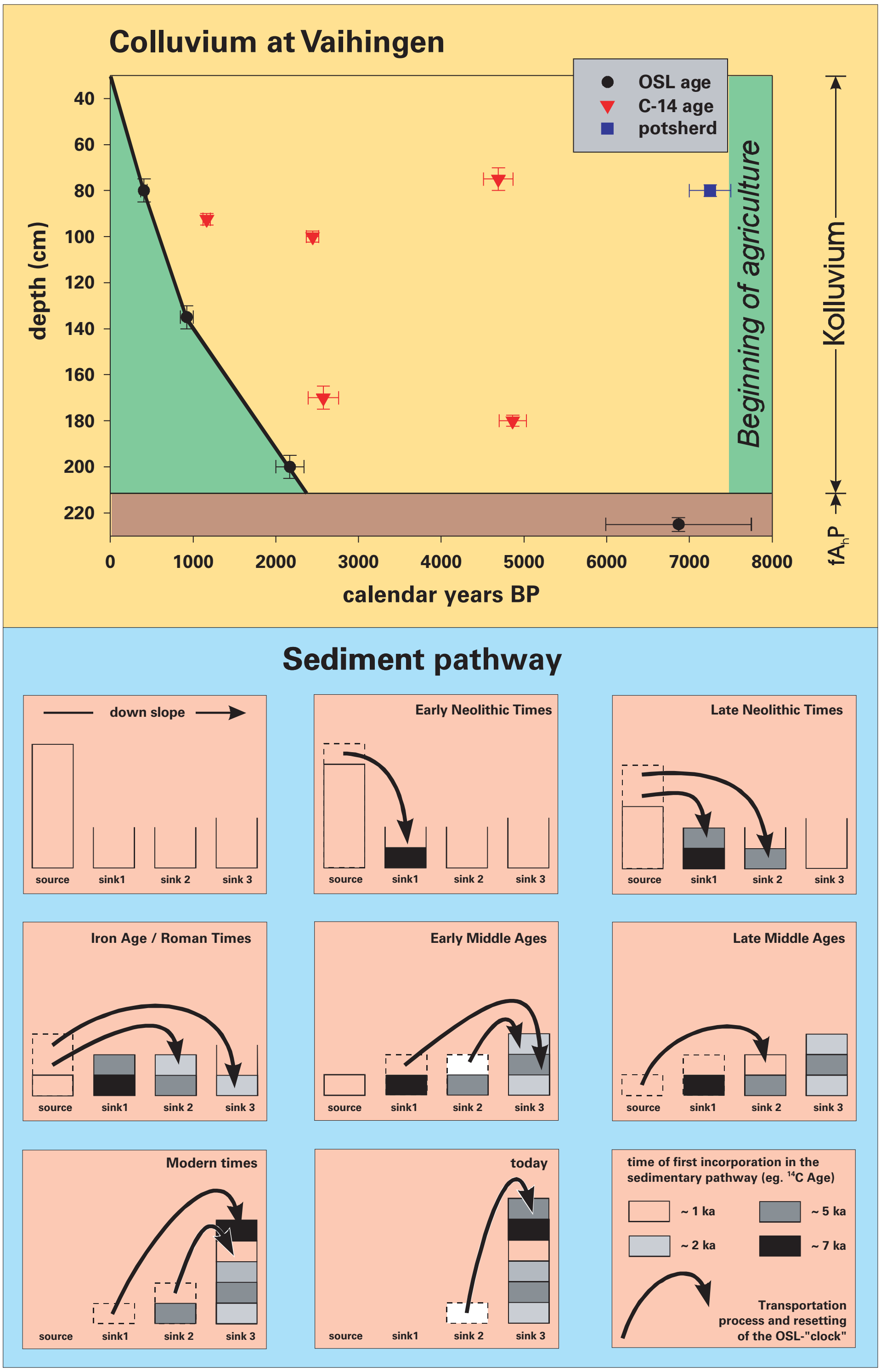

Figure 1: (adapted from Lang and Hönscheidt, 1999)
a) (upper part) Age versus depth plot for colluvium from Vaihingen/Enz. OSL ages and calibrated AMS ^{14}C ages (1 σ confidence level) of organic remains are plotted according to the depth of sampling. The archeological age of a ceramic fragment is also plotted. The ages of the strata imply that most of the material was brought to its present location not in a single event, but after several pulses of transportation with intervening periods of storage.
b) (lower part) Model of colluvium formation at Vaihingen/Enz: The first erosion occurred as early as Neolithic times (at about 7 kyr), partly filling sedimentary traps on the upper slope. As soil erosion proceeded, ca. 5 kyr-old material (Late Neolithic) became trapped in the sinks (represented by the 3030–2700 BC and 2870–2510 BC organic remnants). During the Iron Age/Roman period (around 2.5–2 kyr ago) up-slope sinks were filled up (represented by the 520–370 BC and 760–390 BC organic remnants). During this period for the first time eroded material was transported all the way down to the lower slope (represented by the 2170±170 a old colluvium). When erosion occurred on the crest and the upper slopes, the erosion of sediment trapped in the depressions (sinks 1 and 2) also started. Around 1.5 kyr ago sediment was incorporated in the colluvium which had entered the depositional pathway 0.5 kyr to 3 kyr earlier. About 0.5 kyr ago Neolithic material was deposited on the lower slope, covering sediments deposited here about 1 kyr ago.

