Geomorphology 122 (2010) 213–222

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

# Holocene floodplain formation in the southern Cape region, South Africa

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ARTICLE INFO

*Article history:*
Received 18 June 2008
Received in revised form 16 January 2009
Accepted 16 June 2009
Available online 17 July 2009

*Keywords:*
Floodplain formation
Fluvial geomorphology
Environmental change
Gourits River basin
Cape region
South Africa

ABSTRACT

The sediments of Holocene floodplain banks in several river catchments in the southern Cape region, South Africa, were sedimentologically investigated and radiometrically dated. The study resulted in a differentiation into two sedimentation phases. The sedimentation of the older phase starts directly above the bedrock or above coarse gravels. These sediments are composed of 2.5–3 m of interbedded sand, silt, and clay. In part, they are stratified by organic horizons and inclusions. The radiocarbon dating of numerous organic horizons as well as fossil wood shows that the sedimentation during the older phase occurred between 1215 and 875 years BP at the base, and 670 and 15 years BP at the top of this sequence. The sediments of the younger phase mainly consist of homogeneous fine sand and are at least 3 m thick, stratigraphically above the sediments of the older deposition phase. However, the sediments of the younger layer can also comprise the entire Holocene deposits situated above the current riverbed. These sediments are mainly of modern age and are partly deposits of centennial flood events. The context between the onset of sedimentation and the start of pastoral farming by settlers after AD 400, which has been archaeologically verified, supports the hypothesis that the first sedimentation phase was set off or favoured by the degradation of the natural vegetation cover as a result of livestock farming. Later, increased sedimentation as well as an increase in peak flows resulting from increased landscape degradation due to intensified pasture farming by the European settlers has to be assumed.

## 1. Introduction

Holocene fluvial morphodynamics has been largely disregarded in geomorphological and palaeoclimatological research in South Africa. Up to the end of the 1980s, such investigations were almost completely missing (see Dardis and Moon, 1988). Research such as the work by Helgren (1978), Söhnge (1991), or Hattingh (1994) deals with Holocene deposits in stratigraphic investigations of the fluvial terraces, but abstains however from a genetic interpretation.

Studies of Holocene fluvial deposits that go beyond stratigraphic investigations, such as in the Blydefontein Basin of the northeastern Cape region (see Bousman et al., 1988), or in the Verlorenvlei lake-floor near Eland's Bay in the Western Cape Province (Meadows and Asmal, 1996), are exceptions. In these investigations, in regard to sedimentology and pedology, analyses of pollen, diatoms, and molluscs as well as $^{14}$C-dating, it was possible to prove three or four fluvial cycles. The cycles are based upon different sequences of clastic sediments, distinguished by erosion disconformities, palaeosols, or variable geochemical characteristics. Their formation dates back 5000–8000 years. The fluvial cycles are interpreted as the result of discharge fluctuations and are attributed to Holocene climate variations. It is astounding that in this context the possible anthropogenic impact on fluvial sedimentation is usually not taken into consideration (Holmes and Marker, 1995; Thomas et al., 2002), although the problem of soil erosion in South Africa has been an important research topic (Heine, 1987; Van Breda Weaver, 1988; Marker, 1988). In addition, the importance of soil erosion for landscape development (Rowntree, 1988) as well as for the current discharge behaviour of rivers (Scott, 1993) is well-known.

Current investigations on morphodynamics of South African rivers deal with the temporal development and dynamics of river meanders and avulsions (Tooth et al., 2002; Marren et al., 2006). Pertaining to the control factors of fluvial processes, a meander dynamic that was mostly independent of Holocene climate variations is assumed for the Klip River, a tributary of the Vaal River. The long-term recession rate of the scroll-bars is estimated at ~0.16 m/a. However, there was an obvious increase during the early phase of the 16th century (Rodnight et al., 2005). For the time periods of the late 1800s, the 1930s, as well as the late 1990s, in connection with settlement activity, wetland drainage, intensification of pastoral farming, and the re-introduction of the *hippopotamus*, anthropogenically caused changes of the morphodynamics in the Klip River catchment area are to be expected (McCarthy et al., 1998; Tooth et al., 2007).

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doi:10.1016/j.geomorph.2009.06.025

The essential knowledge of the Holocene landscape and climate development of South Africa is mainly the result of pollen-analytical, micro-palaeontological, and dendro-chronological analyses as well as isotope investigations (Deacon et al., 1983; Deacon and Lancaster, 1988; Tyson and Lindesay, 1992; Avery, 1993; Scott, 1993; Holmgren et al., 1999; Scott, 1999; Holmgren et al., 2003; Scott et al., 2003, e.g.). However, mineral and organic matter for use in corresponding investigations is sparse in the arid and semi-arid regions. The research from the studies mentioned indicates that the regionally differentiated wetter and drier phases that alternated in the Holocene (see Tyson and Lindesay, 1992) may have been superimposed by anthropogenic influences approximately over the last 2000 years. Around this time, the Khoi San started to evolve from hunters and gatherers to farmers and herders (Deacon, 1983). Later, a substantial impact upon the landscape development is assumed, as a consequence of the European colonisation.

Ever since the first comprehensive study by Acocks (1953), it has been controversially discussed if and how the settlement activity resulted in an expansion of the semi-arid parts of the Cape region, in particular the semi-desert Karoo, i.e. whether a desertification process took place (Heine, 1987; Bond et al., 1994). The current perception assumes that in pre-colonial times, the semi-arid Karoo was dominated by grassland and that in post-colonial times a widespread and irreversible degradation has taken place. However, according to Dean et al. (1995), it is becoming apparent that variations in the vegetation of the Karoo must have also occurred before the European colonisation took place (see also Coetzee, 1967; Meadows and Sugden, 1993; Meadows et al., 1994; Scott, 1999). This must have occurred partly due to the phases of increased aridity and partly due to pasturing by the Khoi San hunters and gatherers as well as by the Khoi Khoi herders (Meadows et al., 1994; Dean et al., 1995). However, further research is required in order to determine the type of changes that took place as well as their spatial and temporal dimensions. This research should include investigating various environmental parameters and taking the long-term ecological history of the Karoo into account (Dean et al., 1995). Also associated with the problem of desertification or degradation is the issue, is to what extent is the extensive erosion observed in the semi-arid Little Karoo also due to anthropogenic influences (Hagedorn, 1988).

