Sediment Characterization from the Saale 2013 Flooding Event

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Zusammenfassung

Die Sedimentablagerungen des Saale-Hochwassers im Frühjahr 2013 werden charakterisiert auf der Basis von Probenahmen aus den überfluteten Uferbereichen im Stadtgebiet von Halle. Diese Ablagerungen werden zum einen klassifiziert nach Art des Sediments (Sedimenteigenschaften: Mächtigkeit, Grobkorn-Anteil, Anteil an organischer Substanz, Trockenfestigkeit) und zum anderen nach Art ihres Ablagerungsraumes (Lokationseigenschaften: Abstand vom Saale-Flussbett, Bedeckung durch Vegetation, Relief, Untergrundbeschaffenheit). Diese Sediment- und Lokationskriterien werden hinsichtlich der Häufigkeit ihres Auftretens und eines möglichen Zusammenhangs zwischen Sediment- und Lokationseigenschaften untersucht. Es wird gezeigt, dass sich die Zusammensetzung der Sedimente im Laufe ihres Transports von Süd nach Nord durch das Stadtgebiet von Halle verändert. Es kommt bis in das Gebiet von Trotha/Lettin zu einer Verringerung der mittleren Korngröße und zugleich zu einer Veränderung der Kornverteilung der abgelagerten Hochwasser-Sedimente. Die Dominanz feinkörniger Sedimentanteile wird zunehmend deutlich, je weiter nördlich die Ablagerung stattgefunden hat. Außerdem begünstigen weiche Untergrundbedingungen (wie Wiesen, Kieswege oder unbefestigte Straßen) die Ablagerung von relativ mächtigeren Sedimenten > 1mm. Im Gegensatz dazu dominieren auf festem Untergrund (wie befestigten Straßen und Wegen) Sedimentablagerungen von < 1 mm Mächtigkeit. Aus der durchschnittlichen Mächtigkeit der beprobten, feinkörnigen Hochwasserablagerungen mit Korndurchmessern < 2 mm lässt sich ein transportiertes Sedimentvolumen von 5 bis 15 l/m^2 ableiten. Im gesamten Überflutungsgebiet von ca. 32,8 km^2 in Halle ergibt sich ein geschätztes Sedimentvolumen von $3x10^5$ m^3 an feinkörnigen Ablagerungen durch das Frühjahrs-Hochwasser 2013.

Abstract

Sediment deposition, after the Saale river flooding event of 2013, is characterized here based on samples taken along the river banks in the flooded region.
Based on classifications having to do with both sediment (thickness of sediment; percentage of coarse material; organic material presence; dry strength of the sediment) as well as location (distance to the Saale river; vegetation cover; relief; firmness of the basal layer beneath the flood sediments) it is shown that the transport of fine-grained sediment along the Saale had its direction changed by the flooding in the region between Halle-Trotha and Lettin. There was a sorting of the grain sizes that, on the one hand, lowered the medium grain sizes and, on the other hand, altered the grain size distribution at the same time. The preponderance of fine-grained sediment is more noticeable the further north one progresses along the Saale river.
In addition, soft basal materials such as meadows, gravel paths or dirt roads are associated with relatively thick sediment that is almost always more than 1 mm. In contrast on firm grounds, such as paved roads and sidewalks, the dominance is one of thicknesses smaller than 1 mm. The average thickness of the fine-grained material indicates a transported sediment volume of between about 5 to 15 l/m^2. In the total flooded region in Halle of around 32.8 km^2 one can estimate some $3x10^5$ m^3 of fine-grained material was deposited.

1. Introduction

In June 2013 the Saale river overflowed its banks massively. The main reason for the flooding was due to the torrential rains that had taken place in southern and central Germany during most of May. These waters were ultimately channeled into the flowing rivers (Donau, Saale, Elbe etc.) and, as more and more water found its ways into the rivers, there was a significant rise in river levels. Figure 1 shows the daily amount of rainfall at one measuring station (W-Schönbrunn, Fichtelgebirge) from the beginning of May through early June, which was typical for the whole of southern and central Germany. There was a peak of around 37 mm of rain but also a steady downpour for several days ranging to around 20-25 mm. As a consequence of the focusing of this downpour into valleys the rivers located in those valleys first filled and then overflowed. Figure 2 shows the water level in the Saale river at Halle-Trotha during the flood period. Note from figure 2 that the normal river level is around 3 m but during the flood stage reached a depth of over 8 m.

Because the land around the Saale river is relatively flat and is typically around a meter or so higher than the normal river level the Saale overflowed its banks massively. Indeed in Halle (Saale) there was serious overflooding in the town streets abutting the Saale river and without the voluntary help of many thousands of people who filled sand sacks to raise the level of the earthern Gimritzer dam to the west of Halle one would have had even more enormous flooding of the lower-lying section of Halle known as “Halle-Neustadt”. As it was the overflow came perilously close to breaching the Gimritzer dam and it was not clear for over a week if the dam would hold.

In the midst of this major flooding sediment was transported with the flood waters, some of the sediment was deposited and a fraction later removed by the receding flood waters but not all. The sediment was, generally, made up of coarse-grained material, silt and/or clay particles (mud) and with organic detritus in part. Because the coarse grains are typically much larger than the mud particles there was a tendency for the overflow waters to deposit coarse material closer to the normal river boundaries than for the small mud particles that could be transported considerable distances from the river in the flood waters and that did not settle out as quickly as did coarse material. The origin of the organic material can be twofold: a component can be from