Examples from the Rhine Catchment

The Rhine river drains large parts (189.700 km^2) of central Europe. The river channel stretches 1320 km and drains into the North Sea. On its course the hydrological regime of the Rhine changes from glacio-nival in the Alps and upland areas to pluvially dominated lowlands in the Netherlands. Here the mean discharge is 2500 m^{3s-1}, the mean flood discharge is 6000 m^{3s-1} and the mean discharge at low flow is 1000 m^{3s-1} (IHP/OHP, 1996).

Agricultural activities in the Rhine drainage basin date back to the Neolithic. The loess landscapes of northern Switzerland, southern Germany, and France were especially favourable for settlement due to fertile soils and the relatively mild climate. By medieval times the whole Rhine catchment had been settled, with only a few exceptions in remote mountain environments. Today the Rhine catchment can be characterised as 'advanced industrial' (LUCIFS - PAGES report, Series 96-2).

In this report we present results of two studies from the German part of the Rhine catchment related to the long-term development of the fluvial system under human impact. The first shows the sedimentary record of the entire period of agriculture. The second example is based on field evidences and historic records of the last 1350 years.

Loess Hill-Country

The first case study is located in a tributary catchment of the Rhine river. Large parts of the Rhine drainage basin are covered by loess deposits. Most of these regions can be described as rolling hill country, the so called 'Gäu' areas. In these areas anthropogenic soil erosion has led to extreme truncation of soil profiles and deposition of thick colluvial and alluvial sediments. Colluvial sediments accumulated on the lower slopes have proved to be valuable archives for studying man-landscape interactions over the period of agriculture. The sediments are deposited close to their source areas, so interpretation of results is generally straightforward. However, when looking in detail at such deposits, temporal changes in sediment delivery pathways are obvious. Results obtained at an Early Neolithic settlement near

Rhine, continued from page 11

Stuttgart serve as an example (Fig. 1a; Lang and Hönscheid, 1999). Dating is based on artefacts and ^{14}C dating of organic remains incorporated in the sediments, and on optical dating. Radiocarbon dates the death of an organism, so it determines the time when sediment particles first enter the erosion-transportation-deposition pathway. If deposition follows quickly after, the ^{14}C age provides a close approximation to the time of sediment deposition, but in many colluvial environments this is not the case because reworking of older colluvial sediments occurs. The time of reworking can, however, be estimated by optical dating techniques (Aitken, 1998; Lang *et al.* 1998). Chronological data allow reconstruction of the depositional history of the colluvium and also the identification of temporary sedimentary sinks along transportational pathways. A cascade-model of colluvium formation was developed (Figure 1 b). Colluvial sediments resulting from early soil erosion in the Neolithic to Iron Age periods were mainly deposited on the upper slopes. Significant deposition on the lower slope occurred for the first time during the Iron Age and Roman period. Since then deposition rates have increased because of more intensive land use.

A more general picture of colluvium formation is shown in Figure 2: Optical ages obtained from 54 colluvial sediments in southern Germany are plotted as frequency distributions. Periods of colluvium formation roughly coincide with periods of strong human impact on the environment. Climatic changes seem to play only a minor role.