In summary, it can be stated that up to now, there is a considerable lack of knowledge about Holocene fluvial dynamics in South Africa. Thus, the goal of the present research is to obtain findings on the course of the Holocene fluvial dynamics in the southern Cape region and its temporal and spatial differentiation. In addition, we wanted to gain information about the importance of the anthropogenic impact upon the currently extensive erosion in the semi-arid Little Karoo, an area that had previously been investigated (Hagedorn, 1988).

## 2. Methodology

In the investigation area, the floodplains and floodplain sediments of the Gourits River basin were geomorphologically, sedimentologically, and pedologically investigated (Leser, 1996; Brady and Weil, 1999; AG Boden, 2005). The research aimed at surveying floodplain deposits of the semi-arid Little Karoo as well as from the northern and southern foreland of this region stratigraphically, distinguishing them according to their composition and dating them based on interbedded organic material.

A systematic selection of accessible profiles was arranged in consideration to the results from earlier investigations (Hagedorn, 1987, 1988). All in all, twelve sections were studied in the Gourits river valley and its tributaries, five of them in detail. In the eastern Cape region a further profile was studied and sampled at the Great Fish River basin. This profile was consulted to discuss the radiocarbon dating results with regard to the onset of alluvial sedimentation in different river basins of the Cape region. In addition to surveying the sites, fieldwork in the floodplain banks involved detailed exploratory work as well as sampling for laboratory analyses and dating. In general, the up to 8 m high profiles were artificially made and set up in natural cuts. The sediment sections were analysed layer by layer with respect to density, compaction, colour, and grain size, sedimentary changes and conformabilities, inclusions of humus horizons and organic detritus, and the occurrence of possible fossil land surfaces (see AG Boden, 2005).

The sediment samples were analysed in the geomorphological laboratory of the Geographical Institute of the University of Göttingen. The analyses concentrated on grain size, content of organic carbon and $CaCO_3$ (see Pansu and Gautherou, 2006). The carbon content was determined in a muffel furnace by dry incineration. Organic matter, such as fossil wood, humus-rich sand and silt as well as, in one case, molluscs, was taken in several profiles. A total of 29 separate samples could be used for $^{14}C$-dating, which was organised in the Isotope Dating Laboratory of the Institute of Soil Science at the University of Hamburg, Germany by Dr. P. Becker-Heidmann. Samples with very low carbon content were dated using the AMS-procedure (see Harkness and Becker-Heidmann, 1996; Geyh, 2005). The fossil wood was identified at the Department of Wood Science at the University of Hamburg by Prof. Dr. D. Eckstein.