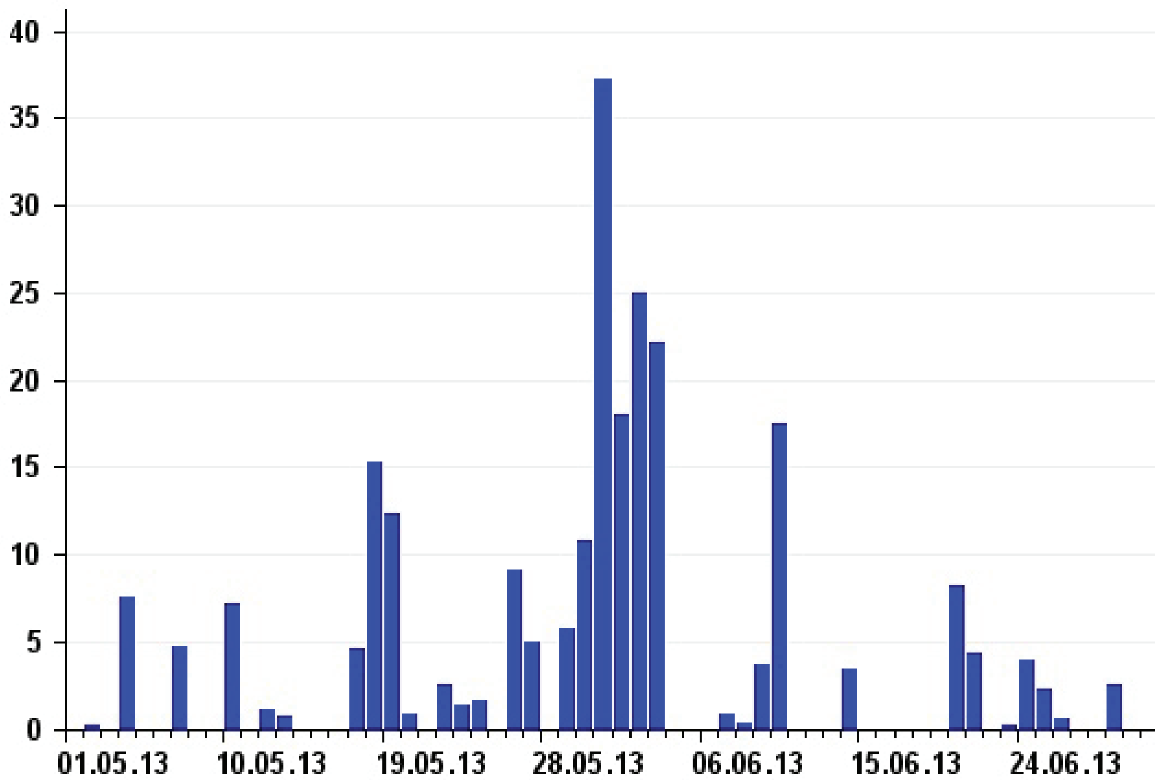

Fig. 1 : Daily rainfall amounts (ordinate in mm) as measured at the weather station Wunsiedel-Schönbrunn (Fichtelgebirge) near the source of the Saale (http://www.wetteronline.de).

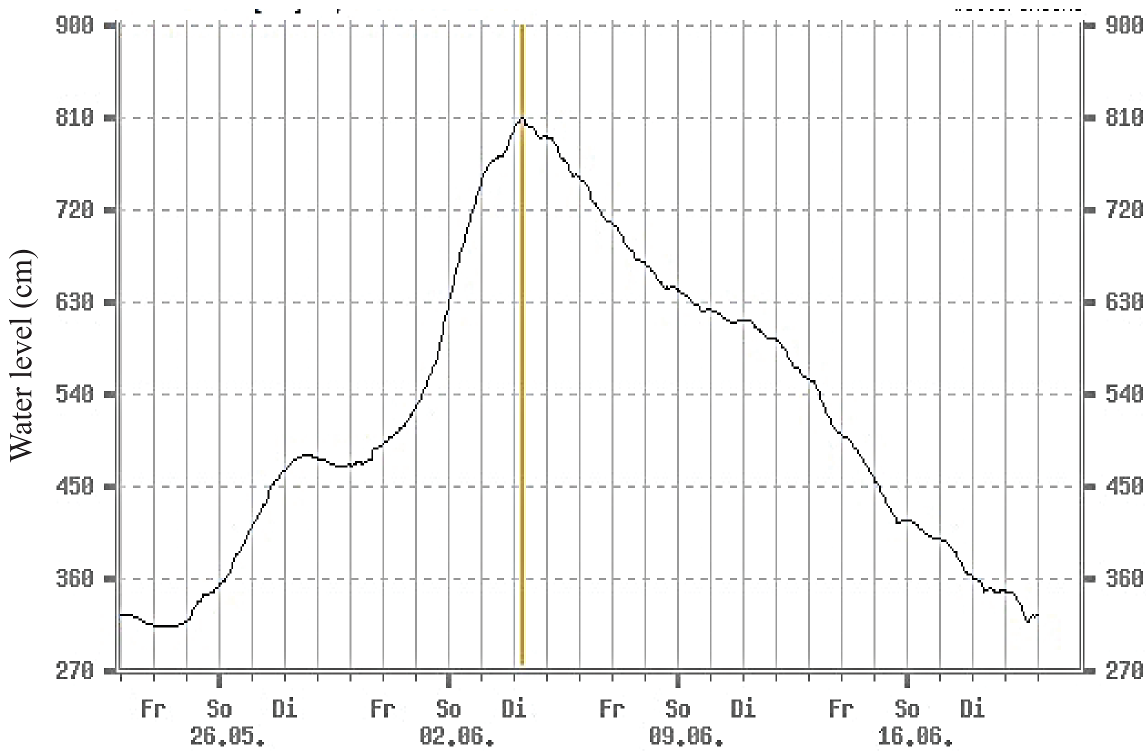

Fig. 2 : Saale water level at Halle-Trotha between 26 May 2013 through 16 June 2013. On 5 June 2013 the maximum of 811 cm was reached.

transport with the flood waters in the river while a second component can arise from the flooding waters picking up organic detritus from the ground as the waters overflow the region.

In addition, while the river banks are, typically, a meter or so above normal water level there are massive exceptions to influence the amount and direction of flow of the flooding. First if the land is locally very flat then the flood waters have an easier time of penetrating further than if the river banks are locally steep. Coarse material can be more easily transported in a flat environment that when the river must expend considerable (relatively speaking) energy to push the coarse material over a steep bank. Second the deposition of sediment depends also on the relative smoothness of the underlying stratum. For instance flow over asphalted streets proceeds more easily than flow over heavily vegetated regions generally leading to a broader but thinner thickness of deposited mud. Measurement location relative to the river banks also plays a role in influencing results obtained. The farther from the river bank one measures the smaller is the amount of transported sediment in general (although a high volume per second transport of flood waters away from the river can mean a corresponding higher amount of sediment at significant distances from the river as shown in Figure 3).

2. Sediment Measurements and Analysis

An analysis of the sediments and their composition was undertaken at several locations in the vicinity of Halle. An overview of the distribution of the fine-grained material is presented in Figure 4 taken at locations along the river. Shown are the mode, median and average grain sizes following the Saale river from south to north (the direction of flow of the river). To be noted is the somewhat "ragged" appearance of the grain sizes at the southern end of the investigated regions with a more gradual trend to smaller grain sizes the further one follows the river north indicating the more general deposition of silts and clays as fine grained material. However, note also

