sand, blast furnace collection fines, ferromanganese), which are recovered at the plant, were also agglomerated there (IRSID, 1984).

5.2.4 Coke

The Pompey plant did not have a coking plant. The coke used came from the” Houillères du Lorraine Basin” (IRSID, 1984). Until the 1950s, the steel industry in Lorraine brought most of its coke from the Ruhr. Indeed methods for generating good quality steel coke from Lorraine coal were only developed in the 1950s

5.2.5 “Fondant” (Smelting)

During the manufacture of cast iron, the production of slag, which results from the melting of the ore gangue, requires a basicity index (CaO/SiO_2 ratio) of the ore gangue of 1.4. However, Lorraine iron ore has the advantage of having layers with gangue that is sometimes more made of limestone and sometimes more of silica. The mixture, in appropriate proportions, of these two types of ores generate a "self-melting melting bed", to which it is not necessary to add a “fondant” (Rogé, 1981).

On the other hand, for the manufacture of ferromanganese, limestone and magnesians “fondants” (limestone, dolomite), even barytes “fondants”, could be used to neutralize silica present in Mn ores and coke ashes. The use of “fondants” then limits the loss of Mn in the slag (Truffaut, 1989 and 2004). In particular, limestone “fondant” was added to the blast furnace during the manufacture of manganese cast iron.

5.3 History of Ban-la-Dame site inside Pompey iron and steel complex

In the first half of the 20th century, the island was occupied by a slag heap with several settling ponds delimited by dikes. A hydraulic pipe crossing the Moselle river brought the sludge produced at the plant across the river (West bank) (Figure 5).

The exact date of the shutdown of the studied basin is not known but several clues suggest that sludge dumping would have ceased in the 1950s. Observation of aerial photographs of the iron and steel complex taken since 1950 show that the basin does not appear to function in 1958, but does not allow to determine the exact date of its shutdown (Schwartz et al., 2001). This is in line with the program to modernize the plant and increase resources production. Indeed, starting in 1957, new facilities (rolling mills, heat treatments, etc.) are set up on the leveled slag heap of Ban-la-Dame island, which was connected to the factory by a bridge built between 1951 and 1953.

In addition, measures taken following pollution of the Moselle river by the spill of cyanides in December 1946, confirm the cessation of the basins on these dates. Indeed, it was diagnosed that the malfunction of the settling pond intended for the purification of gas washing water from the blast furnaces, and the discharge of potassium cyanide into the low-flow river (due to the frost), were at the origin of the pollution of the Moselle river of 12/21/1946; and the death of many fishes (Est Républicain from 28-29 / 12/1946 and 27-28 / 12/1947). Following this incident, a decree of the Nancy Court of Appeal concerning the discharge of water and sludge into the basins of decantation of the Pompey steelworks was taken on 07/28/1948. Moreover, a document from the technical director of the factory of 11/10/1975 testifies that this pollution had led the company to take measures concerning the purification of blast furnace gases and the de-cyanation of process water. In particular, dry gas purification has been generalized at the expense of wet purification in order to limit the volumes of polluted water and promote its treatment. The discharge of large quantities of sludge and polluted water in settling ponds located nearby the Meurthe river was also abandoned (ArcelorMittal archives - file 167/092 Moselle pollution). From the end of the 1980s, piezometers were installed to monitor water quality underground upstream and downstream of the slag heap.

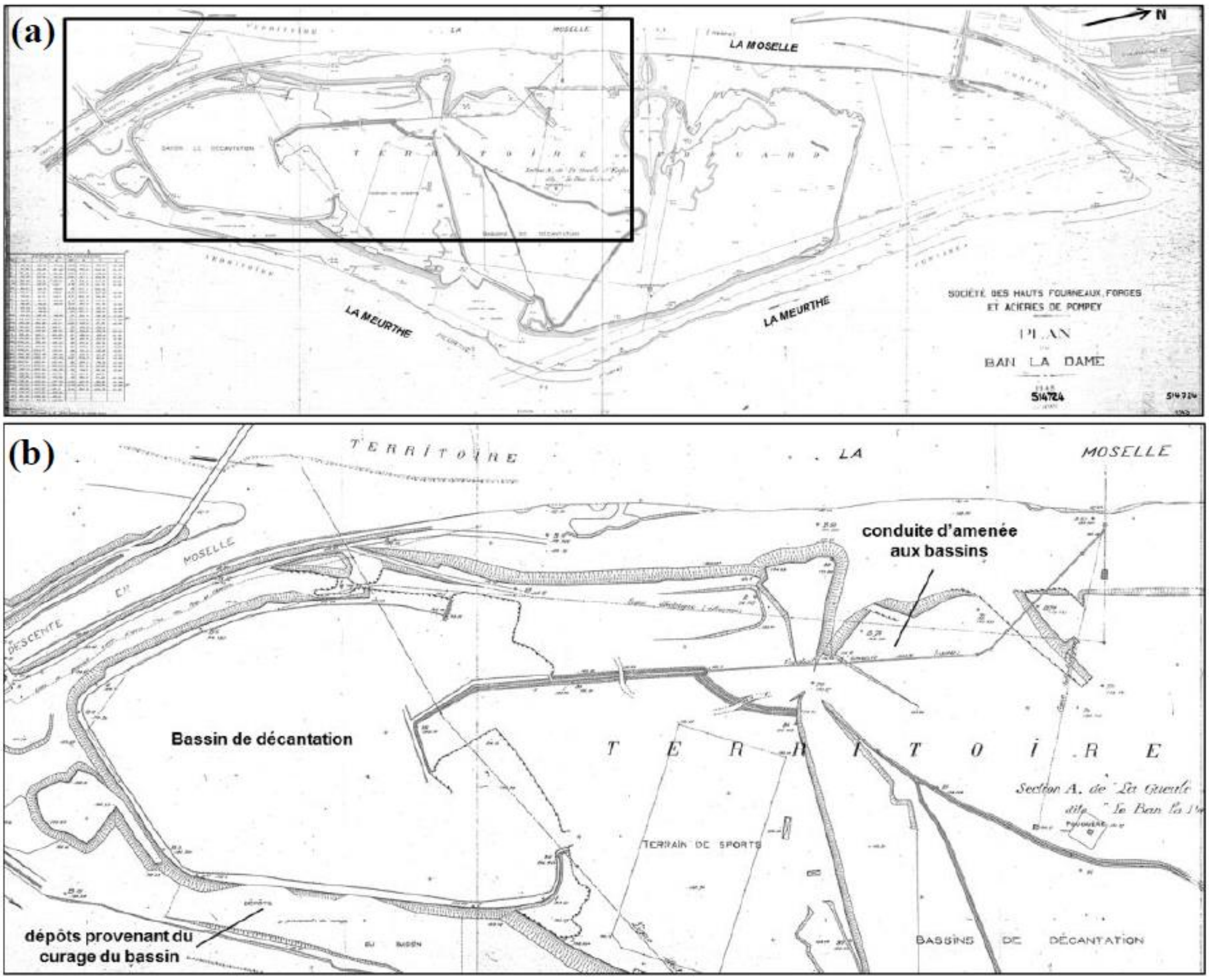


Figure 6: (a) 1943 Ban-la-Dame site plan showing the settling ponds and the pipe from the basins crossing the Moselle river (b) zoom in - scale 1/1 000 (SNAP, 1943 - Espace Archives ArcelorMittal (plan 514-724)).

6 ONGOING RESEARCH ACTIVITIES IN POMPEY

Since bought by EPFL, the Pompey field site is hosting various research activities developed mainly by the University of Nancy and the GISFI (Groupement d'Intérêt Scientifique sur les Friches Industrielles). A report written in 2014 (GISFI, 2014) mentioned the research activities that took place and the ones that were ongoing. They are all listed in the following table, associated to reference publications.