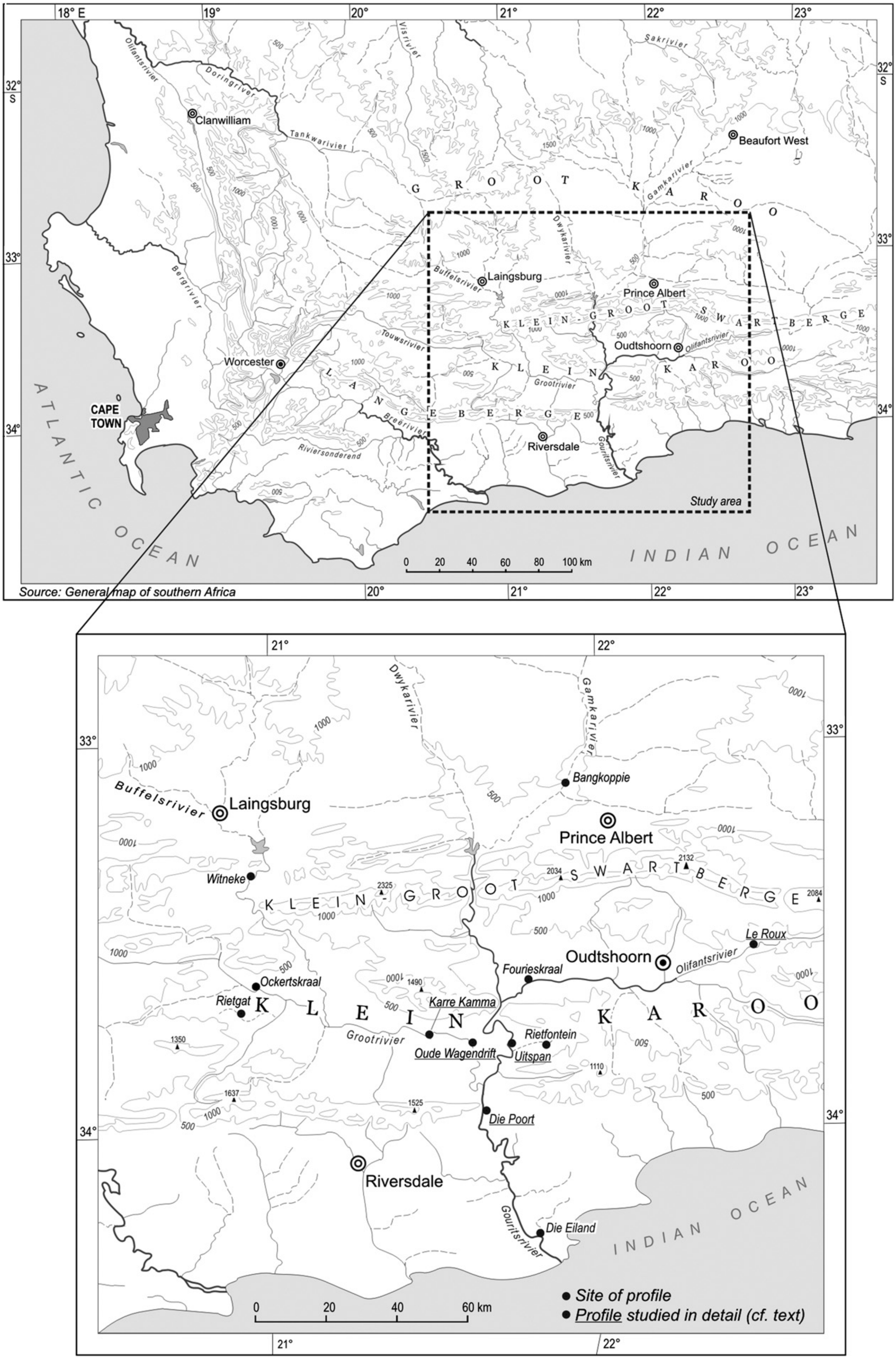
## 3. Regional setting

The present investigation deals with the Holocene floodplain development in the Gourits River basin, which, with its ca. 45,000 km$^2$, is the third largest river catchment in South Africa (Heydorn, 1989) and the largest in the southern Cape region. The Gourits River has several important tributaries, such as the Groot River, the Dwyka/Gamka River and the Olifants River (Fig. 1). The discharge of these rivers varies strongly and the smaller tributaries have periodic to episodic discharge. Minimum and maximum monthly amounts of discharge of the Gourits River between $0.2 \times 10^6$ m$^3$ (February 1946) and $1{,}081 \times 10^6$ m$^3$ (March 1960) can be expected. The maximum flood discharge measured at the mouth of the river was 11,680 m$^3$ s$^{-1}$, and recorded at the end of January 1981 (Heydorn, 1989).

The Gourits River basin includes the Little Karoo, parts of the southern Great Karoo, and parts of the coastal foreland (Fig. 1). The Little Karoo extends from an intermontane basin within the South African Cape Fold Belt and is bordered in the north by the Swartberg Mountains and in the south by the Langeberg Mountains. These mountain ranges are composed of quartzitic sandstones, whereas the areas of the Karoo are formed by Bokkeveld beds, interbedded shales and sandstones. Granite and conglomerates occur secondarily (Hagedorn, 1988). The coastal foreland south of the Langeberg Mountains is mainly composed of shales, mudstones, and conglomerates. Primarily, the Gourits River basin comprises areas with fine and unconsolidated sediments, in which the soils are predominantly developed as *lithosols* (Heydorn, 1989).

This region is in a semi-arid part of the Cape Province, with precipitation values of 200–300 mm/a in the central area, and has 7–12 arid months. There are precipitation maxima in the fall, winter and spring months and on average there are 30–40 days with precipitation annually. Only in the mountain ranges can an annual precipitation of more than 750 mm be expected. During thunderstorms with excessive precipitation, half of the entire annual precipitation may fall within a

**Fig. 1.** The Cape Province in South Africa with the Cape Fold Belt, the Little (Klein) and the Great (Groot) Karoo. The detailed map shows the study area with the Gourits River basin and sites of profiles described in the text.


18° E
19°
20°
21°
22°
23°
32° S
33°
34°
Olifantsrivier
Doringrivier
Clanwilliam
Tankwarivier
Visrivier
Sakrivier
Beaufort West
Gamkarivier
G R O O T K A R O O
Dwykarivier
Bergrivier
Buffelsrivier
Laingsburg
Prince Albert
K L E I N - G R O O T S W A R T B E R G E
Oudtshoorn
Olifantsrivier
Touwsrivier
Worcester
K L E I N K A R O O
Grootrivier
L A N G E B E R G E
Breërivier
Riversdale
Gourtsrivier
Riviersonderend
CAPE TOWN
ATLANTIC OCEAN
INDIAN OCEAN
Study area
0 20 40 60 80 100 km
Source: General map of southern Africa
500
1000
1500
Bangkoppie
Witneke
2325
2034
2132
2084
Le Roux
Fourieskraal
Ockertskraal
Rietgat
1490
Karre Kamma
Oude Wagendrift
Rietfontein
Uitspan
1110
1350
1637
1525
Die Poort
Die Eiland
0 20 40 60 km
● Site of profile
● Profile studied in detail (cf. text)

short time. There will be 10–20 of such thunderstorms in a year, and they will cause surface runoff as well as flash-floods.

In general, the surface runoff on slopes and in channels is enhanced through the widespread semi-arid scrubland, the so-called Karoo-vegetation. Essentially, the Gourits River catchment is in the region of the Succulent Karoo Biome and lies in the transition area of the Nama Karoo (Acocks, 1953; Dean et al., 1995). Hence, succulent bushes of the *Aizoaceae* and deciduous dwarf shrubs of the *Asteraceae* are widespread. In general, the vegetation is sparse and widely spaced. The degree of coverage depends on the irregular distribution and low absolute amount of rainfall (Hagedorn, 1988; Meadows et al., 1994).

## 4. Results

### 4.1. Alluvial sediments and geomorphologic structure in the Gourits River basin

The floodplain deposits of the Gourits River and its tributaries are generally 5–8 m thick sediment layers above the valley floor (Fig. 2). They are mainly composed of sands and silts and are infrequently interbedded with gravel layers or lenses. Due to their sedimentological composition, they are clearly distinguishable from the presumably Pleistocene gravel terraces (Hagedorn, 1988), which are also morphologically differentiable due to altitude differences of partly over 10 m. In general, the floodplain sediments have horizontal bedding with occasional cut-and-fill-structures. Humic horizons help in classifying the sediments.

The valleys and their floodplains are up to 200–300 m wide and frequently carry water only periodically or episodically. In general, the modern-day rivers have eroded the floodplain sediments down to the bedrock (see also Tooth et al., 2007) or respectively down to the coarse gravels and boulders that cover the bedrock. The incision led to the formation of floodplain banks or ridges, whose surfaces are, at least during exceptional floods, still flooded today. Boulders and bedrock form the underlying bed of the investigated floodplain sediments and the boulders usually show signs of modern transport.

### 4.2. Organic interstratifications and inclusions in floodplain sediments

The floodplain profiles investigated in the Gourits River basin are primarily composed of sands and silts and are partly laminated. Generally, layers of loamy to silty sands, silts, and loams appear dark in the exposed profiles, indicating relatively higher soil moisture and/or contents of organic matter. Several samples of organic matter-rich sand, loam, and silt layers were radiocarbon dated (see Table 1).

Dependent upon the characteristics and thickness, the percentage of organic carbon, the position within the stratigraphic sequence, and, with respect to the radiocarbon age, the organic matter-rich layers can be interpreted as indicators of in-situ soil formation on older land surfaces or as eroded and reworked soils. In this respect, the comparatively high content of organic carbon in various samples allows an interpretation of the sampled horizons as relicts of fossil topsoil on older floodplain banks. Under the semi-arid conditions in the investigation area, even low carbon contents of 0.6% can be evaluated to that effect (see Brady and Weil, 1999). However, especially due to their stratigraphic positions, most of the organic layers sampled must be seen as reworked material (Table 1).

