Bedload progression in gravel bed rivers using iron slag as a tracer

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In fluvial dynamics studies, different methods are used to evaluate bedload transport and particle travel lengths : active (radio) tracers and passive tracers (magnetic Pit-Tag, …), and painted markers. These methods however document bedload progression at a relatively short time scale. Consequently, it is difficult to extrapolate these results to whole bedload, because of the burying of particles into the subsurface layer or the trapping of elements in fluvial forms (point bars, riffles, …), which can immobilise elements during long periods.

Bedload progression has been evaluated in Ardenne rivers using slag elements (Fig. 1) produced by the past factories established along rivers between the 14th and the 19th century (Fig. 2). Important quantities of slag were dumped close to rivers (Fig. 3) or even directly into channels. For several centuries, slag elements were dispersed in the bedload and transported by floods of varying importance. Consequently, slag can be considered as a tracer to analyze bedload progression over several centuries.

Fig. 1. Rounded vitreous iron slag found in the Lembrée River (Ardenne)

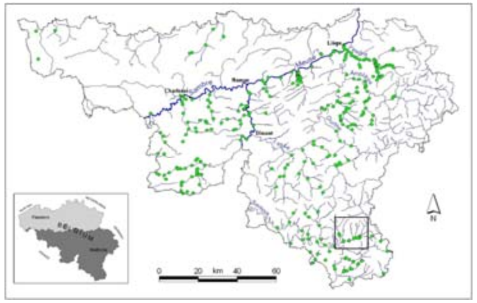

Fig. 2. Location of metallurgic sites (14th – 19th century) in Wallonia and the Rulles River

Fig. 3. Blast furnace from Spa (Belgium) – J. Bruegel de Velours – 1612

In primitive blast furnaces (14th – 19th century), metallurgists produced large quantities of vitreous slag. According to historical studies, we know that the blast furnaces from the 16th century produced about 80 m³ of slag per year. As you can see from this painting, vitreous slag were piled onto the floodplain, often very closed to rivers.

Because of their colours, such as blue or green, vitreous slag can be easily spotted among natural particles.

The size of slag elements was studied along eighteen rivers of different size and properties. These data serve to determine the effective competence of rivers and to analyze the hydraulic sorting. Moreover, downstream of some metallurgic sites, we have constrained the presence of slag elements to the most downstream riffles. Because we know from historical studies the periods of activities of these sites, we may estimate the speed of bedload progression in several gravel bed rivers from the Ardenne Massif.

Figure 4 shows the trend of the size of the 10 largest particles measured by the b-axis using a cumulative distance from the closest iron factory along the Rulles river course (site 1).

Slag elements brought down by tributaries shed light on the increase of the slag size in the Rulles (sites 6 and 11). Downstream of input sites, we systematically observe a rough decrease in particle size, which decreases approximately to 20 mm in diameter in less than 5 km (sites 2-3; 7-9; 12-14). This decrease does not result from modification in hydraulic characteristics of the river nor from a diminution of its competence, since the unit stream power remains constant along its course (25-30 W/m² at the bankfull discharge).

Downstream, the slag size remains almost constant whatever the distance. It represents the effective competence of the river (the particle size transported along substantial distances and evacuated out of the catchment). The particle size (15-20 mm) is relatively small in comparison with observations from other Ardenne rivers. A relationship can be established between the size of slag elements and specific stream power (Q_b) of the rivers where samples were collected (Fig. 5).

Several slag elements (10-14 mm in diameter or 9-12 mm using equivalent diameters) have been found 12.5 km downstream of the nearest iron factory dated from the mid 17th century. This implies that the bedload wave progression is at least 3.3 km per century. The most upstream site in the Semois River, where no slag has been found, shows that the bedload wave progression is less than 17 km (less than 3.9 km per century).

A similar progression (between 1.8 and 2.3 km per century) has been observed in the Ourthe River (Fig. 6). These values are low in comparison with others studies (between 10 and 20 km per century), but most of them have been obtained in mountain rivers with stronger energy

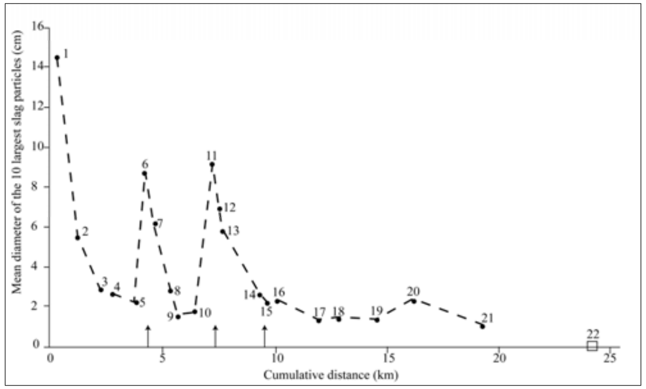

Fig. 4. Size trend of the ten largest slag particles along the Rulles River Course (Belgium)

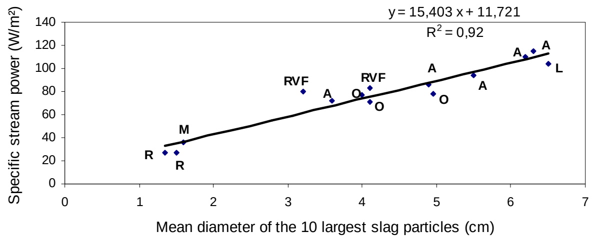

Fig. 5. Relationship between the average diameter of the ten largest slag particles (M10) in constant size sectors and the unit stream power (calculated for bank full discharge). A : Aisne ; L : Lembrée ; M : Mellier ; O : Ourthe ; R : Rulles ; RVF : Ruisseau du Vieux Fourneau

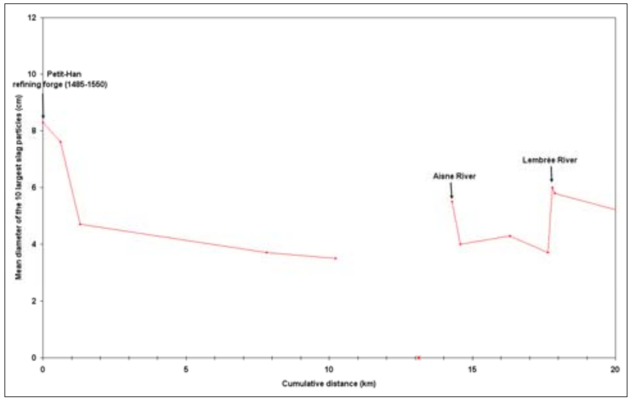

Fig. 6. Size trend of the ten largest slag particles along the Ourthe River Course (Belgium)

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