Tableau 2: Achieved research activities in Pompey

Type of research	Years	Description	Associated publications
Soil characterization	1990's-2004	Knowledge on industrial soils Creation of 1 pit with soil profil description (pH; texture; CEC; C, N, P, Fe and metal contents) → Alternation of layers composed of greyish materials with a schistose structure and blackish pasty materials, from steel-industry by-production decomposition; topped by a humus-rich topsoil	Florentin *et al.*, 1998 Schwartz *et al.*, 2001
Analysis of cyanide compounds	2004	The total cyanide contents vary according to the layers and can reach non-negligible contents. However, they are present in a very poorly mobile form in the soil.	Huot *et al.*, 2013b
Study of silica forms	2006	Study of the forms of silica in soils formed on steel-industry byproducts	Sauer et Burghardt, 2006
Study of biodiversity and metal transfers from the soil to plants and soil fauna	2004-2007	Study of soil surface horizons (agronomical parameters, metallic contents, microstructure and ultrastructure) → soil with high metallic concentration and good chemical fertility → accumulation of organic matter, potentially linked to soil toxicity (lower endogenous species) Study of biological activity and diversity (soil respiration, fauna and flora of soil) → high diversity in plant species in presence (more than 50 species); Study of metal transfer in plants and soil fauna → low transfer in metal concentration from soil to plants	Internship reports: - Muller, 2005 ; - Khalil, 2006 - Otterman, 2008 Cortet *et al.*, paper in preparation in 2014 (check if already published) Technical report of LSE, 2008

		(only 5/50 species with higher metal content) → low metal contamination in fauna	
Study of phytoextraction	2007	Study of soil depollution using plants: *Thlaspi caerulescens* (ability to store metals) fertilized by by-products of the food industry → low potential of phytoextraction using this process	Simon, 2007
Study of the formation, operation and evolution of Techno-soil developed on steel sludge	2009-2013	Understand the processes responsible in building the industrial soil (=techno-soil) → soil creation is equivalent to combining processes responsible for the creation of several different natural soils (e.g. volcanic soils, carbonate soils), that have similar components with the techno-soil (particles from steel industry by-products) Understand the techno-soil functioning → development of vegetation because : alkaline pH, high CEC, high specific surface, high water retention capacity that limit the access to toxic metals. Build hypotheses on its future development Creation of 2 lysimeters (2 m high, 1 m^2) extracted in Pompey and studied in Homécourt experimental station (GISFI)	phD thesis H. Huot (2013) Huot *et al.*, 2013a Huot et al., 2013b
Study of a forest ecosystem developed on a multicontaminated technosol	2011-2013	Litter decomposition experiment on a soil highly contaminated with Zn, Cd, and Pb. → higher decomposition speed for the litter with contaminated soil → no variation of decomposition rate between contaminated and natural litter, potentially linked with a richer macrofauna and bacterial diversity in contaminated soil	*Maunoury-Danger et al, in prep in 2014 (to be checked)* *or* *J.L.Morel et al, in prep in 2014 (to be checked)*

Tableau 3: Ongoing research activities in 2014 in Pompey

Type of research	Years	Description	Associated publications
Study of contaminated ecosystems	2012 - 2015	Development of functional bio-indicators allowing the diagnosis of contaminated soils by providing integrative and complementary information to that provided by traditional bio-indicators Study of litter decomposition as an indicator of contaminated soils functioning	phD thesis p. Lucisine (2012 – 2015)
Study on the use of deposits as resources, especially in terms of metal recovery	2012-2015	Steel-industry sludge deposited in tailing pond are rich in volatile components that concentrate in smoke passing through blast furnace, e.g. Pb, Mn or Zn Development of a hydrometallurgical process	phD thesis J. Mocellin

Ongoing annual field trips

- Annual field trip of students from SGE ENSAIA and IDD master ("Gestion intégrée des friches industrielles") with Christophe Schwartz and Geoffroy Séré (members of GISFI)

- Anual field trip of Master students from Université de Lorraine (« sciences du sol ») with Sylvie Dousset (GISFI member)

7 Pre-existing scientific data

7.1 Soil profile (< 2m depth)

A lot of the data on the Pompey site are extracted from the phD thesis Huot (2013). Very detailed physical and chemical analysis have been made on the first 2 m depth, corresponding to the "technosoil", in which the rhizosphere is growing.

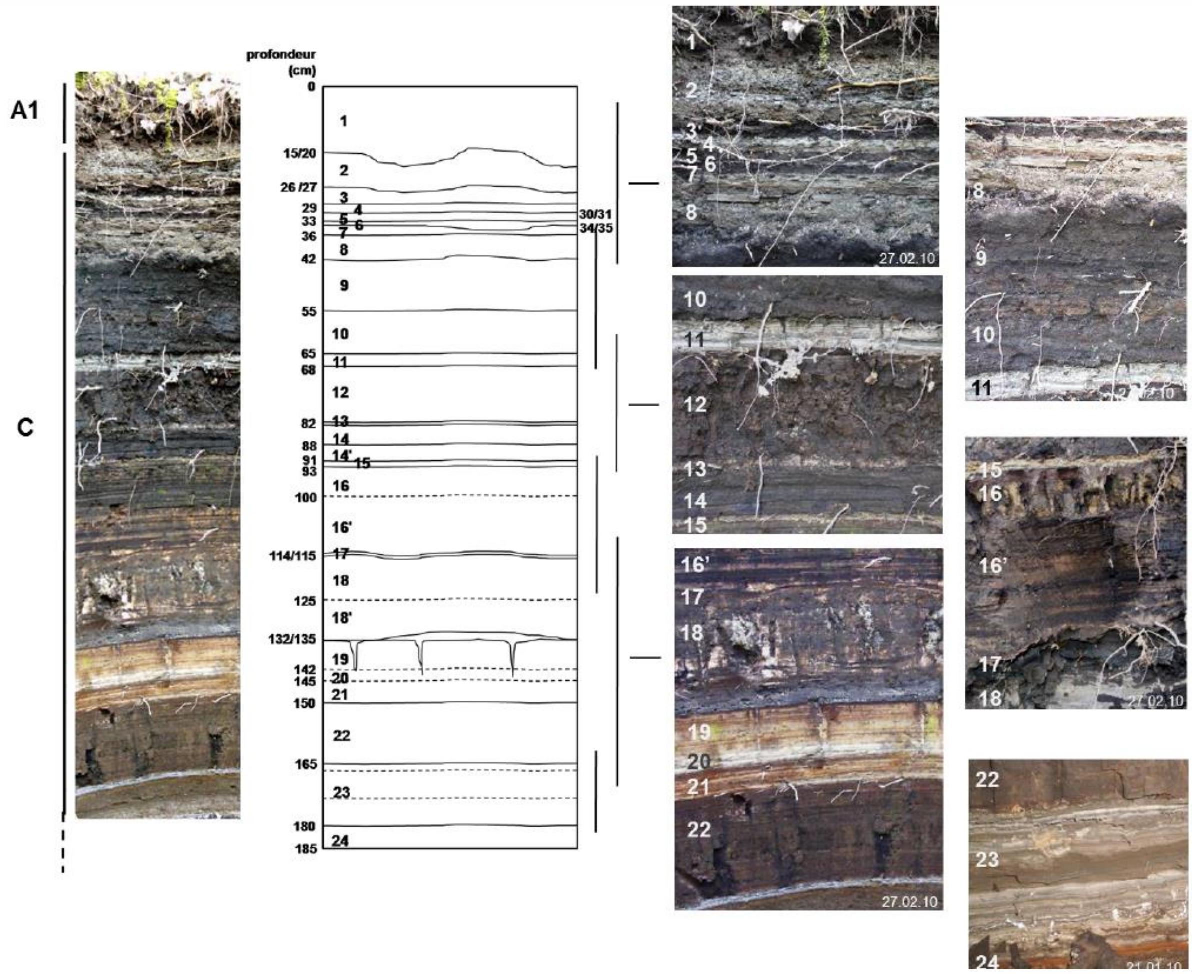


Figure 7: Analysis of soil profil realized in the digged pit. The soil is of A/C type. Identification of the various soil horizons: (1) horizon A1; (2) various layers of horizon C numbered (from Huot, 2013).