Furthermore, organic mud and plant detritus were found embedded in sand and loam beds, as well as in clay lenses in various profiles and were dated. Predominantly, this material is also most likely reworked.

### 4.3. Fossil wood and wood species determination

Fossil wood was sampled from four profiles in the Gourits and Groot River basins. The wood species were determined in 10 samples, out of a total of 13 samples. The samples consisted of remnants of logs and/or branches of different-sized cross-sections and were examined for their microscopic structural patterns. The analyses resulted in two groups of samples, each with similar structural characteristics, as well as three specimens with different patterns (see Table 2).

The wood structures of group 1 correspond to the botanical species *Rhus lancea* of the *Anacardiaceae* family. Wood from this modern species is designated as "Karoo tree" and is a small, rather scrubby bush or a tree up to 10 m in height. The Karoo tree is found along river banks as gallery forest or in habitats with high water levels.

The structures of group 2 correspond to the botanical species *Acacia tortilis* of the *Mimosaceae* family. Wood of this presently occurring species is also called "umbrella-thorn" and is said to be one of the most common acacias. *Acacia tortilis* are small to mid-sized trees from 5 to 10 m in height and usually grow in fairly deep, alkaline soil in association with sweet grasses.

One sample of group 3 corresponds to the botanical species *Acacia karoo* of the *Mimosaceae* family. Wood of this present-day species is called "sweet-thorn" and is said to be the most common type of tree in

**Fig. 2.** Alluvial floodplain and dry channel of the Gourits River near Ottershoek. The deposits are 6–8 m thick and are mainly composed of sands and silts.

**Table 1**
Characteristics and radiocarbon dates of sediments and organic inclusions in alluvial deposits of the Gourits River basin (for location of profiles see Fig. 1).

| Sample number | Laboratory number | Exposure | Type of material | C org. [%] | Dating method | $^{14}$C age/$^{14}$C activity | Cal. $^{14}$C age (95.4%–2 sigma–confidence level) |
|---|---|---|---|---|---|---|---|
| OR1 | HAM-3621 | Le Roux | Sand | 0.67 | AMS | 101.5 ± 0.3 pmC | 1696 cal AD–1919 cal AD |
| OR2 | HAM-3622 | Le Roux | Silt | 2.14 | LSC | 670 ± 50 y BP | 1264 cal AD–1400 cal AD |
| OR4 | HAM-3623 | Le Roux | Loamy sand | 0.42 | AMS | 450 ± 20 y BP | 1422 cal AD–1460 cal AD |
| OR3 | HAM-3624 | Le Roux | Loamy sand | 0.66 | AMS | 1215 ± 25 y BP | 710 cal AD–889 cal AD |
| GR2 | HAM-3625 | Oude Wagendrift | Loam | 2.32 | LSC | 107.1 ± 0.9 pmC | 1694 cal AD–1919 cal AD |
| GR5 | HAM-3628 | Oude Wagendrift | Clay | 5.25 | LSC | 128.7 ± 0.7 pmC | 1681 cal AD–1930 cal AD |
| KK17 | HAM-3629 | Karre Kamma | Sand, organic detritus | 4.95 | LSC | 131.0 ± 0.7 pmC | 1681 cal AD–1930 cal AD |
| UI10 | HAM-3636 | Uitspan | Sand, organic detritus | 10.26 | LSC | 15 ± 20 y BP | 1708 cal AD–1910 cal AD |
| UI7 | HAM-3638 | Uitspan | Silt | 0.81 | AMS | 175 ± 25 y BP | 1661 cal AD–1954 cal AD |
| UI3 | HAM-36– | Uitspan | Clay, organic detritus | 8.93 | LSC | 590 ± 70 y BP | 1282 cal AD–1436 cal AD |
| UI4 | HAM-3640 | Uitspan | Loam, organic detritus | 0.59 | AMS | 755 ± 25 y BP | 1224 cal AD–1283 cal AD |
| UI6 | HAM-3641 | Uitspan | Silt | 0.22 | AMS | 415 ± 40 y BP | 1423 cal AD–1631 cal AD |
| UI5 | HAM-3642 | Uitspan | Loam, organic detritus | 0.37 | AMS | 875 ± 25 y BP | 1046 cal AD–1222 cal AD |
| GOU5 | HAM-3644 | Poort-Ottershoek | Sand, organic detritus | 0.24 | AMS | 113.9 ± 0.3 pmC | 1691 cal AD–1925 cal AD |
| GOU8 | HAM-3649 | Poort-Ottershoek | Sand | 1.31 | LSC | 124.1 ± 0.7 pmC | 1687 cal AD–1928 cal AD |
| GOU11 | HAM-3650 | Poort-Ottershoek | Silty sand | 0.12 | AMS | 123.4 ± 0.3 pmC | 1685 cal AD–1929 cal AD |

$^{14}$C dates and $^{14}$C activity were calibrated by IntCal04 (see Reimer et al., 2004; Ramsey, 2008).

South Africa. The sweet-thorn usually grows to 3–8 m, in favourable habitats up to 12 m high, and in arid environments it is mainly found along rivers and in locations with high water tables.

In addition to these clearly determined species, there were two further samples that could not be classified more unequivocally. For one sample numerous structural characteristics indicated a taxon of the *Apocynaceae* family and for another sample a taxon of the *Loganiaceae* family (perhaps *Strychnos*). A more definite classification was not possible (see Table 2).

Predominantly, the radiocarbon dating of the wood samples analyzed resulted in modern ages. Samples that did not have modern ages were dated between 210 ± 50 years BP and 510 ± 50 years BP. In particular, samples of the species *R. lancea* showed the oldest ages. No fossil wood with an age older than 510 ± 50 years BP was found in the sampled profiles.

### 4.4. Formation and structure of alluvial and hill-wash sediments

Profiles in alluvial sediments were surveyed and sampled in the Gourits, Groot, Olifants, Buffels and Gamka River valleys. Five profiles near Le Roux, Oude Wagendrift, Karree Kamma, Uitspan and Die Poort were studied in detail (Fig. 1). All profiles show a well developed sectional structure and have heights between 2.5 and 6.7 m. In the eastern Cape region a further profile was studied at the Great Fish River near Grahamstown, for comparison in the interpretation of dating results and timing of onset of the alluvial sedimentation in different river basins studied. In the following, the general results are illustrated on the basis of two profiles that are characteristic for the study area.