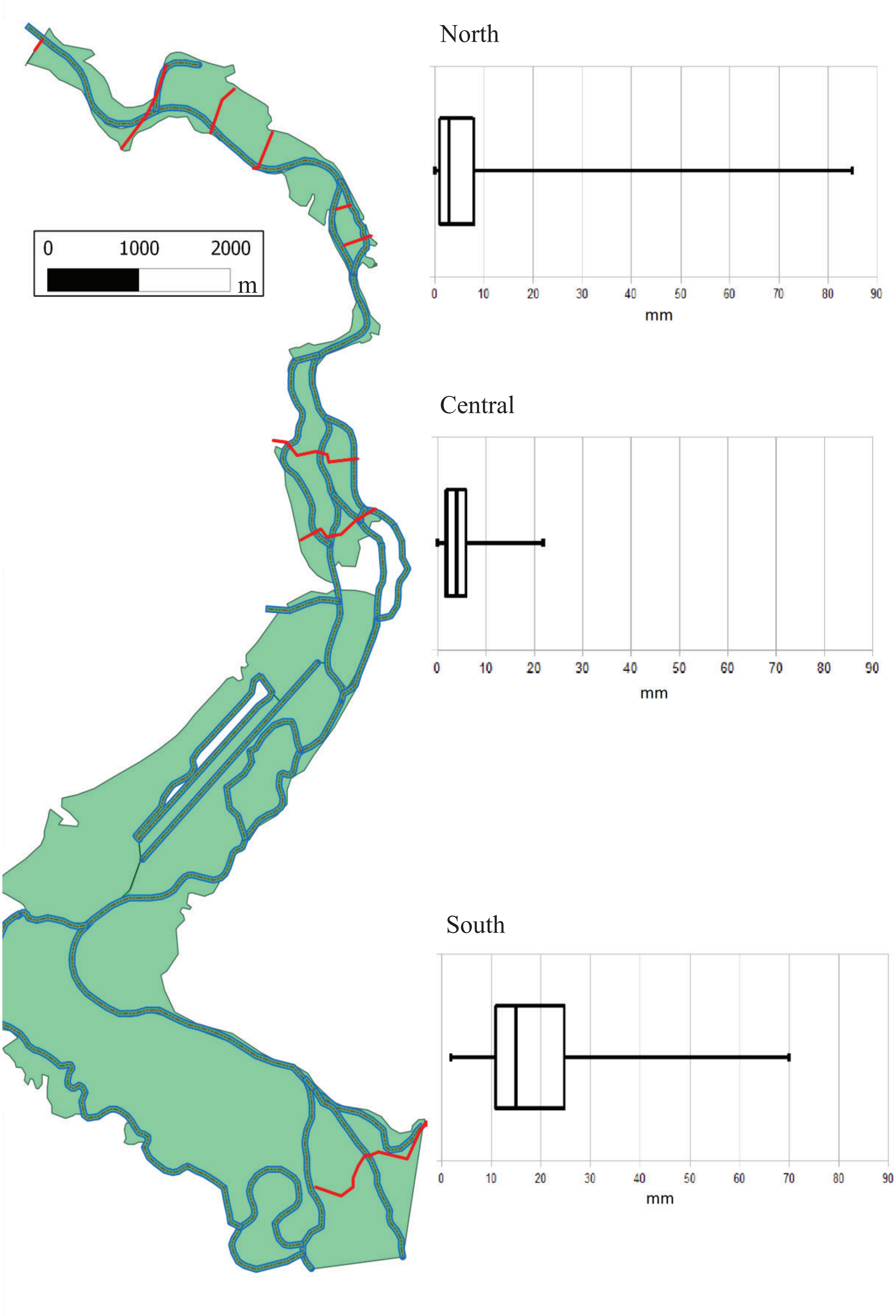

Fig. 3 : Flooded area of Saale river at Halle: Thickness of deposited sediment with distance along the Saale river. The thickness is measured in mm. The boxes show the mean and standard deviation of the thickness with the massive outlier range also given.

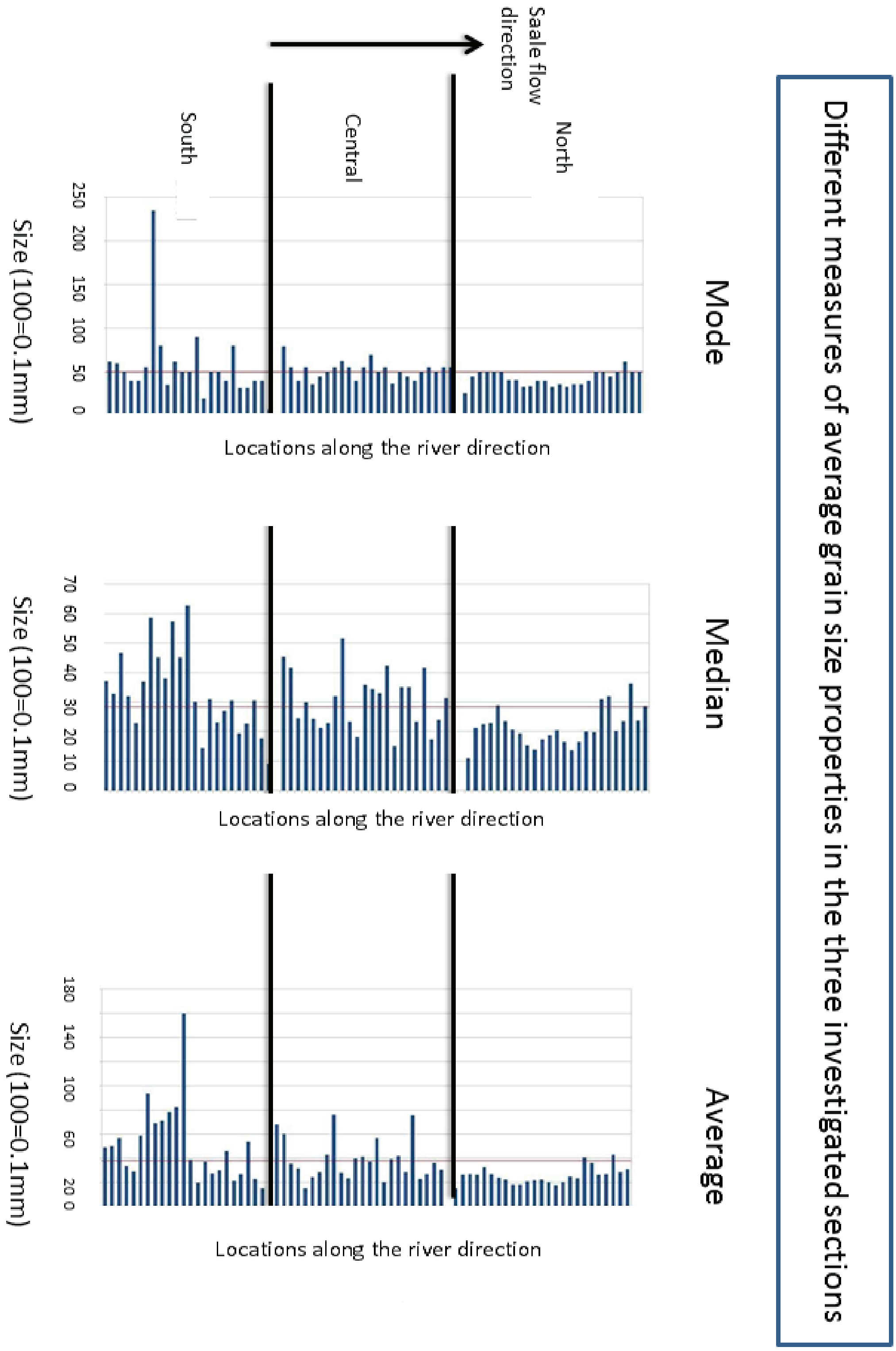

Fig. 4 : Distribution of grain sizes at locations along the direction of flow of the Saale river. Mode, median and average values are presented from south through to north. Note the trend to finer grain sizes as locations progressively head north indicating the preponderance of silt and/or clay deposition at the northern end.

from Figure 3 that in the northern part of the Saale area the thickness of deposited sediment scatters considerably despite the relatively uniform average grain size distribution. For each sample attention was also given to the location conditions. As a result two different groups of effects were in place.