7.1.1 Soil profile physical characteristics

Tableau 4: Weight distribution of particle sizes in five fractions (<2 µm; 2-20 µm; 20-50 µm; 50-200 µm and 200-2000 µm) after destruction of organic matter and without decarbonation according to NF standard X 31-107 for 12 "Technosoil" layers (from Huot, 2013)

couche	profondeur cm	argiles < 2 µm % (m/m)	limons fins 2-20 µm % (m/m)	limons grossiers 20-50 µm % (m/m)	sables fins 50-200 µm % (m/m)	sables grossiers 200-2000 µm % (m/m)
1	0 - 18	19,1	20,2	23	33,9	3,8
2	18 - 26	34,6	21	18,6	18,7	7,1
9	42 - 55	22,8	40,8	16,8	10,8	8,8
11	65 - 68	34,2	34,7	6,5	4,2	20,4
12	68 - 82	33,3	23,4	35,4	4,8	3,1
14	82 - 91	32,7	45,1	12,4	8,4	1,4
16	93 - 100	34,8	30,7	16,9	16	1,6
18	112 - 134	34,5	30,3	15,9	14,4	4,9
19	135 - 150	42,8	37,6	12	7	0,6
22	150 - 165	26,5	35,3	21,5	9,6	7,1
23	165 - 180	27,9	35,1	21	10,7	5,3
24	> 180	27,5	50,6	12,5	6,8	2,6

Les fractions sont exprimées en % massique et la somme des cinq fractions est égale à 100 %.

Tableau 5: Dry bulk density (ρ_{as}), real density (ρ_d) and total porosity (ε) for 11 "Technosoil" layers (from Huot, 2013)

couche	profondeur cm	ρ_{as} $g.cm^{-3}$	ρ_d $g.cm^{-3}$	ε $cm^3.cm^{-3}$
1	5 - 10	0,61 ± 0,1	2,71 ± 0,2	0,78 ± 0,04
1/2	16 - 21	0,77 ± 0,1	2,94 ± 0,1	0,74 ± 0,03
9	45 - 50	0,31 ± 0,03	n.d.*	n.d.
11	65 - 70	0,32 ± 0,01	2,62 ± 0,05	0,88 ± 0,01
12	70 - 75	0,21 ± 0,01	2,78 ± 0,06	0,92 ± 0,004
14-14'	85 - 90	0,23 ± 0,005	2,66 ± 0,04	0,91 ± 0,001
16'	100 - 105	0,19 ± 0,01	2,85 ± 0,01	0,93 ± 0,002
18	120 - 125	0,28 ± 0,03	2,57 ± 0,03	0,89 ± 0,01
19	135 - 140	0,25 ± 0,004	2,48 ± 0,02	0,90 ± 0,002
22	155 - 160	0,26 ± 0,02	2,46 ± 0,02	0,89 ± 0,01
23	165 - 170	0,51 ± 0,005	2,67 ± 0,04	0,81 ± 0,002

** n.d. signifie « non déterminé »*

7.1.2 Soil profile water content

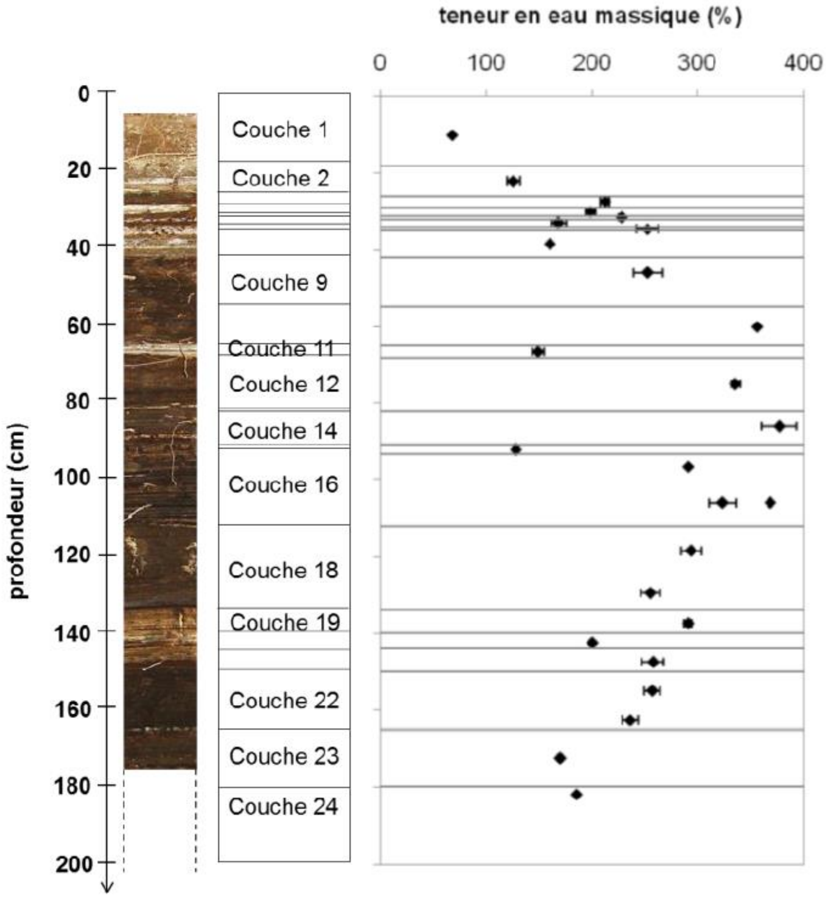


Figure 8: Soil massic water content measured for the 24 identified soil layers in the pit. Percentage of dry mass (measured in May 2010) (from Huot, 2013).

