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Short communication

Discussion: Alluvial architecture of the Quaternary Rhine-Meuse river system in the Netherlands, by G.H.J. Ruegg, *Geologie en Mijnbouw 72: 321–330, 1994*

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Introduction

In a recent paper, Ruegg (1994) presented a general overview of the depositional history of the Rhine-Meuse river system in the Netherlands during the Quaternary. He argues that the dominant characteristic is a climatically controlled alternation of braided and meandering fluvial styles. The point of Ruegg's paper is embodied in his fig. 11, showing the stacking pattern of braided and meandering-river deposits in settings upstream (fig. 11a) and downstream (fig. 11b) of the so-called terrace intersection. Ruegg suggests that in terraced landscapes meandering-river deposits have a relatively low preservation potential and are most likely to be found in the basal parts of the terraces, covered by relatively thick braided-river deposits. Although more data on this seem to be necessary (actually the example presented by Ruegg in fig. 7b appears to be an exception to the rule since it shows lateral-accretion deposits in the upper part of a terrace), his conclusions concerning potential for dating terrace sequences, as well as the study of meandering-braided transitions are important.

In the present discussion, I will focus specifically on Ruegg's fig. 11b, which suggests that meandering rivers incised into braided-river deposits during interglacials in the area downstream of the terrace intersection, in the same way as in the upstream area discussed above. The definition of the concept of the terrace intersection is crucial in this respect, and I will raise some questions concerning Ruegg's fig. 11b from the perspective of current sequence-stratigraphic theory.

The 'terrace intersection' concept

A valuable aspect of Ruegg's paper is the extensive discussion of the important concept referred to as the 'terrace intersection'. According to him, the terrace intersection of the Rhine is located in a 100-km-long zone near the Dutch-German border (for locations see fig. 1). However, I have some problems with the way in which the concept is defined. Ruegg (1994: 322) provides two descriptions, which, when inspected in detail, have different meanings. He first describes the terrace intersection as "the location where the fluvial terrace landscape (exhibiting net incision) changes downstream into a non-terraced landscape (characterized by net aggradation)", and subsequently adds that "upstream of the intersection the depth of a river's incision exceeds the thickness of its own previous deposits, whereas downstream of the intersection the reverse applies". Both definitions make sense. But in my opinion they are not compatible, as I will explain below.

The first, broad definition by Ruegg conforms to the concept of the 'hinge line', which has been widely used in connection with the Lower Mississippi River (reviewed by Autin et al. 1991). The hinge is an important concept in sequence-stratigraphic models (Jervey 1988; Posamentier et al. 1988; Posamentier & Vail 1988), defined as "a position of no subsidence of the basement surface when movement is measured against some fixed datum. Subsidence occurs basinward of the hinge with rate of subsidence increasing toward the basin centre" (Jervey 1988: 53). This definition, according to which the hinge line is primarily determined by tectonism, corresponds neatly to the first def-

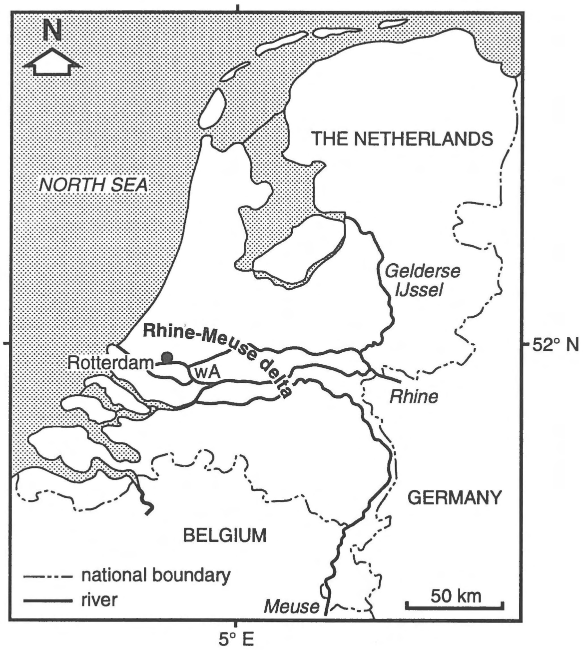

Fig. 1. Location map with topographic names referred to in the text. wA = western Alblasserwaard.

inition by Ruegg. The hinge line is likely to have a relatively fixed position over relatively long time scales, like the entire Quaternary. This is due to the fact that a basin margin will change its position only very slowly (e.g. Nunn 1985).