A. Sediment characteristics:

Thickness of sediment;

Percentage of coarse-grained material;

Organic material presence;

Dry strength of the sediment.

B. Location characteristics:

Distance to the Saale river;

Vegetation cover;

Relief;

Firmness of the basal layer beneath the flood sediments.

A total of 234 sediment measurements were made at different locations along the Saale in the flooded domains after the flood waters receded (Figures 5, 6).

The sediment characteristics were more sharply defined as follows:

The sediment thickness varied considerably in the area. The majority of samples had thicknesses in the range from less than 1 mm to around 3 mm, although exceptional measurements to 0.5 m were also obtained. The choice of a thickness limit of 1 mm is somewhat arbitrary but happens to indicate a group of thickness measurements dominated by fine material in contrast to those measurements that had most often a vertical gradient and so were more easily measurable.

The samples were divided into those containing coarse material and those without. Based on DIN EN ISO 14688-1 coarse grains have sizes between 0.063 mm to 2 mm. Fine particles of clay and silt require less energy to be transported and , in addition, no particles with sizes greater than the coarse grain sizes were considered.

The samples were also separated depending on their content of organic versus no organic material.

The last characteristic used was the dry strength of sediment based on DIN EN ISO 14688-1 that allows one to decide between different degrees of dry strength. Although the complete spectrum of dry strengths was found in the investigated area, the low and medium dry strengths dominated because the difference between coarse grains and fine mud particles provides an overriding control.

The location characteristics were defined as follows:

The distance from the main flow channel of the Saale was used as one location characteristic with a separation for those sediment samples at distances greater than (less than) 100 m. This choice split the samples into two roughly equal groups and is also simple to measure.

A significant role is played by the physical character of the ground: it is relatively easy to distinguish between paved areas such as streets or the Saale Kai in comparison to softer grounds such as fields, meadows and woods.

A further influencing factor is the presence of low or high vegetation. Low vegetation is mainly meadow and grassland while high vegetation has bushes and trees. One would anticipate a correlation in organic content of the samples with the type and amount of each such vegetated region as well as an influence on the thickness of residual flood sediments.

A more difficult determination is that of the steepness of the relief away from the river despite the fact that the steepness must influence the coarse fraction of sediment deposition at least. Only in a few places it was possible to measure directly the relief steepness - such as in the region of Lettin. In other areas the steepness of the normal Saale river bank was used as a proxy.

There are several aspects of the sediment and location characteristics that can be investigated (comp. Baron 2013, Weiße 2013). To obtain a total overview of the interaction between sediment characteristics and the location descriptions one can consider all the individual measurements together.

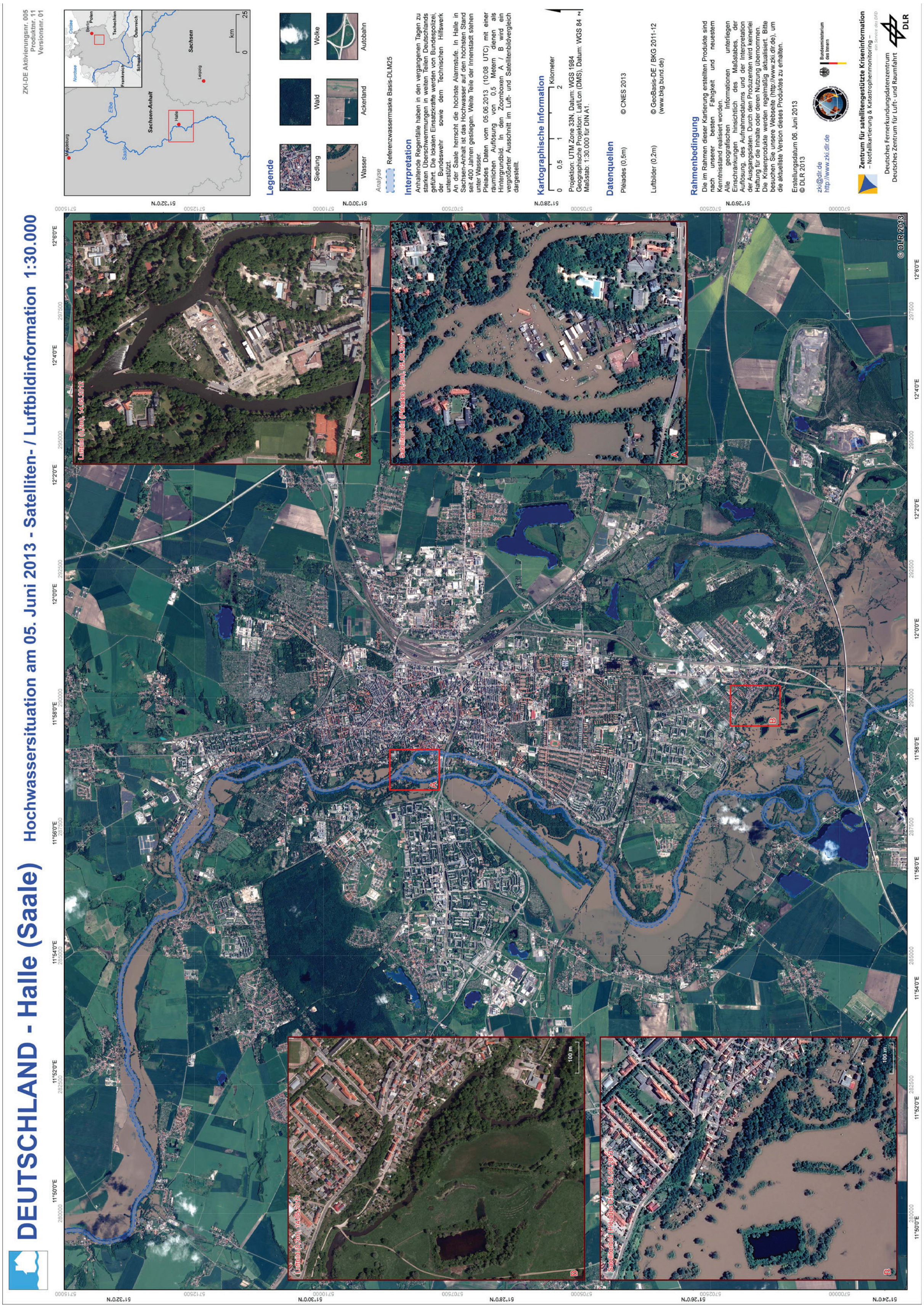

Fig. 5 : Investigation was mainly undertaken in the northern parts of Halle. Map shows the extent of the flooding, including two example areas to compare normal and flooded situations. (© ZKI/DLR).