7.1.3 Soil profile mineralogy

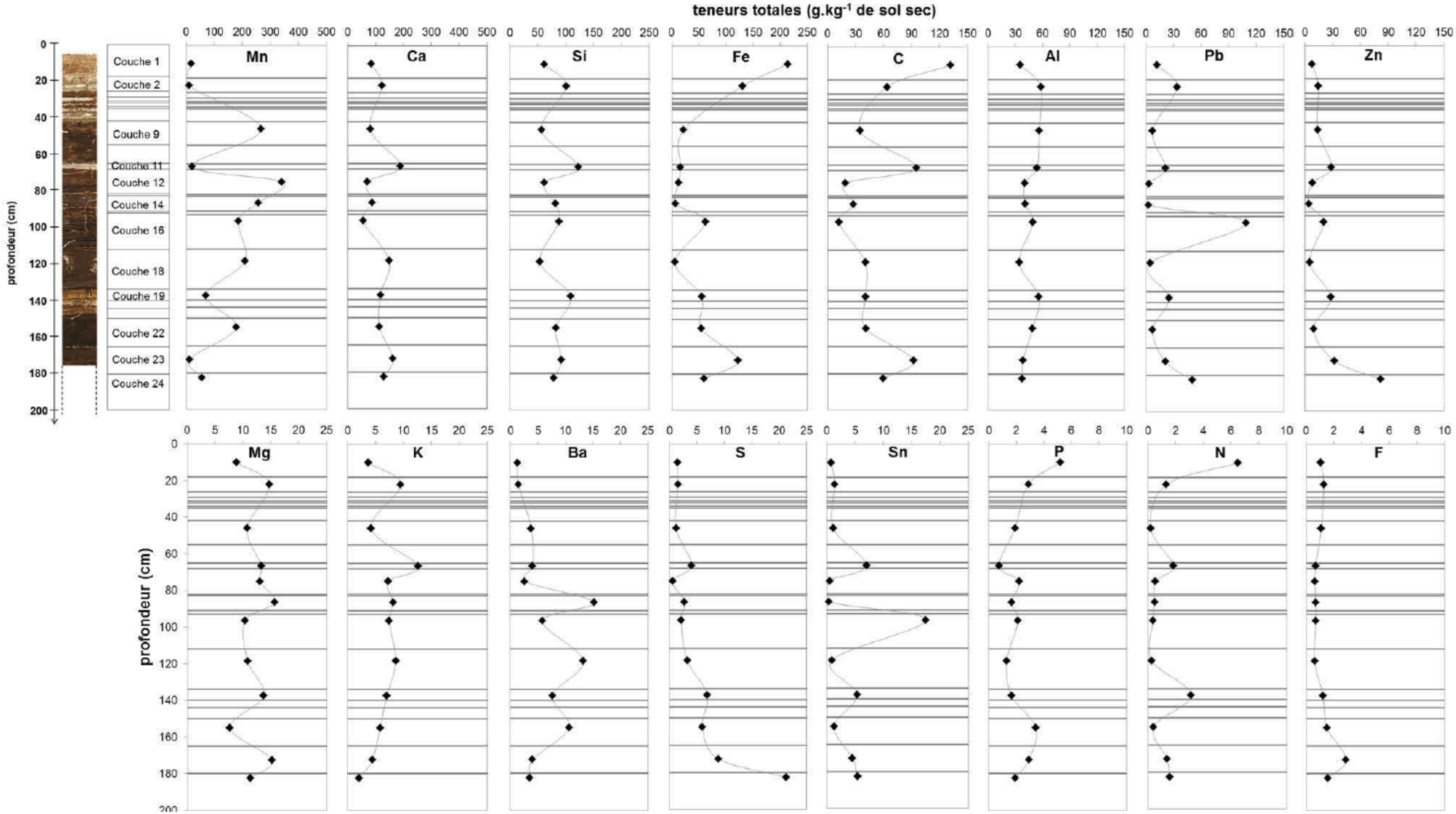


Figure 9: Distribution of the total content of major elements (elements with an average content greater than 1 g.kg^{-1} of dry soil) vs depth along the profile for 12 layers of "Technosoil" (from Huot, 2013)

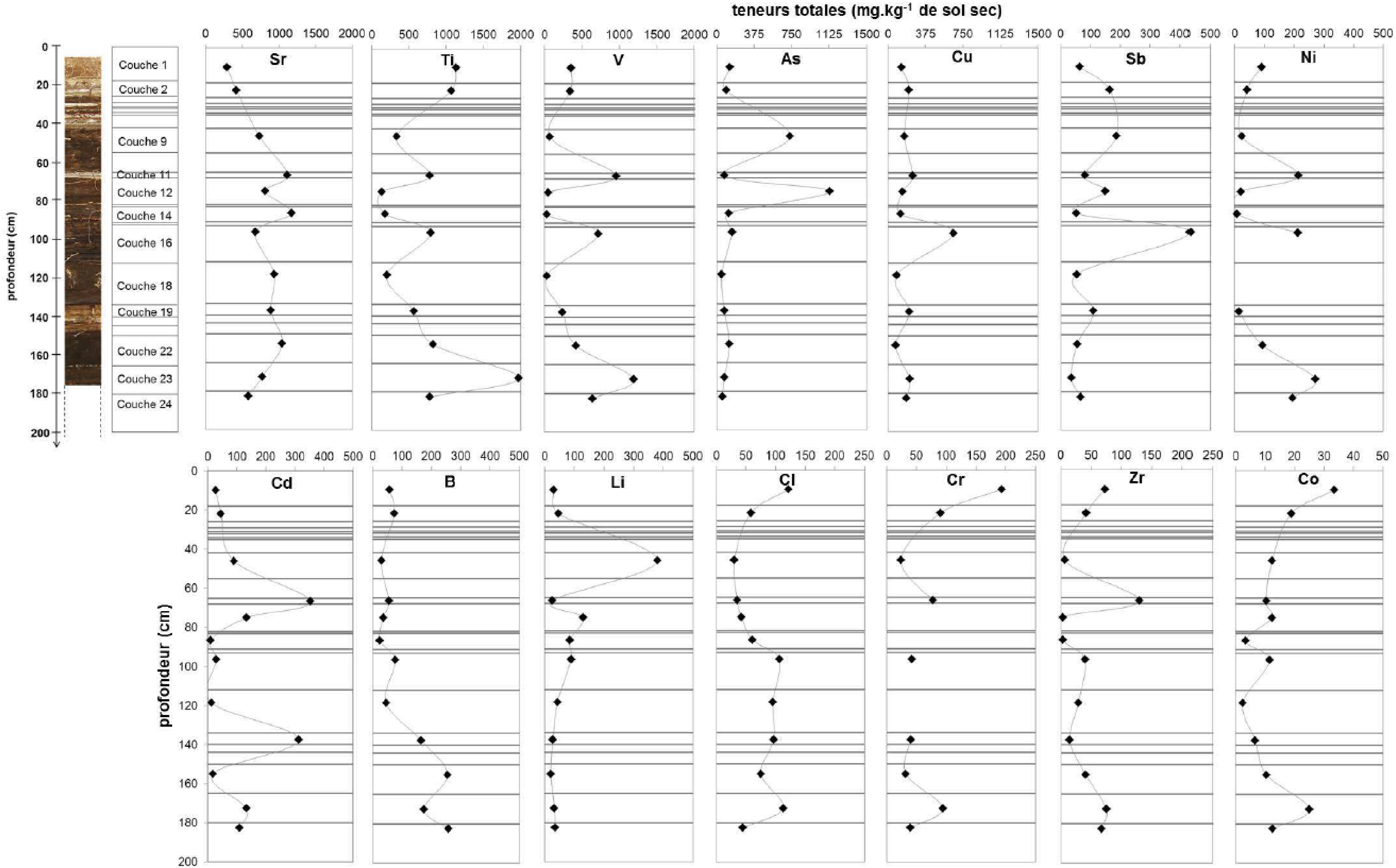


Figure 10: Distribution of the total content of trace elements (elements with an average content lower than 1 $g.kg^{-1}$ of dry soil) vs depth along the profile for 12 layers of "Technosoil" (from Huot, 2013)

Tableau 6: Mineralogical phases detected using a combination of laboratory experimentations (DRX, IR spectroscopy, Mossbauer spectroscopy, SEM-EDX and TEM-EDX, Tam and Mehra-Jackson extraction methods)

		aluminosilicates					(hydr)oxydes de Mn		(hydr)oxydes de Fe					carbonates		sulfates				autres phases			
couche	profondeur (cm)	produits allophaniques	verre silicaté	phyllosilicates/zéolites	silicates de Mn	silice - feldspaths	(hydr)oxydes de Mn non cristallisés	oxydes de Mn cristallisés	ferrihydrite	hématite	goethite	magnétite – spinelles	wüstite	calcite	carbonates ou hydroxydes de Pb	gypse	anhydrite	ettringite	barytine	Fe métallique	(hydr)oxyde de Ca	composés du Sn	cyanures
1	0 - 18	O	O	ox	o	x	o		X	X	X	x	o	oX	o					x	o		
2	18 - 26	O	O	ox			o		X	X	X			X	o					x	o		
9	42 - 55							x						X									
11	65 - 68	O	O		o		o	x						X							o	o	x
12	68 - 82	o	o				O	ox						oX							o		
14	82 - 91													X									
16	93 - 112	o	o				O							oX	o				o			o	
18	112 - 134							x						X				x					
19	135 - 150													X									x
22	150 - 165			x										X									
23	165 - 180	O	O	x		ox			X	X	X			oX		ox			o	x		o	x
24	> 180			x		x								X		x	x						x

O: phase fréquemment observée en MEB-EDXS et/ou MET-EDXS ; o : phase rarement observée en MEB-EDXS et/ou MET-EDXS ; X : phase majeure détectée en DRX, spectroscopie IR et/ou en spectroscopie Mössbauer ; x : phase mineure détectée en DRX, spectroscopie IR et/ou en spectroscopie Mössbauer ; ? : phase probable

Le tableau ne présente que la liste non exhaustive des phases minérales ayant été détectées par les différentes techniques analytiques employées. Ainsi, l'absence d'une phase dans le tableau ne signifie pas forcément son absence dans la couche correspondante, d'autant plus que certaines couches (1, 2, 11, 12, 16 et 23) ont été analysées de manière plus fine que les autres.