#### 4.4.1. Profile Le Roux

In the Olifants River valley near Le Roux (33°32′40″S/ 22°27′25″E, see Fig. 3) 5.30 m thick, fine alluvial sediments, which show a bipartite vertical structure, cover the basal river gravels. The upper 3.3 m of these sediments consist of grey-yellow, horizontally bedded fine sands. At 1.4 m below the surface, this sediment section is crossed by a dark, humus-rich layer, and at 3.3 m below the surface it is bordered by a similar humous layer. The underlying deposits consist of a bed, ca 2 m thick, of interbedded layers of fine sands, silty sands, silts, and loamy sands, from 5 to 25 cm thick. Two horizons of humus-rich loamy sands are interbedded at 4.70 m and 5.20 m respectively.

The $^{14}$C-dating of the humus-rich and sandy layer at 1.4 m resulted in a modern age. In contrast, the mentioned layer above the base gravels at 5.2 m yielded an age of 1215 ± 25 years BP, being the oldest of all samples dated here (see Table 1). Dating of the organic carbon-rich layers at 3.3 and 4.7 m shows an inverse age of the profile succession most likely due to reworking of the older organic material.

#### 4.4.2. Profile Uitspan

The second profile described here in detail is located at Uitspan (33°47′15″S/21°44′50″E, Fig. 4), in the Gourits River floodplain (Fig. 1). The alluvial sediment on top of the Palaeozoic Bokkeveld schists is almost 6 m thick. The sediments show a bipartite vertical structure as well. In the upper section, to a depth of about 3.3 m, the floodplain sediments consist of silty, light-coloured fine sands with

**Table 2**
Characteristics and radiocarbon dates of fossil wood in alluvial deposits of the Gourits River basin (for location of profiles cf. Fig. 1).

| Sample number | Laboratory number | Exposure | Fossil wood species | Dating method | $^{14}$C age/$^{14}$C activity | Cal. $^{14}$C age(95.4%–2 sigma–confidence level) |
|---|---|---|---|---|---|---|
| GR6 | HAM-3626 | Oude Wagendrift | *Rhus lancea* | LSC | 130.8 ± 0.7 pmC | 1681 cal AD–1936 cal AD |
| GR4 | HAM-3627 | Oude Wagendrift | *Acacia tortilis* | LSC | 370 ± 50 y BP | 1445 cal AD–1637 cal AD |
| KK11 | HAM-3629 | Karre Kamma | *Rhus lancea* | LSC | 100.2 ± 0.6 pmC | 1696 cal AD–1919 cal AD |
| KK1 | HAM-3630 | Karre Kamma | *Acacia tortilis* | LSC | 145.7 ± 0.7 pmC | 1680 cal AD–1940 cal AD |
| KK12 | HAM-3631 | Karre Kamma | *Loganiaceae, Strychnos?* | LSC | 115.2 ± 0.7 pmC | 1691 cal AD–1920 cal AD |
| KK14 | HAM-3633 | Karre Kamma | – | LSC | 430 ± 50 y BP | 1410 cal AD–1632 cal AD |
| KK15 | HAM-3634 | Karre Kamma | *Acacia tortilis* | LSC | 140.6 ± 0.7 pmC | 1680 cal AD–1940 cal AD |
| UI1 | HAM-3635 | Uitspan | – | LSC | 210 ± 50 y BP | 1524 cal AD–1955 cal AD |
| UI2 | HAM-3637 | Uitspan | *Rhus lancea* | LSC | 360 ± 50 y BP | 1449 cal AD–1639 cal AD |
| GOU2 | HAM-3645 | Poort-Ottershoek | – | AMS | 120.8 ± 0.3 pmC | 1686 cal AD–1928 cal AD |
| GOU1 | HAM-3646 | Poort-Ottershoek | Apocynaceae family | LSC | 101.7 ± 0.6 pmC | 1694 cal AD–1919 cal AD |
| GOU3 | HAM-3647 | Poort-Ottershoek | *Acacia karoo* | LSC | 143.8 ± 0.7 pmC | 1679 cal AD–1940 cal AD |
| GOU4 | HAM-3648 | Poort-Ottershoek | *Rhus lancea* | LSC | 510 ± 50 y BP | 1305 cal AD–1463 cal AD |

$^{14}$C dates and $^{14}$C activity were calibrated by IntCal04 (see Reimer et al., 2004; Ramsey, 2008).

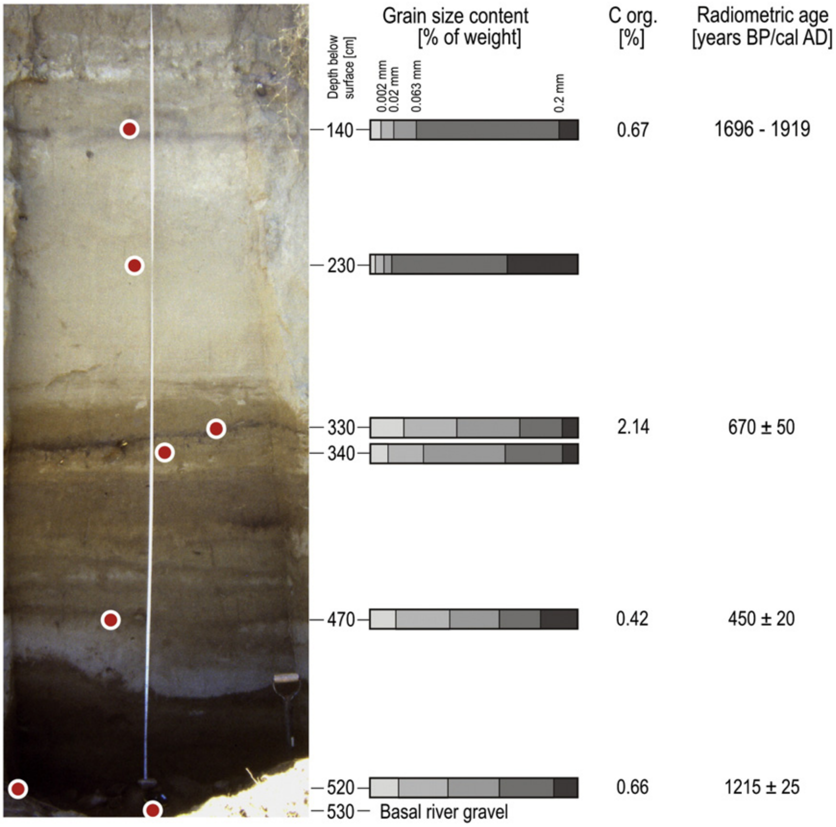


**Fig. 3.** Section in the alluvial floodplain of the Olifants River near Le Roux (33°32′40″S/ 22°27′25″E). The deposition, which shows a bipartite vertical structure, is 5.30 m thick and covers the basal river gravels. The upper section of the sediments consist of horizontally bedded fine sands, the underlying section of a 2 m thick interbedded strata of fine sands, silts, and loamy sands.