The situation is rather different when the second definition by Ruegg is considered. Here we deal with a phenomenon that is much more liable to large fluctuations in time and space. The terrace intersection according to this definition was first discussed for the Rhine-Meuse system by Pons (1957), who envisaged considerable horizontal movements of the terrace intersection around the Pleistocene-Holocene transition (Pons 1957: fig. 16). As shown by Törnqvist (1993; based on data from Van Dijk et al. 1991), the terrace intersection was located near Rotterdam by 8000 yr B.P., and presumably much further to the (south)west around the Pleistocene-Holocene transition, which is far downstream of the position envisaged by Ruegg (1994). The pioneering work by Pons (1957) makes clear that the position of the terrace intersection according to the second definition is mainly controlled by base level (sea level) and climate. Sediment supply is likely to be another critical factor.

The second definition by Ruegg contradicts his notion (Ruegg 1994: 322) that the Rhine and Meuse terrace intersections remained within 100-km-long zones in the (south)eastern part of the country throughout the major glacio-eustatic cycles of the Quaternary. I would therefore suggest that a clear separation be made in connection to the different meanings of the terrace intersection concept. The hinge line (terrace intersection *sensu lato*) is primarily structurally controlled and is relatively fixed in space over relatively large ($\sim 10^5 - \sim 10^6$ yr) time intervals. In contrast, the terrace intersection *sensu stricto (s.s.)* is rather climatically and/or eustatically controlled, and thus spatially variable over short ($\sim 10^3 - \sim 10^4$ yr) time intervals (at least during geologic periods with major climatic cycles, like the Quaternary).

In the case of the Rhine, the present terrace intersection *s.s.* is located close to the hinge line (near the Dutch-German border). However, the situation in the Lower Mississippi Valley exemplifies the difference between the two. The hinge line has been located near Baton Rouge (30°30′ N) during the Late Pleistocene and Holocene (Autin et al. 1991: 552). As can be deduced from the Quaternary geological map of the Lower Mississippi Valley (Autin et al. 1991), the present-day terrace intersection *s.s.* is located just north of Memphis (35°30′ N), approximately 600 km to the north. This is the upstream limit of the area where net aggradation has occurred during the (Late?) Holocene, as indicated by the first downstream presence of flood basins (vertically aggrading overbank deposits on top of Late Pleistocene substratum), and the occurrence of avulsions.

All in all, the examples from the Rhine-Meuse and Mississippi systems make clear that the tectonically controlled hinge line has a relatively fixed position, whereas the climatically and/or eustatically controlled terrace intersection *s.s.* can be rapidly displaced over large distances, and can be found both upstream and downstream of the hinge line.

Fluvial style, aggradation, and incision

The relationship in areas upstream of the hinge line between braided fluvial style and aggradation on one hand, and meandering fluvial style and incision on the other (fig. 2A), seems relatively well established on the basis of the arguments presented by Ruegg. It is supported by modelling exercises for the Meuse by Veldkamp & Van den Berg (1993), who show that terrace sediments are mainly deposited during cold-climate intervals, whereas subsequent interglacial (meander-

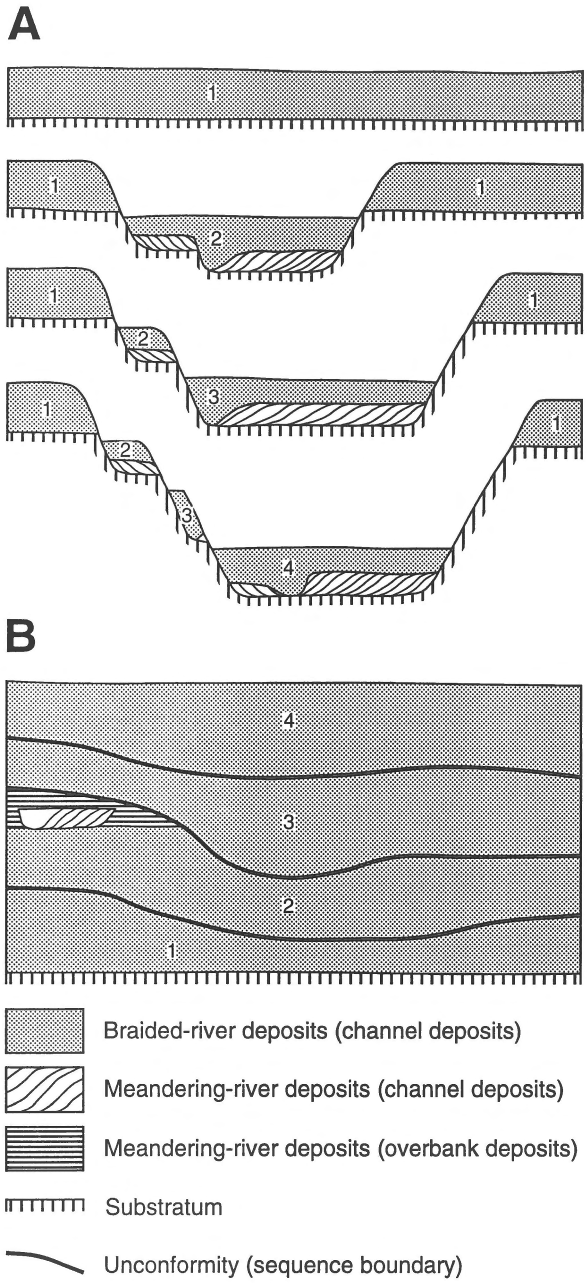

Fig. 2. Stacking pattern of braided and meandering-river deposites upstream (a) and downstream (b) of the hinge line, representing the situation in the Rhine and Meuse valleys, and the west-central Netherlands, respectively. Figure 2a is redrawn after Ruegg's fig. 11a:; fig. 2b is the proposed alternative to Ruegg's fig. 11b.