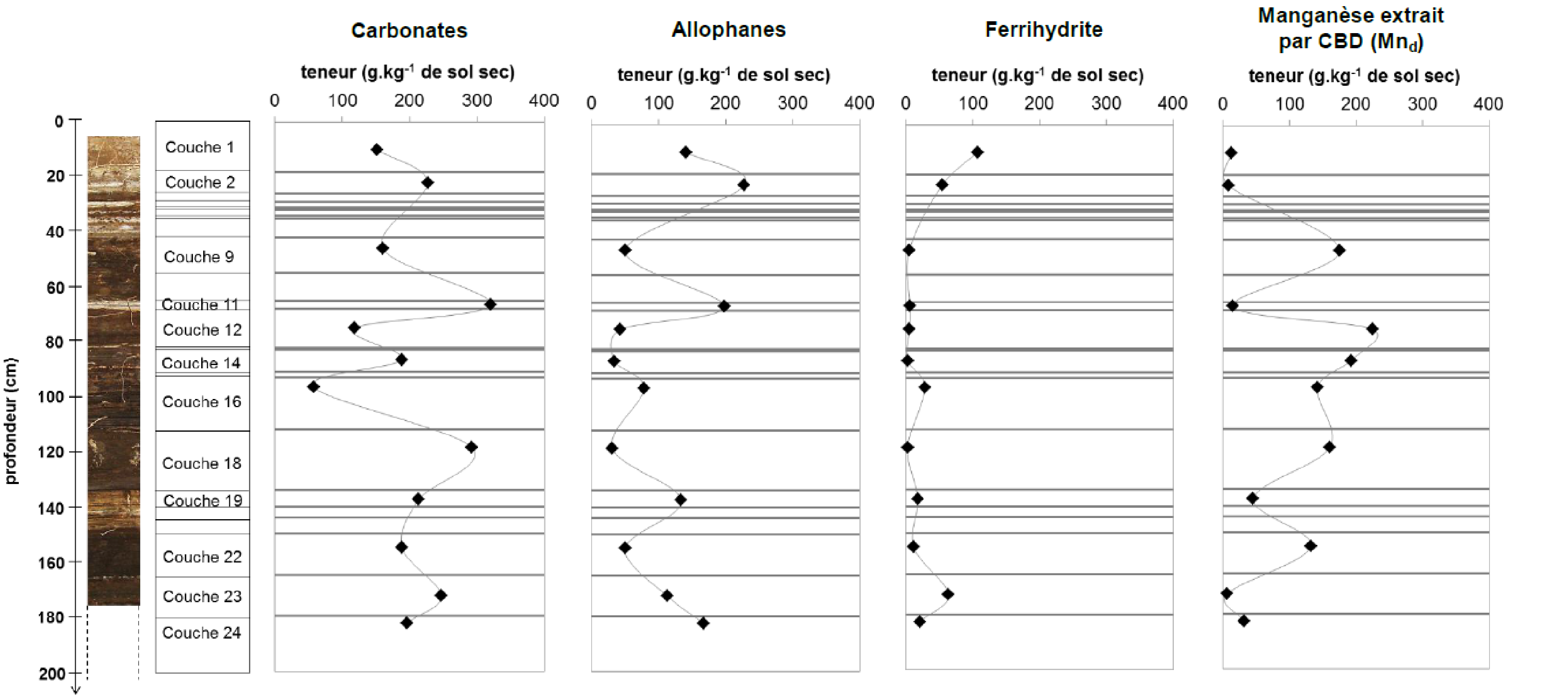


Figure 11: Distribution of carbonate, allophanes, ferrihydrite and Mn contents extracted with CBD (Mn_d) according to the Mehra-Jackson method along the "Technosoil" profile (from Huot, 2013).

The contents are expressed in $g.kg^{-1}$ of soil dried at 105°C. The carbonate contents were determined by calcimetry. The ferrihydrite contents were estimated from the Fe contents extracted with oxalate (Fe_o) according to Tamm's method by the following formula: ferrihydrite = $1.7xFe_o$ (Childs, 1985). The allophan contents were estimated from the Si contents extractedwitht oxalate according to the Tamm method (Si_o) by the following formula: allophanes = $7.1xSi_o$ (Parfitt and Wilson, 1985). CBD extraction allowing the dissolution of oxides, the Mn content, extracted with CBD, can be considered proportional to the content of Mn oxides.

7.1.4 Soil profile hydrocarbon distribution

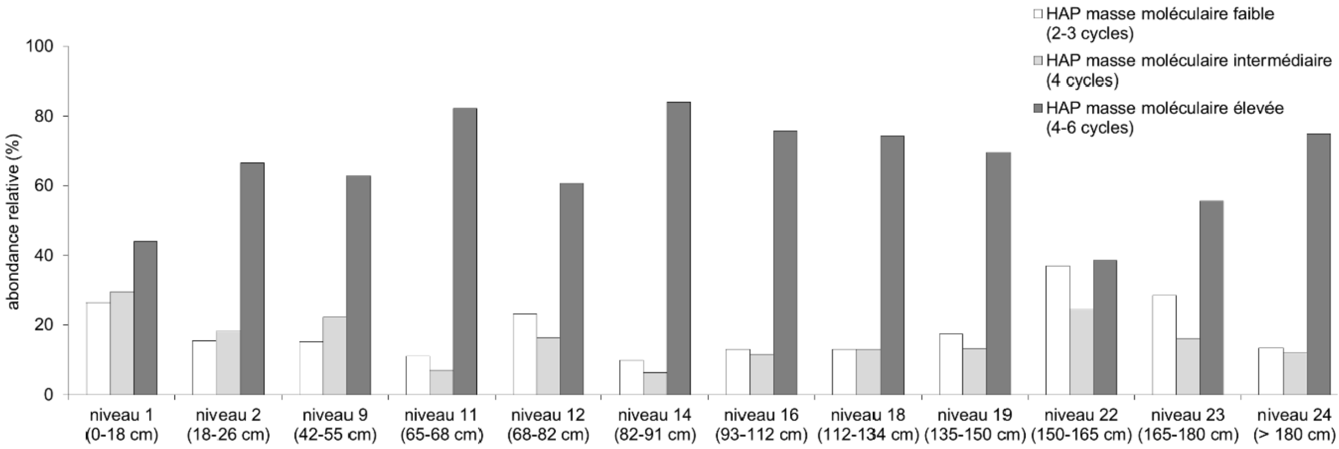


Figure 12: Distribution of polycyclic aromatic hydrocarbons (PAHs) in 12 layers of Technosoil (from Huot, 2013) according to their molecular mass and their number of cycles in 3 categories:

- ***i)*** ***Low molecular weight PAHs (128-178 g.mol^{-1}) with 2-3 rings: naphthalene, acenaphthylene, acenaphthene, fluorene,phenanthrene, anthracene;***
- ***ii)*** ***PAH of intermediate molecular mass (202 g.mol^{-1}) with 4 rings: fluoranthene, pyrene,***
- ***iii)*** ***High molecular weight PAHs (228-278 g.mol^{-1}) with 4-6 rings: benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a, h)anthracene, indeno(cd-1,2,3)pyrene, benzo(ghi)perylene.***

7.2 GEOTECHNICAL TESTS (< 10 M DEPTH)

Fondasol and Antea did several geotechnical analysis in order to stabilize the former tailing pond. Several boreholes were digged and analyzed in terms of soil type. A few remarkable results are listed bellow

7.2.1 FONDASOL report (1993): 3 boreholes at the limit of the tailing pond

The natural terrain (alluvial deposits) is situated at the elevation 189 m NGF. This report is the only evidence of the elevation of the tailing pond.