Fig. 6 : A more detailed view of the main area of investigation with the locations of the various profiles marked in red - except that along the river for the Saale Kai (marked in yellow). Note this map is without indiction of flooded areas. (Open Street Map- Daten/Lizenz Open Database License, ODBL).

This particular aspect forms the basis for the rest of the article. In addition, one can investigate the corresponding interactions for individual profiles measured at increasing distances away from the Saale river and at different locations along the river. Such profile locations are marked in red and yellow on Figure 6. However their investigation would make for a very long article indeed and for that reason, as well as the fact that

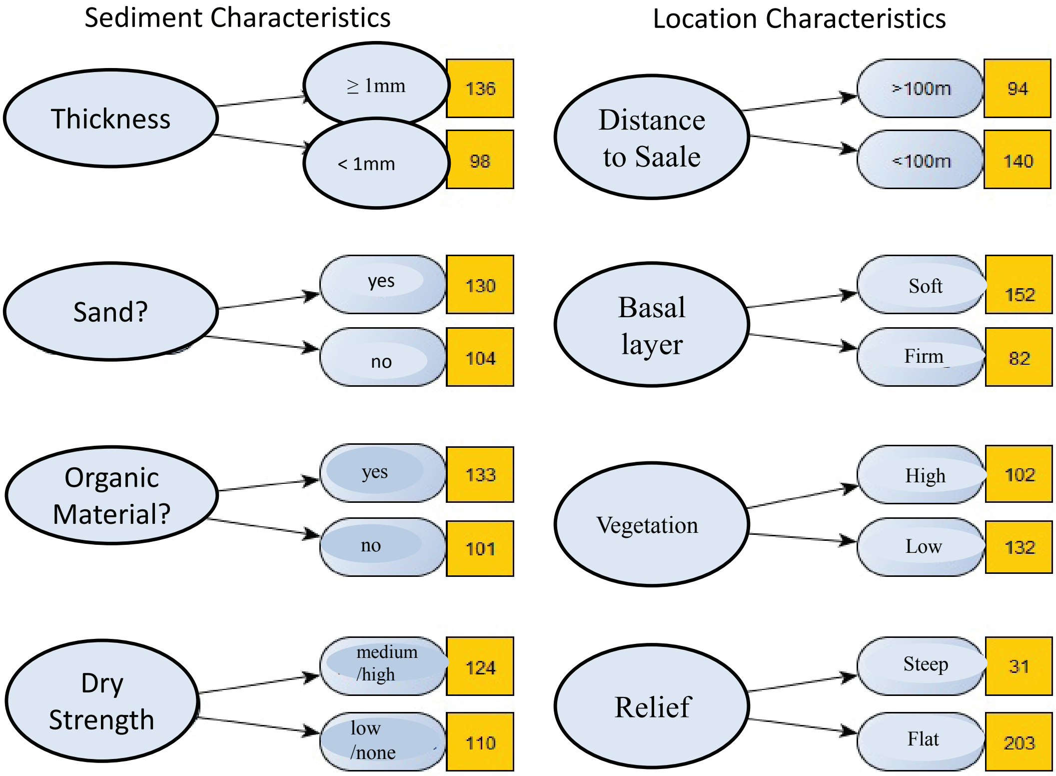

Fig. 7 : Summary of events and their sediment and location characteristics considered separately.

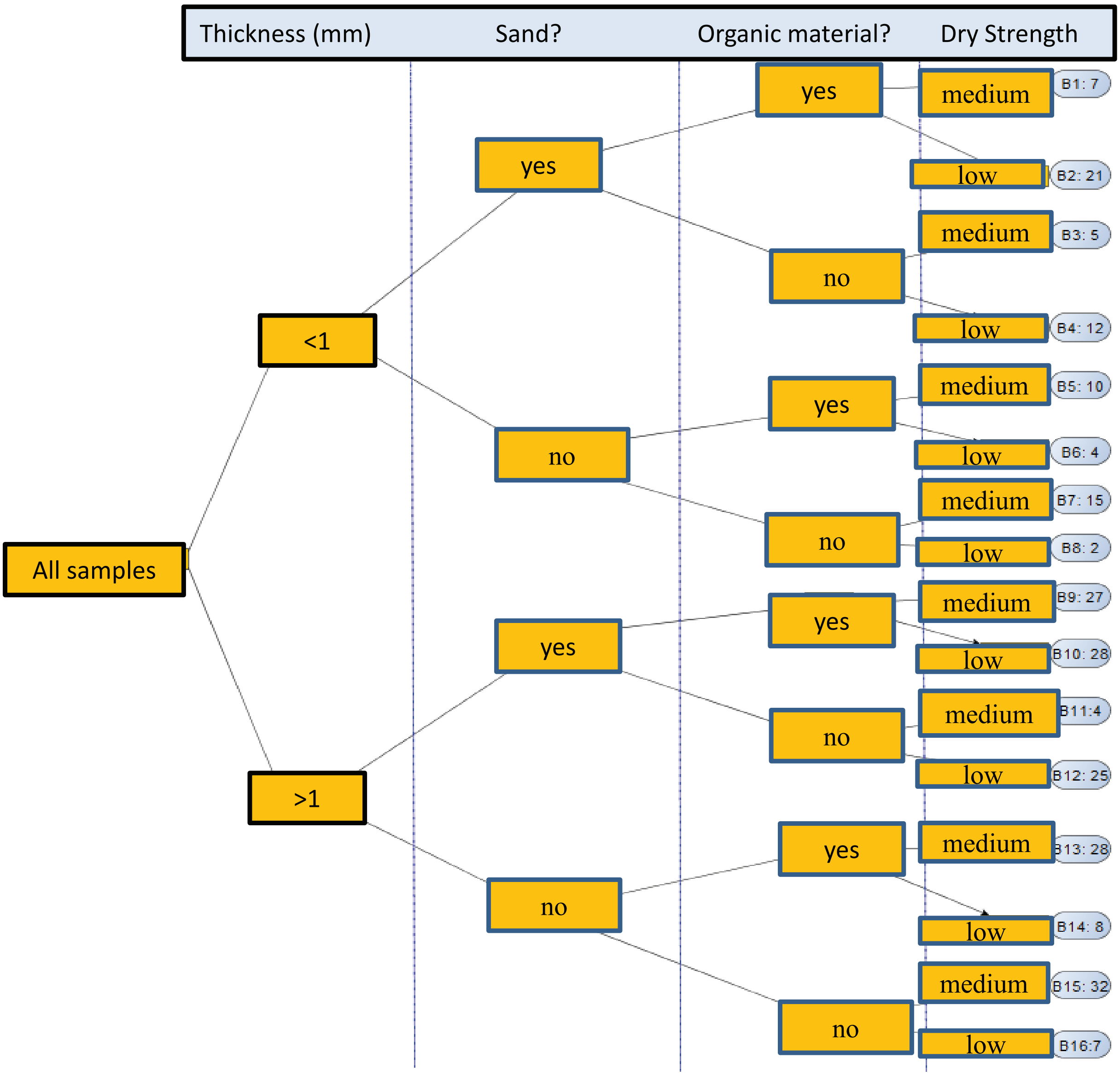

Fig. 8 : Individual sediment characteristics defined in terms of positive/negative appearances of events as shown for each characteristic.

such a detailed investigation has already been undertaken by Thonig (2014), individual profiles are not considered further here.