rarely visible, but essentially horizontal bedding. A further differentiation is macromorphologically not possible. At a depth of 2.3 m, a *R. lancea* branch taken from the sediments was dated to 210 ± 50 years BP. However, in context of the profile succession, the sample must be regarded as redeposited fossil wood.

Below a depth of 3.3–3.4 m, the mostly homogeneous fine sands are replaced by a sequence, 5–30 cm thick, of olive-green to brown silt layers interbedded with light silty sands, and below 5.3 m by silty loams, which contain sporadic individual floating clasts. Several organic-rich silt layers were sampled for dating at depths of 3.7 m and 5.5 m. In addition, organic mud originating from loam layers at 5.3 m and 5.7 m below the surface, as well as plant detritus from a clay lens in 5.2 m were dated. The $^{14}$C-ages of these samples are between 175 ± 25 years BP at a depth of 3.7 m, and 875 ± 25 years BP near the base of the sediment sequence (Fig. 4). At a depth of 5.5, an age of 415 ± 40 years BP indicates an inverse age of the sediment succession, suggesting that the overlying date is from re-worked material.

The change of the sediment characteristics at 3.3 m below the surface is not only reflected in a different grain size spectrum. Exact determination of the bedding direction shows that the several sediment strata below 3.3 m dip from the slope to the valley bed, respectively perpendicular to the valley direction, with values between 15° and 30°. In this position, the sediments are to be regarded as hill-wash, instead of as alluvial sediments. Consequently, the upper and lower sediment sections of the Uitspan profile are separated by a stratigraphic unconformity. Alongside, the well bedded hill-wash sediments are covered by sparsely layered, fluvial fine sands. At the base of these sands, at a depth of 3.4 m, organic mud was encountered that had an age of 15 ± 20 years BP. Finally, the several layers of humus-rich sand and silt in between the hill-wash sediments should be regarded as originating from fossil soil formations on top of ancient land surfaces and/or as redeposited former soil material from higher slope positions. However, based on stratigraphic analyses, and the radiocarbon dating alone, no further differentiation is possible.

To a large extent, the essential characteristics of sedimentation and structure of both profiles described above are also observed in the other sections studied in the Gourits River basin. In general, the upper sections of the sediments are composed of homogenous fine sand, which hardly shows any bedding. The sediments can achieve considerable thicknesses upstream of valley constrictions, as for example 6.5 m at the Groot River near Oude Wagendrift, or ca. 5 m at Karre Kamma, and also lie directly above the base gravels. In these sediments, organic sand and silt horizons are mostly absent. In contrast, fossil wood is sometimes embedded, which usually has a modern age. Several dated samples of fossil wood are between 370 ± 50 years BP and 510 ± 50 years BP old, which by their stratigraphic position, must have been redeposited.

### 4.5. Flood discharge and deposit of alluvial sediments

Field study, laboratory analyses, and radiocarbon dating suggest that the deposits, on average 3 m thick, of the upper sediment sections, and locally, also the up to 6.5 m thick sand deposits on top of the gravel base can be regarded as modern sediments. In some specific cases, this could directly be verified.

In 1997, at the confluence of a Groot River tributary near Karre Kamma (33°46′40″S/21°30′35″E, Fig. 5), alluvial sediments were exposed in a floodplain profile for more than 100 m, with a vertical thickness of almost 5 m. The upper sediment section, ca. 3 m thick, was composed of solid, densely bedded grey-yellow fine sands. Situated below, fluvial sediments of interbedded gravels, clays and silty sands followed down to the gravel base. Embedded in sand lenses and beds, fossil wood, organic mud, as well as the bones of an animal (most likely antelope), were found. Except for a remnant of wood at a

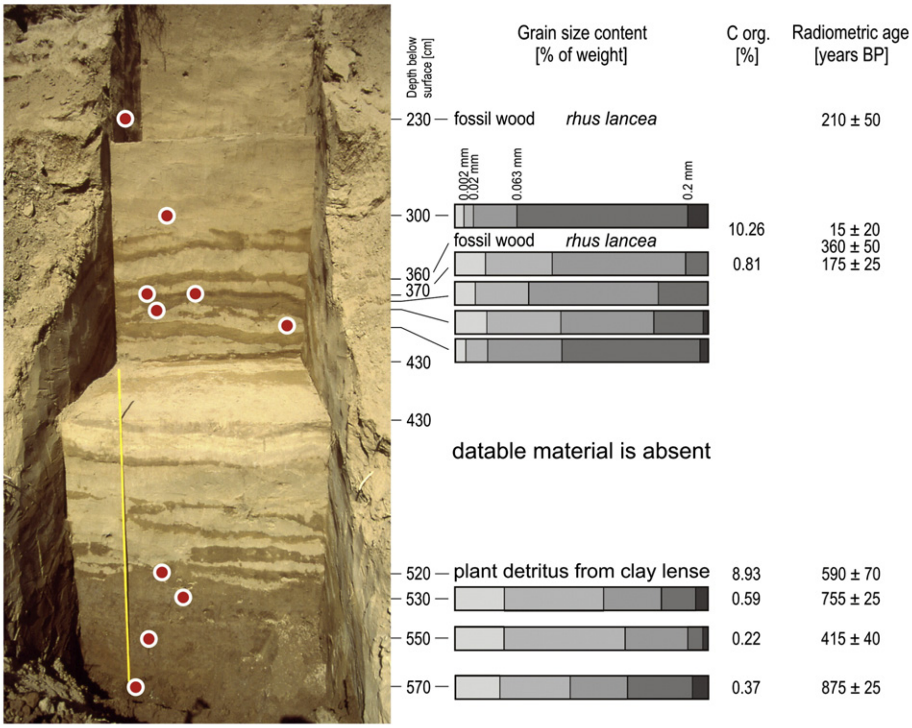


**Fig. 4.** Section in the alluvial floodplain of the Gourits River at Uitspan (33°47′15″S/21°44′50″E). The deposition, which also shows a bipartite vertical structure, is 6 m thick and covers the Palaeozoic Bokkeveld schists. In the upper section the floodplain sediments consist of fine sands with hardly visible, but essentially horizontal bedding. The lower section is a colluvium.