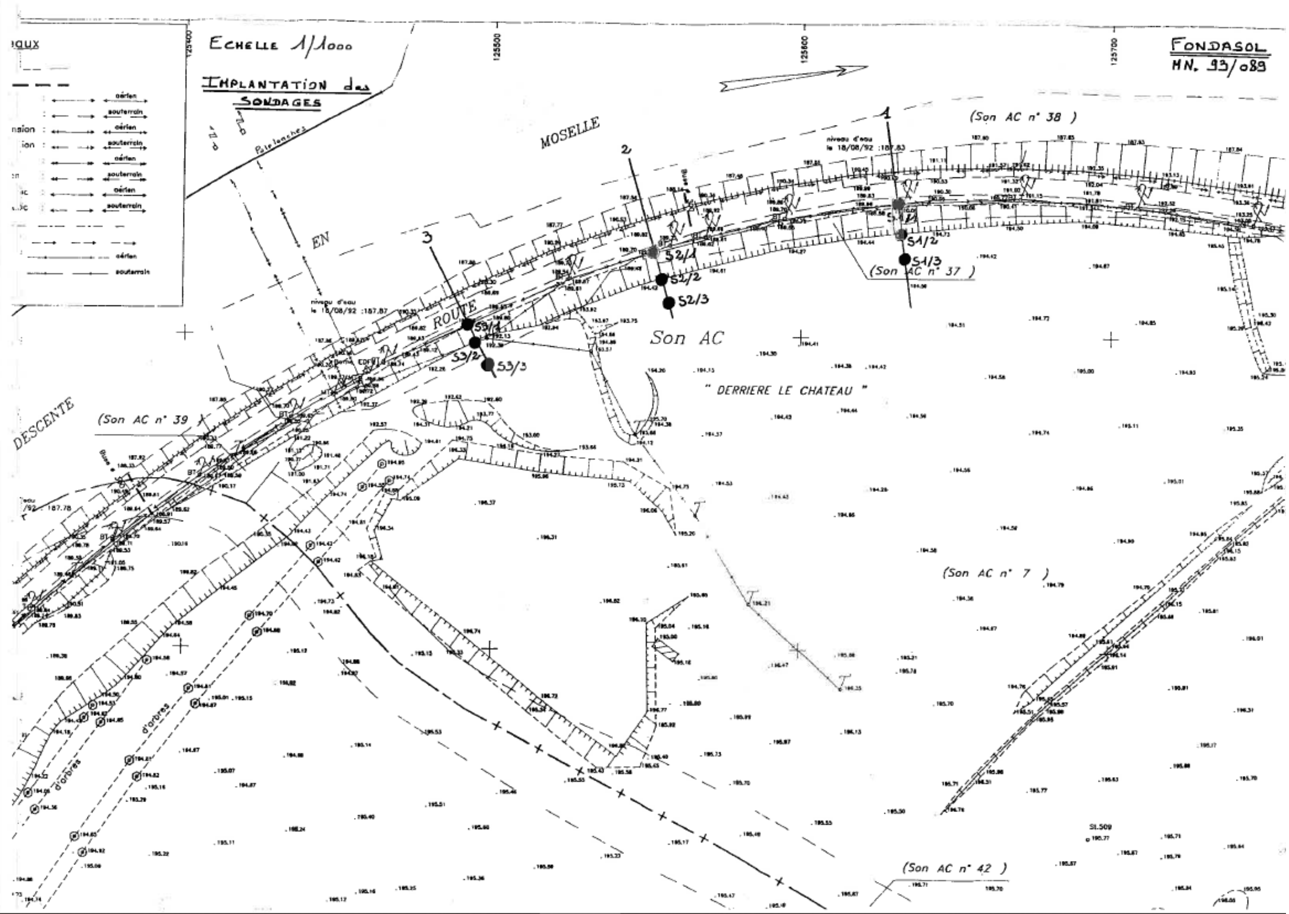


Figure 13: Localization of the 9 boreholes created by FONDASOL (1993): S1/1 S1/2, S1/3; S2/1 S2/2, S2/3; S3/1 S3/2, S3/3.

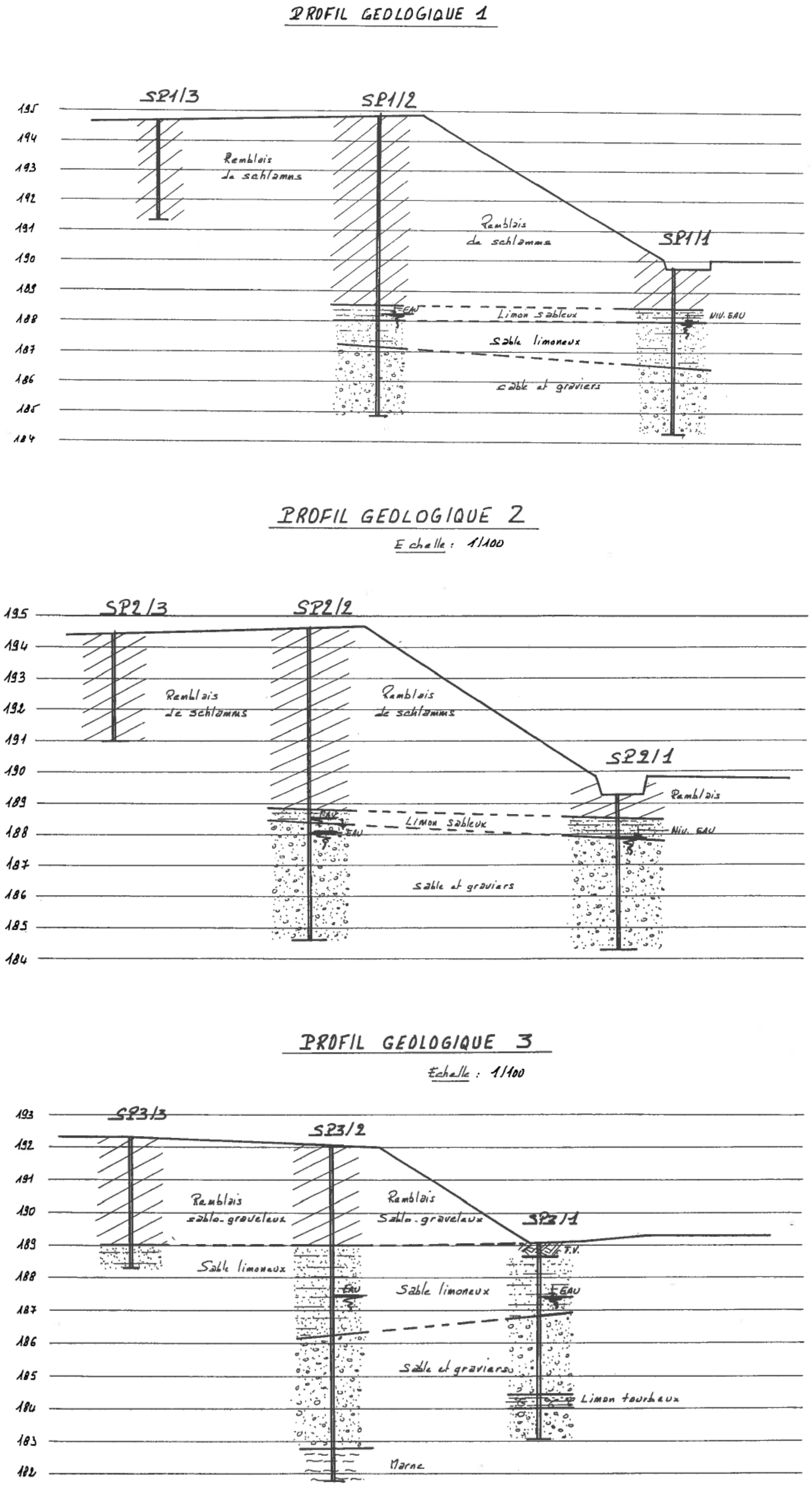


Figure 14: Interpretation of the soil profiles observed in the various boreholes dug by Fondasol (1993).