The total sum of the measured points is first broken up into groups that refer to their sediment characteristics irrespective of location characteristics (Figure 7). In this way one obtains a rough overview of the frequency of occurrence of each sediment characteristic. The left hand side of Figure 7 depicts this breakup with the corresponding absolute frequency of occurrence of each factor. Equally one can group the measurements by their location characteristics irrespective of the sediment behavior to obtain a rough idea of the influence of location characteristics on the frequency of occurrence of each type of location parameter. This breakdown is shown on the right hand side of Figure 7.

In addition one can take each individual sample and set up a categorization of the sediment characteristics based on the attributes each sample possesses. As shown in Figure 8 such a process groups the samples into several classes by asking whether each sample is thicker or thinner than 1 mm,

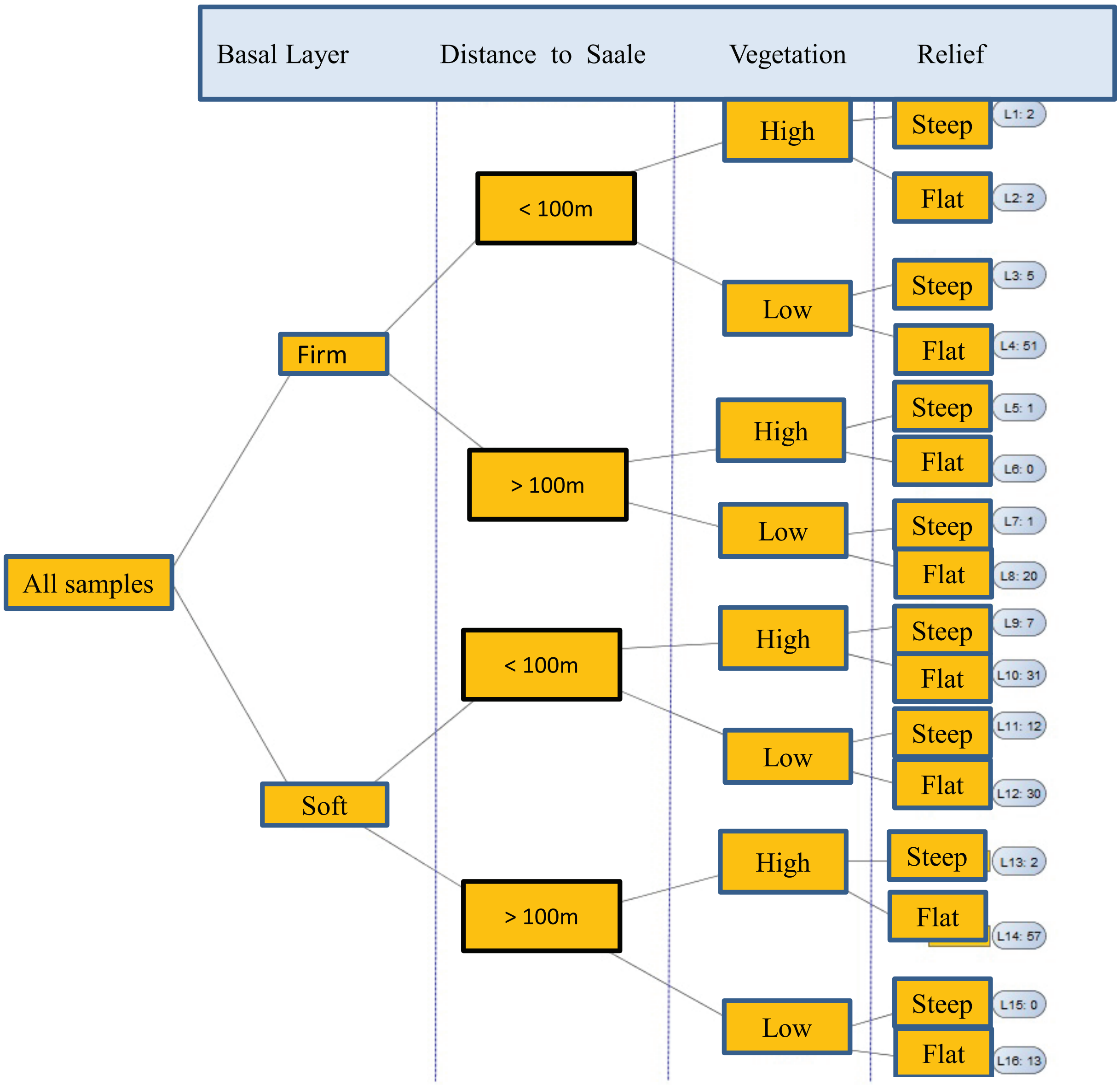

Fig. 9 : Individual location characteristics defined in terms of positive/negative appearances of events as shown for each characteristic.

whether each sample contains coarse material or not, whether each sample contains organic matter or not and whether each sample has low or medium dry strength. In this way one generates 16 different groups and, as shown in Figure 8, one can so obtain the number of samples that fall into each group. These classes are noted by symbols B1 to B16 with the corresponding number of samples in each B classification given as shown also in Figure 8.

Equally, one can categorize the location characteristics of each sample in a similar manner. Shown in Figure 9 are the 16 groupings based on the four location criteria namely: is the substrate hard or not, is the sample taken at a distance greater or less than 100 m from the Saale river, is there low or high vegetation for the sample location, and is the relief steep or not. These classes are labeled L1 to L16 on figure 10 and the number of samples falling into each of the L classes is also give in Figure 9.