depth of about 4 m, dated to 430 ± 50 years BP, all radiocarbon dates yielded modern ages (see Table 2). In the following year, a section of the profile had collapsed, thereby exposing a buried fence post. On inquiry, local farmers told that the alluvial sediments had been deposited during a flood event in January 1981, the so-called "Laingsburg flood" (Kovacs, 1983; Heydorn, 1989). In the course of this flood event, large parts of the city of Laingsburg in the Great Karoo were destroyed. By the onrushing flood wave more than 100 people died. The flood had been a direct consequence of long-lasting and wide-ranging rainfall in the Little and Great Karoo (ca. 4000 $km^2$) with a 48-hour total of more than 200 mm (Kovacs, 1983).

Maximum flood discharges of 11,400 $m^3 s^{-1}$ and 11,000 $m^3 s^{-1}$ were calculated for the Gourits River near Die Poort and for the Groot River west of Karre Kamma, the highest known discharges in the southern Cape region. In general, during the flood, a deposition of less than 0.5 m of fluvial sediments was estimated (Kovacs, 1983). Higher sediment thicknesses were observed at the Gourits River floodplain near Die Poort, with an average of ca. 1 m, and up to 3 m near Laingsburg, yet further details of the studied localities were not given. There is also no reliable information as to the maximum flood level. However, analyses of airborne and terrestrial photos and the report from Kovacs (1983) allow the conclusion that in general, during the

**Fig. 5.** Section at the confluence of a Groot River tributary near Karre Kamma (33°46′40″S/21°30′35″E). The sediment composed of interbedded sands and gravels on top of the gravel base was deposited in January 1981 during the so-called "Laingsburg flood".

peak of the flood the floodplains were inundated several metres deep. The suspended load was up to 10 vol.% of flood discharge (Heydorn, 1989), which is why considerable aggradation of the floodplains can be assumed.

A recurrence period of more than 200 years was calculated for the precipitation event in January 1981. However, floods with similar effects can also be triggered by less intensive rainfall, if it follows a period of wet conditions (Heydorn, 1989). In this context, field work proves that, for example, during the flood event on 22 Nov. 1996 at the Olifants River, the water level near Calitzdorp rose to more than 10 m above the river bed. Furthermore, it must also be taken into consideration that in the course of earlier floods in the Gourits River basin, the vertical thickness of floodplain deposits above the stream bed was most likely smaller and thus floodplains could be inundated by lower water levels.

## 5. Discussion

Essentially, the erosion and denudation processes in the southern Cape region are controlled through the fluvial dynamics of the large valleys (see Hagedorn, 1987, 1988). Among other reasons, this is due to the fact that the different planation surfaces are each aligned to the higher river terraces as well as to the floodplain deposits investigated in this study, respectively the youngest planation surface to the present valley floor. Thus, the material that structures the river terraces and floodplain deposits must be, at least partly, considered to be sediments correlative to the denudation processes affecting the adjacent land surfaces.

However, the question arises as to how the deposition of the lower sequence of alluvial sediments is to be explained, which has been stratified by organic inclusions, and from which conclusions can be drawn with respect to their formation as well as to the factors controlling erosion and sedimentation. In this context, it must be considered that the floodplain deposits near Le Roux and Uitspan are in topographical positions, in which they are protected against lateral erosion, at least under conditions of average high water levels. However, this does not explain the fact that during the deposition time of the lower floodplain section, over 600–800 years, no flood sediments were deposited that correspond to the young sediment of the upper section in grain structure and thickness. In any case, two phases of different sedimentation can be distinguished with rates of ca. 0.3 m in 100 years for the older, and 2–3 m in ca. 50 years for the modern depositional phase. Thus, it can be concluded that a change in discharge and, respectively, of sedimentary conditions must have occurred.

A likely model of development of the floodplain deposits might be as follows: the aggradation of the lower (gravel) terrace, most likely during the last glacial epoch, was followed by incision resulting in the present-day valley floor, primarily through flood events and simultaneously, strong lateral erosion. At least locally, the bedrock was affected by fluvial erosion. At low-level and mean discharge, the alluvium was temporary deposited on the valley floor until the next flood event. Not until the younger Holocene, according to the radiocarbon dating since 1215–875 years BP did the deposition of fine alluvial sediments start, which may have occurred in the context of moderate flood events. In part, sediment was also eroded from the slopes and deposited as hill-wash. As a result of these sedimentation processes, the formation of floodplains was initiated and the deposits grew in thickness to 2–3 m. As the floodplains grew, they could only be inundated at increasingly higher water levels, and were covered by, to some extent, thick sediments. Sedimentation like this, due to extremely high flood events, cannot be ascertained for the time before the 20th century, at the earliest.

According to the present state of knowledge, there is little evidence that the change in sedimentation is the result of climate variations. Relevant investigations based on different proxy data show that the hygric conditions in South Africa developed from semi-arid or sub-humid to drier conditions during the period (Deacon and Lancaster, 1988; Meadows and Sudgen, 1994; Scott et al., 2005; see Table 3). At the same time, after an initial cooler phase around AD 800–900 and the following Medieval Warm Epoch, a general cooling trend, interrupted by fluctuations, was ascertained (Tyson and Lindesay, 1992; Holmgren et al., 1999, 2003; see Table 4). Especially in connection with the increasing aridity during the last 300 years, a decrease in the vegetation density and thus an increase in soil erosion cannot be excluded (see also Hahn et al., 2005; Kraaij and Milton, 2006). However, neither the reconstructions of temperature and precipitation for the past 1500 years, nor the radiocarbon dating of the present study on fluvial morphodynamics with its imprecise temporal resolution, allows a more definite evaluation of the causal connections.