6.2.2. Antea report (2001): water analysis in 2 piezometers

This report deals with groundwater quality upstream and downstream the tailing pond. The water level is located within the alluvium deposits on which the tailing pond is lying.

The water samples analysis show a high concentration of Manganese, Chromium and Bore in the groundwater. It seems that groundwaters are not enriched by metallic compounds from the tailings.

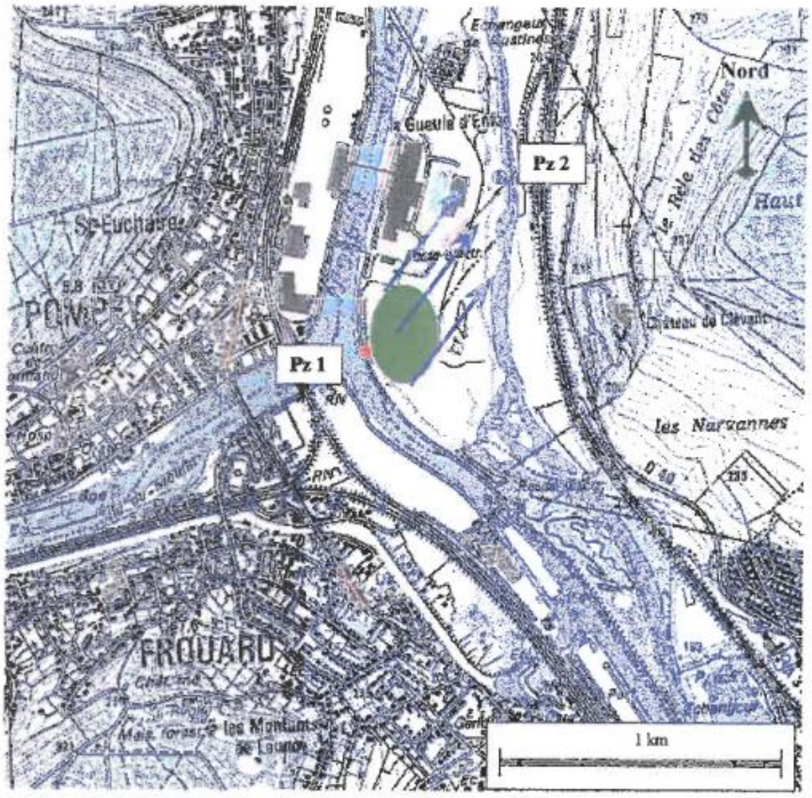


Figure 15: Localization of the 2 piezometers built by ANTEA in 2001. Pz1 is upstream and Pz2 is downstream. The arrows are indicating the main water movement direction (from ANTEA, 2001).

Tableau 7: Water analysis for the two piezometers built by ANTEA in 2001, upstream (“amont”) and downstream (“aval”) the tailing pond. Element concentrations are given in µg/L)

Valeurs issues du Guide E.S.R. Version 2 - Juin 2000	ANTEA 2001		VCI eaux souterraines		VCI eaux surperficielles		IRSID 1984			
	Pz 1 Amont	Pz 2 Aval	*Sensible*	*Non sensible*	Sensible	Non sensible	Moselle Blénod		Moselle Liverdun	
	En microgramme par litre		*En microgramme par litre*		En microgramme par litre		En microgramme par litre			
							Moy 71-78	Max 78	Moy 74-78	Max 78
K	10 700	103 300	12 000	24 000	ND	ND	9 100	9 900		
Na	46 100	48 800	150 000	300 000	ND	ND	175 500	216 000		
SO4	134 000	233 200	250 000	500 000	250 000	500 000	76 700	125 000		
Cl	64 700	35 300	200 000	400 000	200 000	400 000	561 000	600 000		
NH4	< 50	1 520	500	4 000	50	4 000	730	1 450		
NO3	< 500	3 600	50 000	100 000	50 000	100 000	6 060	11 000		
NO2	10	10	100	500	ND	ND	270	400		
CNlib.	15	456	50	250	50	250				
CNtot.	17	495	ND	ND	ND	ND	4	12	0	ND
F	244	925	1 500	3 000	1 500	3 000	421	1 250	246	ND
H.A.P.										
Benzo(b) fluoranthène (3-4)	< 0.010	< 0.010	ND	ND	ND	ND				
Benzo(k) fluoranthène (11-12)	< 0.005	< 0.005	ND	ND	ND	ND				
Benzo(a) pyrène (3-4)	< 0.010	< 0.010	0,01	0,05	ND	ND				
Benzo(ghi) pérylène (1-12)	< 0.015	< 0.015	ND	ND	ND	ND				
Fluoranthène	< 0.010	< 0.010	ND	ND	ND	ND				
Indéno(1-2-3) pyrène	< 0.060	< 0.060	ND	ND	ND	ND				
Naphtalène	ND	ND	ND	ND	ND	ND				
Somme des 7	< 0.110	< 0.110	0,20	1,00	0,20	1,00				
Indice CH2	< 10	< 10	10	1 000	50	1 000				
Métaux et métalloïdes										
Ag	< 5	< 5	10	50	ND	ND				
Al	< 30	< 30	200	1 000	ND	ND				
As	< 10	12	50	250	50	250	ND	40	ND	ND
B	302	943	ND	ND	1 000	5 000				
Ba	48	34	ND	ND	100	500				
Bé	< 5	< 5	ND	ND	ND	ND				
Cd	< 2	< 2	5	25	5	25	ND	2	ND	ND
Co	3	4	ND	ND	ND	ND				
Cr	86	77	50	250	50	250	ND	4		
Cu	5	7	1 000	2 000	50	250	59	NR	ND	ND
Fe	50	260	200	1 000	300	1 500	355	640	1 152	3 480
Li	30	60	ND	ND	ND	ND				
Mn	2 344	454	50	250	50	250	117	120	76	ND
Mo	ND	ND	ND	ND	ND	ND				
Ni	9	12	50	250	ND	ND				
Pb	< 2	< 2	50	250	50	250	62	NR	ND	ND
Sé	ND	ND	10	50	10	50	68	NR	ND	ND
Sb	ND	ND	10	50	ND	ND				
Si	13 200	10 300	ND	ND	ND	ND				
Sr	570	430	ND	ND	ND	ND				
Th	ND	ND	ND	ND	ND	ND				
V	ND	ND	ND	ND	ND	ND				
Zn	9	5	5 000	10 000	3 000	15 000	215	NR	57	ND
Hg	< 0.5	< 0.5	1	5	1	5				

7.3 AERIAL PHOTOGRAPHY THROUGH TIME

On the web portal of the French national geographical institute (https://www.ign.fr/), ten aerial photographies of the Pompey site can be found. They run from 1920, when the Pompey site steel industry was fully active, to 2009, when the former tailing pond was already remediated and under the surveillance of EPFL (former EPFGE).

Slags and other blast furnace wastes were deposited until 1950-1955. From 1955, vegetation took over the slags. An endemic forest is now installed on the entire area.

The most interesting photos are from 1947 and 1948, where dams are visible. These dams seem to show several subsets in the tailing pond, with different compounds concentration and physical characteristics (change in colors).

