Sediment transport, bedforms and drainage pattern of laterally unconfined, low-sinuous, multiple-channel braided streams: the example of the Solling Fm (Middle Buntsandstein, Central Germany)

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1. Introduction and key objectives

In the vicinity of the town Nebra (Sachsen-Anhalt, Central Germany) fluvial sandstones of the Solling Formation (Middle Buntsandstein, Lower Triassic) crop out in an about 70 km² large area. Along the Unstrut river and its tributaries the formation is exposed in several up to 500 m wide and up to 10 m high key sections. Numerous smaller outcrops, mostly abandoned quarries, contribute to the excellent exposures of the Solling Formation.

The detailed analyses of bounding surfaces, lithofacies, sedimentary architecture and palaeohydraulics on more than 100 individual outcrops revealed a low-sinuosity, multiple-channel braided stream. The stream was laterally unconfined and the basinal setting aggradational.

Key sections provide detailed cross-sectional views along and across main channels, along channel-floodplain and channel-crevasse splay-floodplain transects and give considerable insights into:

- bedforms and migration of braided bars
- architecture of braided channel fill
- bedforms, formation and architecture of levees, crevasse plays and sheet floods
- sediment transport and drainage pattern of channels and floodplains

2. Results

The up to 30 m thick Solling Formation shows an aggradational pattern of up to 4 m thick units marked by flat slightly erosional bounding surfaces at their bases. These bounding surfaces can be traced along large key sections and correlated between them and are thus considered to represent 5th-order or higher bounding surfaces of large-scale depositional events. Internally these large-scale depositional events are characterised by pronounced lateral facies shifts from braided channel to overbank environments.

2.1 Braided channels

Individual channels are up to 250 m wide and their fill never exceed 4 m in thickness resulting in width/depth ratios (F) of 50 to 60 and low sinuosities (P) of 1.1 to 1.22 using the equation according to Schumm (1963). Three co-occurring non-incisional channels could be reconstructed that dissect the approx. 12 km wide exposed part of the fluvial plain. Mapping of channel and overbank environments revealed slightly bended channels of low sinuosity. The course of channels vary between NNW-SSE to NE-SW and the overall network comprises a typical braided pattern. The **braided channel** fill is dominated by large- to medium-scale cross-bedded lithofacies forming gravely and sandy bedforms (GB, SB). Linguoid bars in mid-channel position are generated by lateral and downstream accretion (LA, DA) and vertical aggradation of these bedforms. Calculated mean azimuths of palaeocurrent data measured at several locations vary between NNW (350°) and NE (40°) and correspond to mapped river courses. Maximum angular ranges (θ) of these measurements are between 90° and 108° resulting in low sinuosities (P) of 1.15 to 1.23 using the equation of Miall (1976).

2.2 Overbank environments

Laterally the channels are flanked by up to 140 m wide and up to 5 m thick **natural levees**. Natural levees (LV) are thickest at their channel side and sloping gently away towards the floodplain. Vertically levees consist of fining-upward units with cross-bedded gravely sandstones at the base followed by thick horizontal-laminated to low-angle cross-bedded silty sandstones. The top experienced pedogenesis and comprises immature calcisols. The sharp and slightly erosional base of cycles and their upward change from lower to upper plane-bedforms indicate levee formation by channel overtopping during floods.

Levees are partly eroded by up to 30 m wide and up to 3 m deep steep-sided **crevasse channels** (CR) whose axis are oriented oblique to almost perpendicular (60-79°) to the axis of the respective river channel. The symmetric channels cut into levees and comprise a simple ribbon-like fill of cross-bedded lithofacies that is laterally not associated to levee-forming strata. The cut-and-fill relief indicates overbank flow and incision of crevasse channels during flood stages and their plugging during low stages.

Towards floodplains crevasse channels are connected to lobate shaped **crevasse splays** (CS). Attached to natural levees these splays have radii between 100 m and 1 km. The overall geometry is characterised by sharp and flat bases, convex-up tops and thinning out at distal ends. The multi-storied internal organisation shows fining-upward units of cross-bedded lithofacies separated by bounding surfaces gently dipping towards the floodplain. The resulting downlapping pattern suggest the stepwise progradation of crevasse splays onto floodplains. Corresponding to the lobate shape of crevasse splays measured transport directions have maximum angular ranges (θ) between 145° and 216°.

The up to 3 km wide areas between braided channels are characterised by stacked fining-upward units of up to a few metres thicknesses. At the proximal **floodplain** (close to channels) medium- and small-scale cross-

bedded lithofacies form up to 3 m thick amalgamated sheet sandstones. More distally thicknesses of sheet sandstones decrease and laminated floodplain fines (FF) become more and more important. Therefore sheet flooding was controlled by bedload at proximal and suspended load at more distal floodplains. Following deposition floodplains have been subject to intense pedogenesis. Mature calcisols point to lowered groundwater level after flood events and high evaporation rates.

3. Conclusions

The Solling Formation (Middle Buntsandstein) exposed around Nebra (Central Germany) provides a considerable good ancient example of a low-sinuosity, multiple-channel braided stream. In contrast to modern examples the system was laterally unconfined and the basinal setting aggradational.

The example of the Solling Formation comprises the following channel and interchannel environments:

- low-sinuosity **braided channels** (max. 250 m wide, 4 m deep), *F*: 50-60, *P*: 1.1-1.23, max. 3 km wide interchannel areas;
- channels not incised, coarse grained bedload, linguoid bars, DA, LA, θ max. 108°;

- **natural levees** (max. 140 m wide, 5 m thick), mixed-load, immature palaeosols;
- **crevasse channels** (max. 30 m wide, 3 m deep), cut-and-fill, axis oblique to braided channel;
- **crevasse splays** (max. 1 km radius), coarse to fine grained bedload, progradational pattern, θ max. 216°;
- proximal **floodplains**, sheet sands (max. 3 m), coarse to fine grained bedload (proximal);
- distal **floodplains**, floodplain fines, suspended-load, mature palaeosols.

References

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