An alternative way to view the breakdown of the sediment and location characterizations into classes is to plot just the frequency of

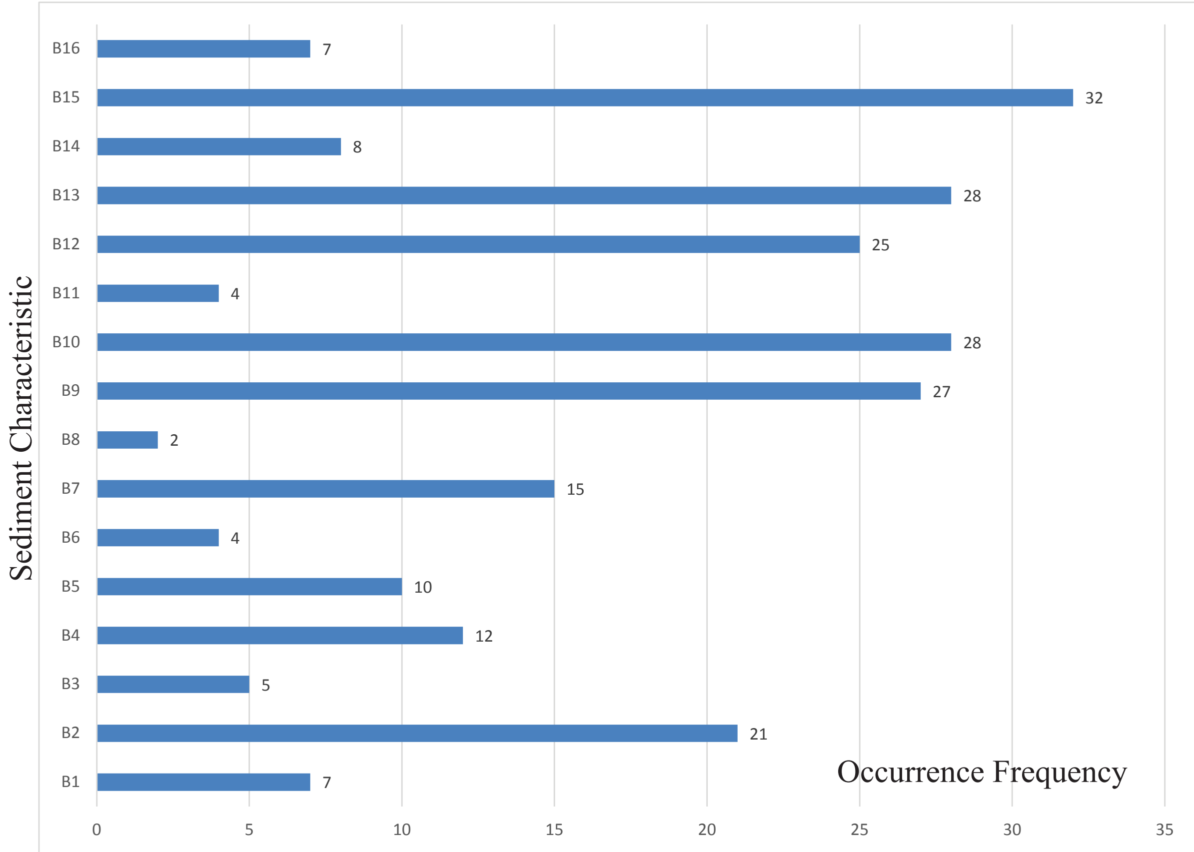

Fig. 10 : Frequency of occurrence of events for sediment characteristics only.

occurrence of members in each class. Figure 10 shows this frequency diagram for the 16 sediment classes from which one notes the dominance (in the sense of more than 20 sample values in the class) of just six of the sixteen classes. Equally, Figure 11 presents the corresponding information for the location classes from which one notes that just two classes (L4 and L14) dominate all the other classes with memberships of over 50 each, with a secondary grouping for classes L8, L10 and L12 containing memberships of 20 to 31.The two highest classes have in common that they both have flat relief despite all other attributes being different.

While this breakdown of the information is instructive it misses a major point in that the sediment characterization is considered independently of the location characterization, and vice versa of course. In order to incorporate both sorts of information at the same time and so to form a more complete picture of the flooding events and their interdependence on the total characteristics one proceeds as follows. First a matrix is constructed of all entries according to both schemes of classification.

A pictorial representation of the complete matrix of occurrence frequency is shown in Figure 12 from which one notes immediately the region of high frequencies of occurrence between classifications L16-L8 and B16-B11 with a secondary group of relatively high frequencies lying between L8-L4 and B1-B6. The high group has a common denominator in that the samples represent deposition on soft grounds and with thicknesses dominated by those greater than 1mm. The secondary group represents deposition on hard basal grounds with a concomitant very thin layering of less than 1 mm.

There is a strong connection between the basal support and the thickness of sediment. Soft basal materials such as meadows, gravel paths or dirt roads are associated with relatively thick sediment that is almost

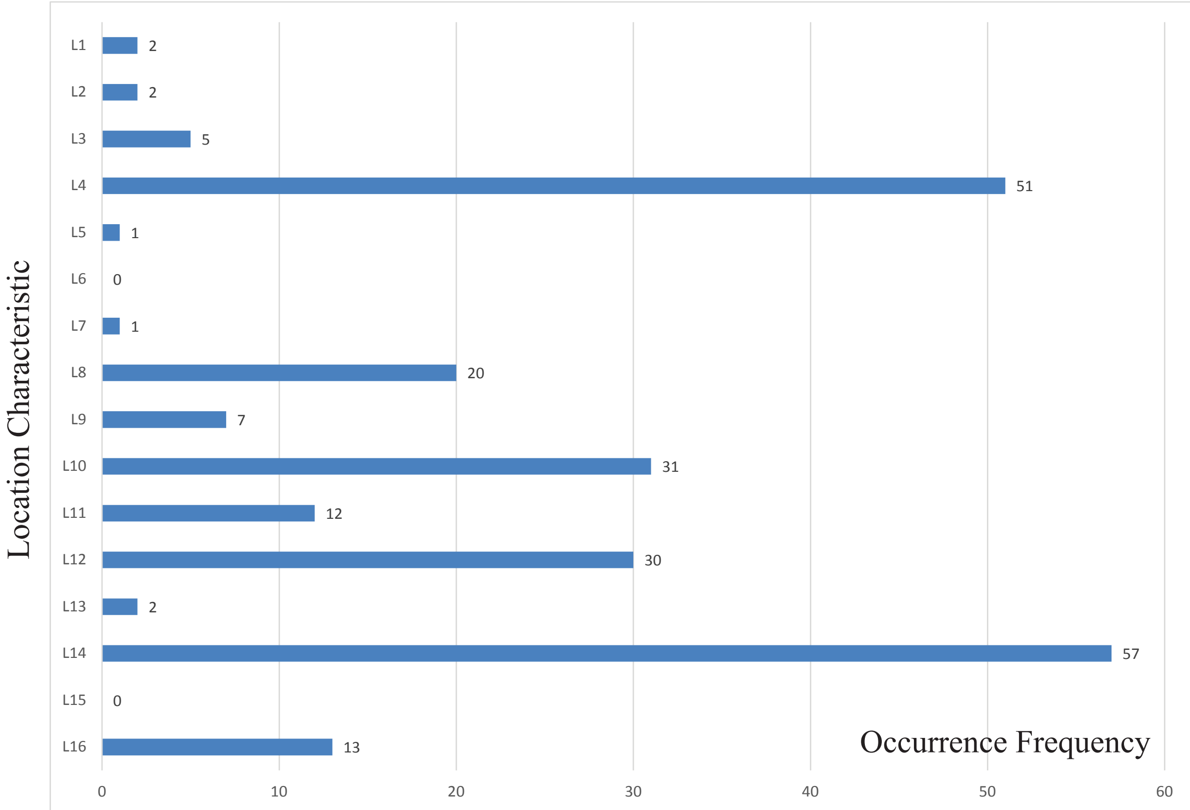

Fig. 11 : Frequency of occurrence of events for location characteristics only.

always more than 1 mm. In contrast on firm grounds, such as paved roads and sidewalks, the dominance is one of thicknesses smaller than 1 mm.