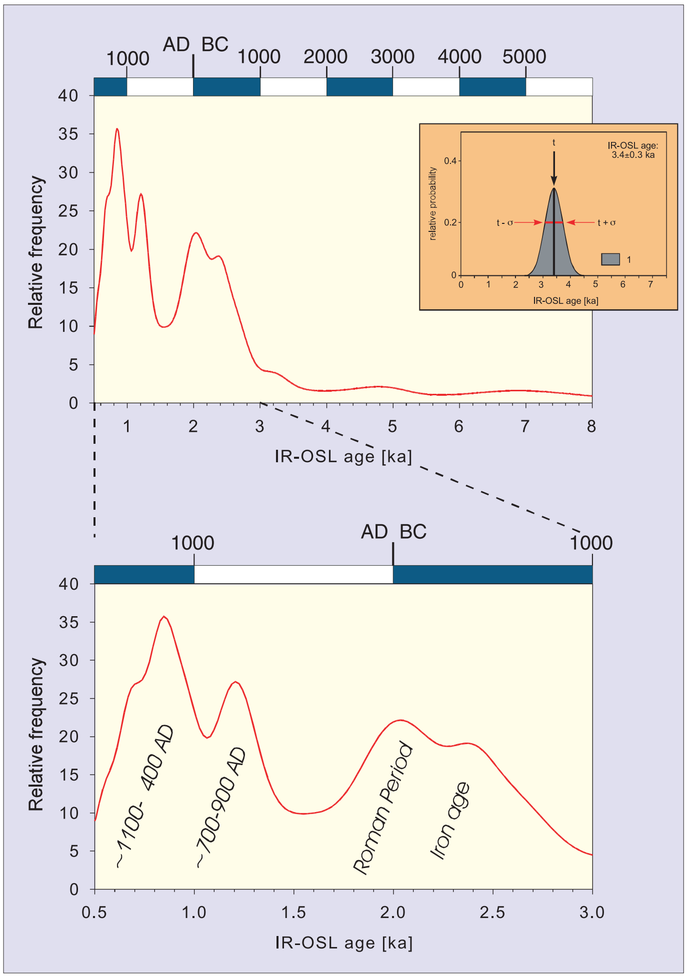

Figure 2: Frequency analysis of OSL-ages. OSL ages obtained on soil erosion derived sediments from several different sites in the loess hills of South Germany. OSL-ages are plotted as Gaussian-curves and the area below the curves set to one (see inset). The individual curves were then summed and the resulting distribution plotted. The lower plot gives an enlargement of the upper plot. Only the number of ages is used for analysis, and volumes of sediment deposited is not considered. Nevertheless, phases of colluviation clearly coincide with phases of strong human impact: First colluvial sediments were deposited during early Neolithic times. A second small maximum in the distribution occurs towards the end of the Neolithic period. Many colluvia originate in the Iron Age and Roman periods, while the maximum number of optical ages relate to Medieval times. (from: Lang 2000)

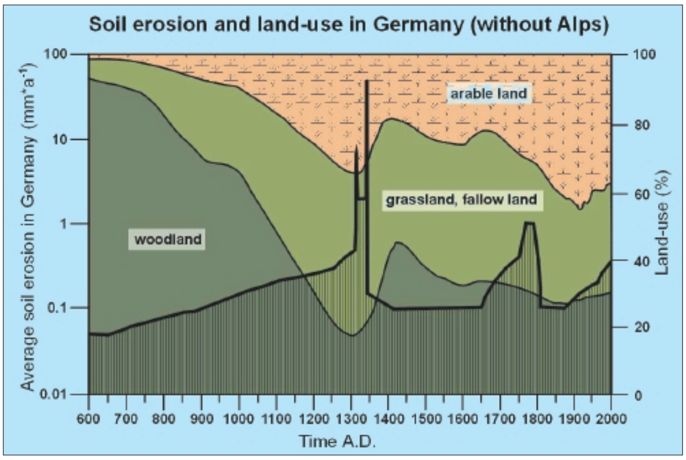

Figure 3: Soil erosion and land use in Germany during the last 1400 years (changed after Bork et al. 1998a). The average soil erosion in Germany (thick line, left axes, note: log scale!) and the percentages of woodland, fallow and arable land (right axes) are plotted on a calendar scale. Extreme rainfall events during the 14th century coincided with high percentages of arable land and fallow land and caused extreme soil loss.

Landscape Dynamics in Germany During the Past 1350 Years

The population density in Germany was reduced drastically during the Dark Ages as a result of diseases (e.g. the bubonic plague), cold and humid weather conditions resulting in crop failures, famines, ecological catastrophes and migrations from central to southern Europe. Most settlements of the Roman Ages were abandoned and forest returned to the former agricultural land. In the mid 6th century AD around 90% of Germany was again covered with nearly natural woodland (Bork *et al.* 1998a). In addition to historical documents, this is also evidenced by a period of rather intense soil formation. In early Medieval times areas with fertile soils and favourable climatic conditions for agriculture were again cleared. When population density increased the hilly regions in southern, western and central Germany as well as the lowlands of northern and northeastern Germany were also cleared and used for agriculture. By the early 14th century the area covered by woodland was reduced to only 15% (Figure 3).