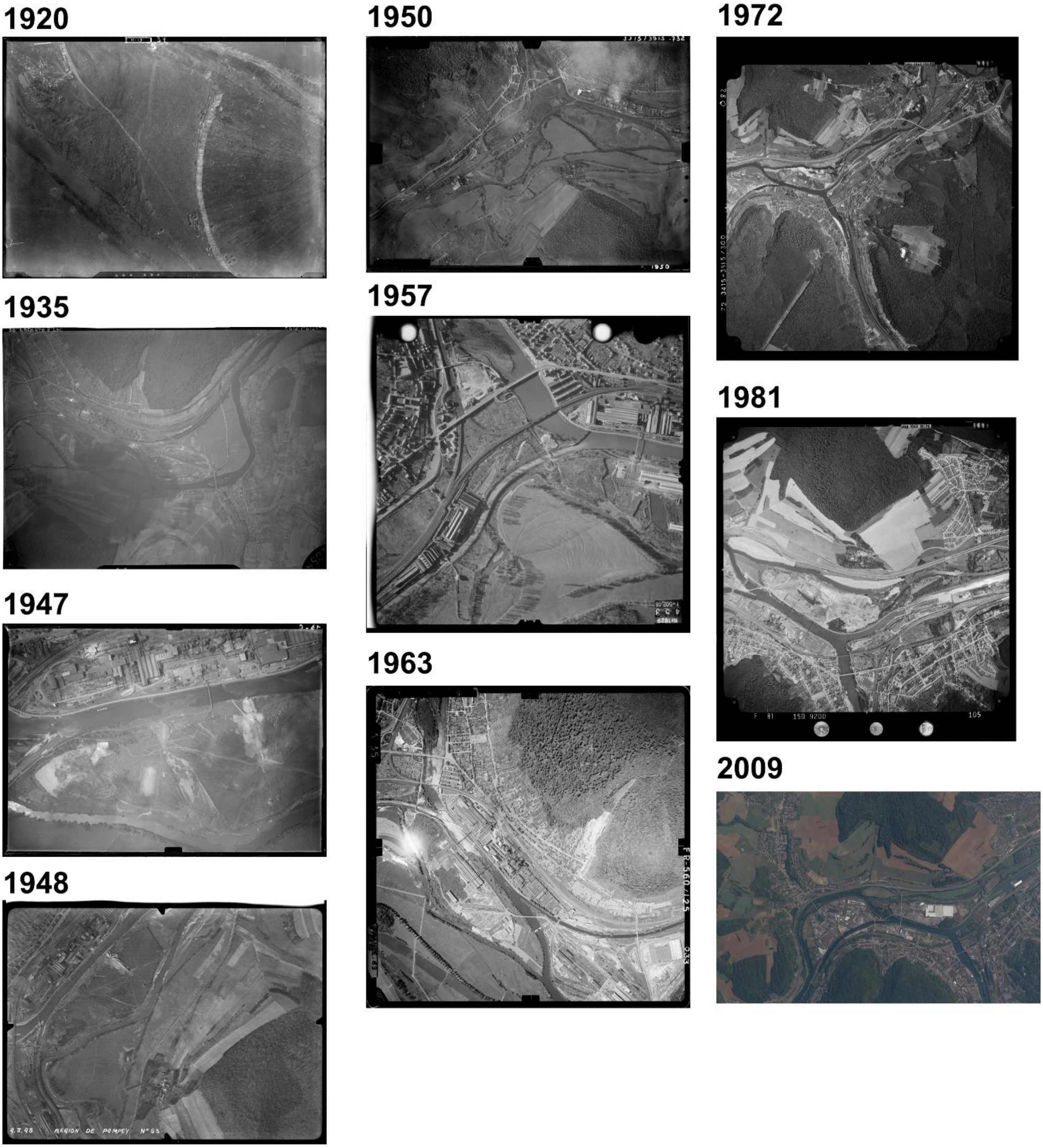


Figure 16: Aerial photographs of Pompey-Frouard-Custines iron and steel complex

Aerial photography of the Pompey area – **1920a**

Figure 17: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1920 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1920b**

Figure 18: Second aerial photography of Pompey-Frouard-Custines iron and steel complex in 1920 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1935**

Figure 19: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1935 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1947**

Figure 20: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1947 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1948**

Figure 21: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1948 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1950**

Figure 22: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1950 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1957**

Figure 23: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1957 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1963**

Figure 24: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1963 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1972**

Figure 25: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1972 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **1981**

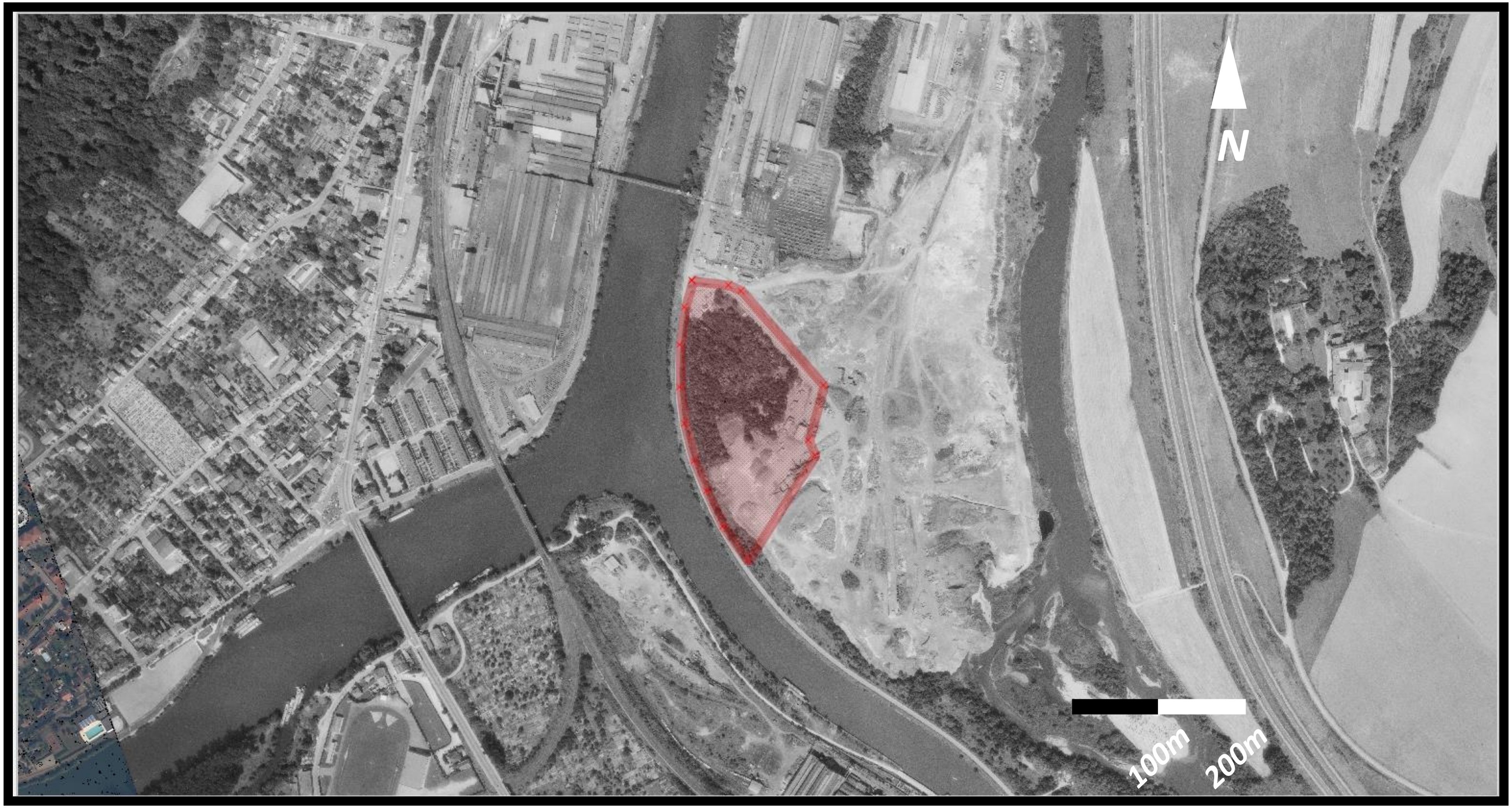


Figure 26: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 1981 with the limits of the Ban-la-Dame investigated area

Aerial photography of the Pompey area – **2009**

Figure 27: Aerial photography of Pompey-Frouard-Custines iron and steel complex in 2009 with the limits of the Ban-la-Dame investigated area

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