ing) incision produces the terrace morphology. On the other hand, this rather simple view on terrace formation has recently been challenged by Vandenberghe (1993).

The situation is completely different for the area downstream of the hinge line, and this is the main focus of my critique. According to Ruegg (1994: 324–325), meandering rivers are by definition degrading. This is definitely not true, as witnessed by the widespread occurrence of aggrading Holocene meandering fluvial systems in the Rhine-Meuse delta (e.g. Edelman 1956; Berendsen 1982; Törnqvist 1993). Innumerable examples of vertically aggrading meandering-river deposits are available, both from modern and ancient settings. In addition, the most widely known computer model of (aggradational) alluvial stratigraphy (Bridge & Leeder 1979) simulates deposition by a typical meandering fluvial system.

The schematic cross section of Ruegg's fig. 11b suggests that unconformities were produced downstream of the hinge line as a result of incision by meandering rivers. This would imply that the terrace intersection *s.s.* was located far downstream of the hinge line during time intervals with meandering fluvial style. This is highly unlikely, since meandering-river activity took place during interglacials (highstands), which, as Ruegg (1994: 327) correctly argues, are the periods when the terrace intersection moves farthest upstream. It is therefore extremely improbable that these highstand meandering rivers exhibited net incision. If the subrecent (Holocene) is taken as an analogue, it is clear that meandering (or anastomosing) rivers downstream of the hinge line were predominantly aggrading (Törnqvist 1993). Comparable fine-grained fluvial deposits from the last highstand (Eemian) have hardly been found in the substratum of the present-day Rhine-Meuse delta (Verbraeck 1984: 106–107), but it is very likely that they have once existed. Although the Rhine flowed northward through the Gelderse IJssel valley during the Eemian (Van de Meene & Zagwijn 1978), interglacial aggradation by the Meuse must have taken place in the west-central Netherlands. I therefore propose that the scarcity of meandering and/or anastomosing fines in the Pleistocene sequence of the west-central Netherlands is rather a result of erosion by glacial-age braided streams (fig. 2B), triggered by base-level falls during lowstands (cf. Posamentier et al. 1988; Posamentier & Vail 1988).

In any case, the scarcity of Pleistocene fine-grained sediments has not much to do with time, as suggested by Ruegg (1994: 326–327). This is exceptionally well illustrated by the thickness (~15 m) of the Holocene fluvial sequence (transgressive and highstand systems tracts) in the west-central Netherlands (western Alblasserwaard) that was formed in ~8000 years, compared to the underlying Weichselian lowstand systems tract, which comprises not more than ~10 m in ~100 000 years (Bosch in press). So instead of time, accommodation (Jervey 1988) is the crucial factor controlling sediment thickness.

Once again, an interesting comparison can be made with the Lower Mississippi River, where fine-grained fluvial and deltaic highstand deposits (presumably mainly Sangamonian, possibly partly Wisconsinan; Autin et al. 1991: 558, 582) are locally still preserved as terrace remnants, for instance along the northeastern boundary of the Holocene deltaic plain. Since adjacent braided-river deposits which were formed during the subsequent lowstand are found at a much lower elevation (~40 m), underlying the Holocene deltaic package, it is clear that substantial erosion has taken place during the last glacial maximum. I envisage a similar situation for the Rhine-Meuse delta, with the only difference that no Eemian deposits have been preserved there. My conclusion therefore is that in settings like the Late-Quaternary Lower Rhine-Meuse system, characterized by high-amplitude (>100 m), short-period (<100 ka) glacio-eustatic cycles, preservation potential of coarse-grained braided-river deposits is much greater than that of fine-grained meandering-river deposits. This is true both upstream and downstream of the hinge line.

In summary, I believe that the model presented by Ruegg (1994: fig. 11) provides a useful working hypothesis for the area upstream of the hinge line (fig. 2A), although the proposed vertical succession from meandering to braided-river deposits may need more field evidence to be confirmed. However, as I have pointed out, the situation downstream of the hinge line is very likely to be different (fig. 2B). I expect this area to consist (at least for the large glacial cycles of the later part of the Pleistocene) of stacked packages of braided-river deposits, separated by eustatically controlled type-1 sequence boundaries (Van Wagoner et al. 1988).

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