In a modelling approach where climatic conditions were held constant during the past 1350 years the effects of land use change were investigated (Bork *et al.*, 1998a). The drastic decrease of the total biomass reduced evapotranspiration (-20%) and raised total runoff in Germany considerably (+60%). These effects are confirmed by field data. Soil profile analysis show a strong rise in the mean groundwater level from the Dark Ages until the late high Medieval Ages. Oxidation horizons of Gleysols from the early 14th century often lie 2 or 3 m above those of the 7th century AD. Soils at concave downslope sites were deeply decalcified during the Dark Ages, while higher groundwater levels since the high Medieval Ages have reversed this trend through imported calcium. Thus calcium enriched horizons developed in horizons that had earlier been leached.

Besides the changes in the average water balance, an increased number of extreme rainfall events characterised the first half of the 14th century as is clearly documented in sediment successions (Bork *et al.*, 1998a). During the first half of the 14th century widespread colluviation and fan development started. Fertile ploughing horizons of fields not densely covered with summer crops were frequently totally eroded. Half of the total hillsope erosion since 650 AD occurred during 1310 to 1350 AD. Where shallow fertile soils were completely eroded above stony layers the areas were abandoned and in many cases have been woodland since then. Where infertile sands were exposed by soil erosion (Bork *et al.* 1998b, Schatz, 2000) agricultural land use had to stop until soils enriched in organic matter were newly developed under woodland. In dells and furrows of sparsely vegetated fields (e.g. in ridge and furrow areas) deep U- or V-shaped gullies were formed. Some gully systems achieved depths of more than 8 m, widths of several decameters and lengths of several hundred meters to some kilometers. In some areas the development of extended badlands precluded further agriculture use. The formation of these extended gully systems based to only one or few catastrophic overland flow events which was shown by detailed analysis of erosional forms, their sedimentary fills and fan sediments (Bork, 1988, Bork *et al.*, 1998a). Where forests returned the gullies are still present today. In areas subsequently used for farming the gullies were quickly filled up over periods of some few decades.

Extreme weather events, famines, runoff, and floods during the second decade of the 14th century and in July 1342 are reported in contemporary written documents. In July 1342 a 1000-year rainfall event hit Central Europe (Alexandre, 1988, Flohn, 1949/50, 1958, 1967, Lamb, 1997, Pfister, 1980, 1985). Waterlevels for the period from the 19th to 25th of July 1342 are by far the highest ever recorded at several sites (Alexandre, 1988, Weikinn, 1958). Most stone bridges over the major rivers were destroyed. In July 1342 the overland flow rates in the catchments of the major central European rivers exceeded the 20th century maxima by factors of 50 to 200 (Bork *et al.* 1998a)! As a result of these catastrophes and of the Black Death during the years 1348/50 more than a third of Germany's population died. The area covered by woodland increased by three times from the mid 14th century until the late 15th century. Thus, also the average rates of transpiration increased and runoff decreased. Soil erosion again was of minor importance in most German landscapes until the mid 18th century.

Population density increased and woodland area decreased again during the 16th and 17th centuries. In the late 16th century a third of the landsurface of Germany was covered with woodland – most of it grazed. The size of the forest areas has not changed much since then, although the grazing intensity has been lowered in German forests since the 19th century.

Soil erosion rates increased again in many German landscapes during the fifth decade of the 18th century, in others a few decades later. Until the end of the 18th century, in some areas until the second or third decade of the 19th century, severe gullying was common. From soil and sediment analysis and from contemporary documents the occurrence of gullying can clearly be linked to an increased number of rainstorms. Of importance was the field size and the cropping sequence (namely the presence of fallow land). Hillslope erosion increased by an order of magnitude during the second half of the 18th century and was recognised as a severe problem. It was during this period that the first measures for soil erosion were proposed and used (cf. the publication of Heusinger, 1815, priced by the Royal Academy of Science at Goettingen).

After one and a half centuries of low hillslope erosion and an absence of gullying, soil erosion rates increased again significantly in the sixth and seventh decades of the 20th century. On average the rates tripled, due to changed crop sequences, increased field sizes and further mechanization. Today agricultural subsidies and the world market determine crop selection more than site characteristics. Crops with a low vegetation cover density in the erosive early summer months are common today (Dikau, 1986). Fields increased as a result of the reallocation of ground property. Soil conservation measures such as terraces and hedges that have been existing since the last period of intensive soil erosion (the late 18th century) were removed. The development of large and heavy agricultural equipment led to soil compaction and thus reduced infiltration capacities.

Summary

In the Rhine river catchment changes in the fluvial system seem to be dominated by changing human impact during the Holocene. Clearing of woodland and agricultural activities made the drainage basin susceptible to soil erosion by water. These changes influenced the water balance and runoff production. River dynamics changed dramatically due to the high supply of fine sediments that were produced by soil erosion. Today, smaller valleys are filled up several meters with flood loam – a sediment that has been developed mainly since Roman times.

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