An explanation for this connection is that soft basal material provides an uneven surface and so has a higher potential to accumulate sediment. For instance in puddles and small depressions it is easier to accumulate sediment than on smooth asphalted areas. In addition, in meadows the vegetation can lead to retention as well. A second possibility is that on hard grounds it is much easier to measure the sediment thickness so that an extremely thin sediment cover of less than 1 mm is relatively easily measured. In contrast on soft ground the boundary between sediment and basal layer is more difficult to determine. It can happen that one errs on the side of setting a thickness at more than 1 mm due to this uncertainty. However, because there was no hard ground throughout most of the study region this potential error is unavoidable.

Further connections between the criteria used are also to be noted. For instance all high occurrence frequencies related to vegetation and thickness indicate that where one had low levels of vegetation the sediment thickness was less than 1 mm while high levels of vegetation were almost all blessed with thicker layering of sediment. One cause can be that thick vegetation hinders the flow speed of the flood waters and so allows more deposition of sediment. Note that thick vegetation is usually correlated with a soft basal layer so that one anticipates a similar behavior as indeed seen while hard grounds tend to lack thick vegetation to a significant extent. A connection of vegetation degree to other criteria used, such as organic material content in the samples, could not be determined.

A further dependence between the criteria used is to be seen in the coarse grained content of the samples: those with high content mostly show low to zero dry strength. If no coarse material is present then the dry strength tends

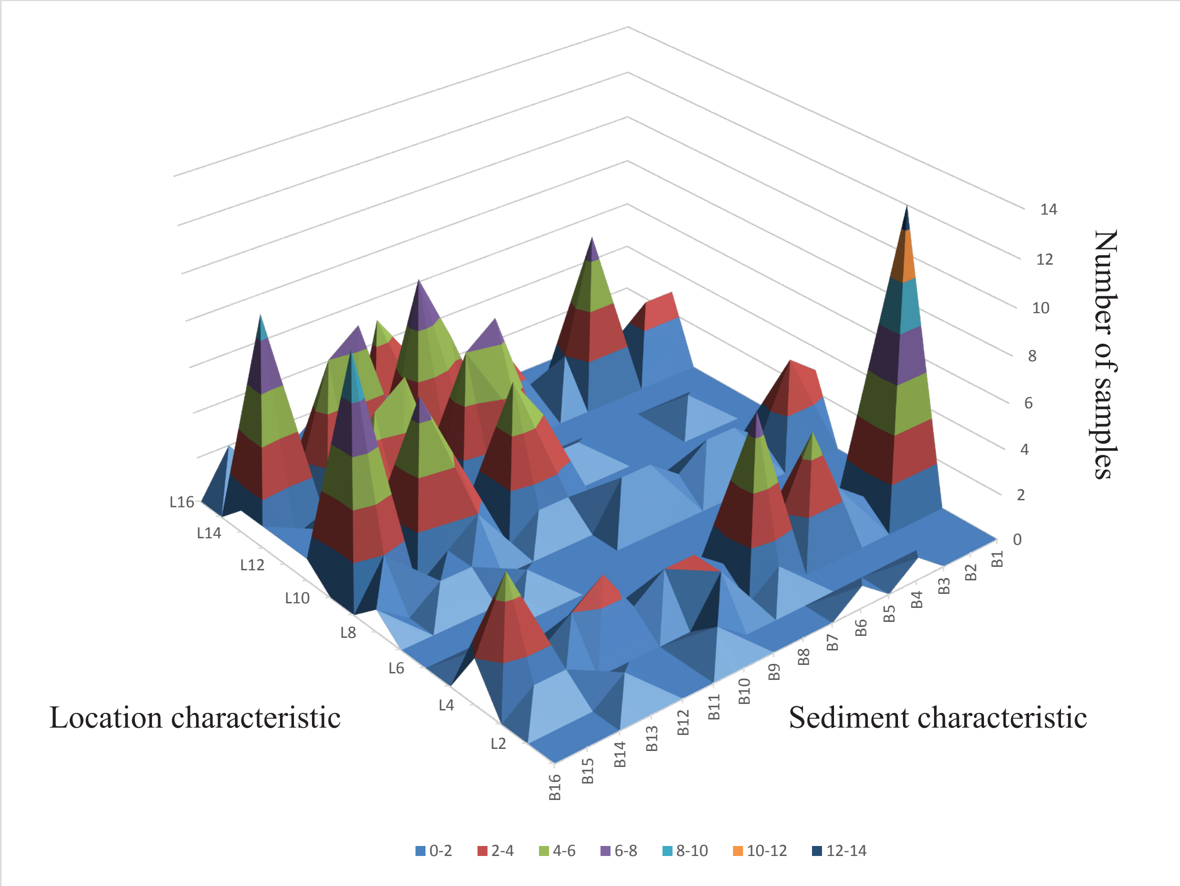

Fig. 12 : Occurrence frequency of events when both sediment and location characteristics are considered simultaneously.

towards medium to high values. This result is not unexpected because the larger grain size particles tend to lower significantly both the dry strength and the binding ability of deposited sediments.

3. Interpretation and Conclusion

The massive flooding of the Saale had interesting consequences for sediment behavior in the flooded regions. Sediment deposition was dominant in regions without hard grounds but with vegetation and was much less in hard substrate regions.

The average thickness of the fine-grained material indicated a transport volume of between about 5 to 15 l/m^2. In the total flooded region in Halle of around 32.8 km^2 one can estimate some $3x10^5$ m^3 of fine-grained material was deposited.

The transport of fine-grained sediment along the Saale had its direction changed by the flooding in the region Halle: Between Trotha and Lettin in the north, a sorting of the grain sizes was reached, that, on the one hand, lowered the medium grain sizes and, on the other hand, altered the grain size distribution at the same time.

The combined influence of location characteristics and sediment characteristics led to a pattern of sediment deposition in the flooded domains that typifies the significant variations between hard and soft grounds, vegetation cover, relief (flat versus steep) and coarse grain content. This information can likely be of use in the event of a further flood event of the magnitude of that from June 2013.

4. Acknowledgements

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