However, anthropogenic impact upon the fluvial morphodynamics in the southern Cape region is indicated by the settlement history. In the pre-colonial period, the land use was that of the hunters and gatherers of the Khoi San, and partly intensive herding by the Khoi Khoi. Archaeological investigations suggest initial sedentary herding in the study area around AD 396–476 (Deacon, 1995), i.e. circa 400 years before the deposition of floodplain sediments started. For this pre-colonial period, a degradation of varying, and in places possibly high intensity of the natural vegetation cover up to the start of soil erosion is assumed (Dean et al., 1995). The degradation of the vegetation cover due to pasture farming (see Kraaij and Milton, 2006) increased soil erosion and thus the influx of fine soil into the fluvial system, which could then be deposited as alluvial floodplain sediment (see Van Breda Weaver, 1988; Boardman et al., 2003).

A significant increase in pasturing and thus of soil erosion in the study area was initiated through the immigration of white settlers, especially their introduction and intensification of sheep and goat herding (Acocks, 1953). In addition, a strong population growth in the Cape Province between 1750 and 1815 went along with an increase of livestock. At first, between 1750 and 1850, the Europeans lived as nomadic herders in the arid areas. However, after 1850 they became more sedentary (Meadows et al., 1994). After capacity limits of the pastures had been reached by around 1865, ring fences and rotating pastures became compulsory at the beginning of the 20th century. Subsequently, by 1981 the livestock in the Karoo decreased by up to 50% in response to the increasing dryness and thus lower productivity of the pasture land (Dean and Macdonald, 1994).

The knowledge about the climate and landscape change in the study area with respect to radiometric dating and averaging of alluvial sedimentation in the Gourits River basin is presented in Fig. 6. Aside from the results already discussed that the floodplain sedimentation

**Table 3**
Hygric conditions and vegetation cover based on different proxy data a) for South Africa, after Deacon and Lancaster (1988) and Meadows and Sugden (1993) and b) for the Karoo, after Scott et al. (2005).

| Period [years BP] | Hygric conditions | Vegetation cover | Reference |
|---|---|---|---|
| 4500–1800 | Semiarid to sub-humid, increasing temperature | No reference | South Africa: Deacon and Lancaster (1988) Meadows and Sugden (1993) |
| 1800–1000 | Semiarid, decreasing precipitation, increasing temperature | No reference | |
| Since 1000 | Semiarid, slight variable | No reference | |
| 2000–1300 | Sub-humid | Grassy | Karoo: Scott et al. (2005) |
| 1300–1100 | One or two dry events | Brief spread of Asteraceae | |
| 1000–400 | Sub-humid | Grassy | |
| 300–20th century | Gradual drying | Increasing Asteraceae | |

**Table 4**
Thermal conditions since 40 AD in South Africa based on different proxy data, after Tyson and Lindesay (1992), Holmgren et al. (1999) and Holmgren et al. (2003).

| Period [years AD] | Thermal conditions | Characteristics |
|---|---|---|
| 40–600 | Warm (wet) | Cooling between 100 and 200 AD/440 and 520 AD (dry spells prevailed) |
| 600–900 | Cooling | Variable period, cool between 800 and 900 (dry spells prevailed) |
| 900–1300 | Generally warmer | “Medieval Warm Epoch”, high variability |
| 1300–1850 | Cool (and dry) | “Little Ice Age”, warm episode 1500–1675, lowest temperatures at 1700 |

started around 1215 years BP at the earliest, it is striking that fossil wood from the time before 510 years BP is completely absent in the analysed sections. However, more research is needed to determine whether and what kind of ecological and temporal connection exists between the change of the Karoo vegetation from a grassland to a scrubland, since part of the dated fossil wood may have originated from gallery forests or river-bank vegetation. In any case, it is notable that 50–70% in vertical thickness of the studied floodplain sediments has been deposited over the past ca. 250 years. In contrast, only 30–50% of the sediments were deposited in the previous circa 950 years. Sedimentation ratios of 1–4 and, respectively, 1–9 are the result of this.

Preliminary analogies to the fluvial morphodynamics in the Gourits River basin may be drawn, with respect to this study, from the history of settlement and land use in the Cape region (cf. Fig. 6). As a result of this study, the context between land use change and fluvial sediment load as a consequence of increased erosion is indicated and could explain the exceptional thickness of the upper sediments within the sequence of floodplain strata. Among other facts, the change of sedimentation rates in the Gourits River basin is also consistent with the change of Late Holocene sedimentation rates in the Verlorenvlei lake basin in the western Cape region (see Meadows and Asmal, 1996). In connection with the immigration of the European colonists, an increase in the lake sedimentation rate in this area over the past 250 years was identified. After 200 years BP, sedimentation increased to 5.75 mm/a, after it had varied between 1.0 and 2.3 mm/a for the past 5500 years.

As yet, the preliminary conclusions of this investigation are based on a comparatively low number of profiles and datings. In principle, it cannot be ruled out that fluvial sediments older than those of our radiocarbon dates may be found, perhaps by coring, at other sites than those studied here. For example, studies at the Great Fish River in the eastern Cape region, i.e. in the wetter environment of the Bushveld, indicate that floodplain sedimentation there already started between 2690 years BP and 3455 years BP. For the future, progress in understanding the floodplain formation of the southern Cape region can be expected from additional coring or drilling in the alluvial sediments, analyses of pollen and phytolites, as well as OSL-dating. Current research, especially in the Klip River catchment, indicates the general suitability of OSL-dating for fluvial sediments (Rodnight et al., 2005; Tooth et al., 2007). In addition, further studies should consider the question, to what extend soil formation took place on the alluvial sediments under “stable conditions” during the Holocene, if it is possible to quantify number and duration of stable periods, and if there are differences in the intensity of pedogenesis.

## 6. Conclusions

For the first time, a stratigraphic division of the Holocene fluvial deposits has been provided for the Gourits River basin and some other parts of the Karoo. One surprising result is that in large part, the floodplain sediments, frequently the upper 3 m, and in places the entire vertical profiles, have been deposited by a once-in-a-hundred-years flood during the 20th century. It is also astonishing that the deposition of alluvial floodplains started comparatively late, not

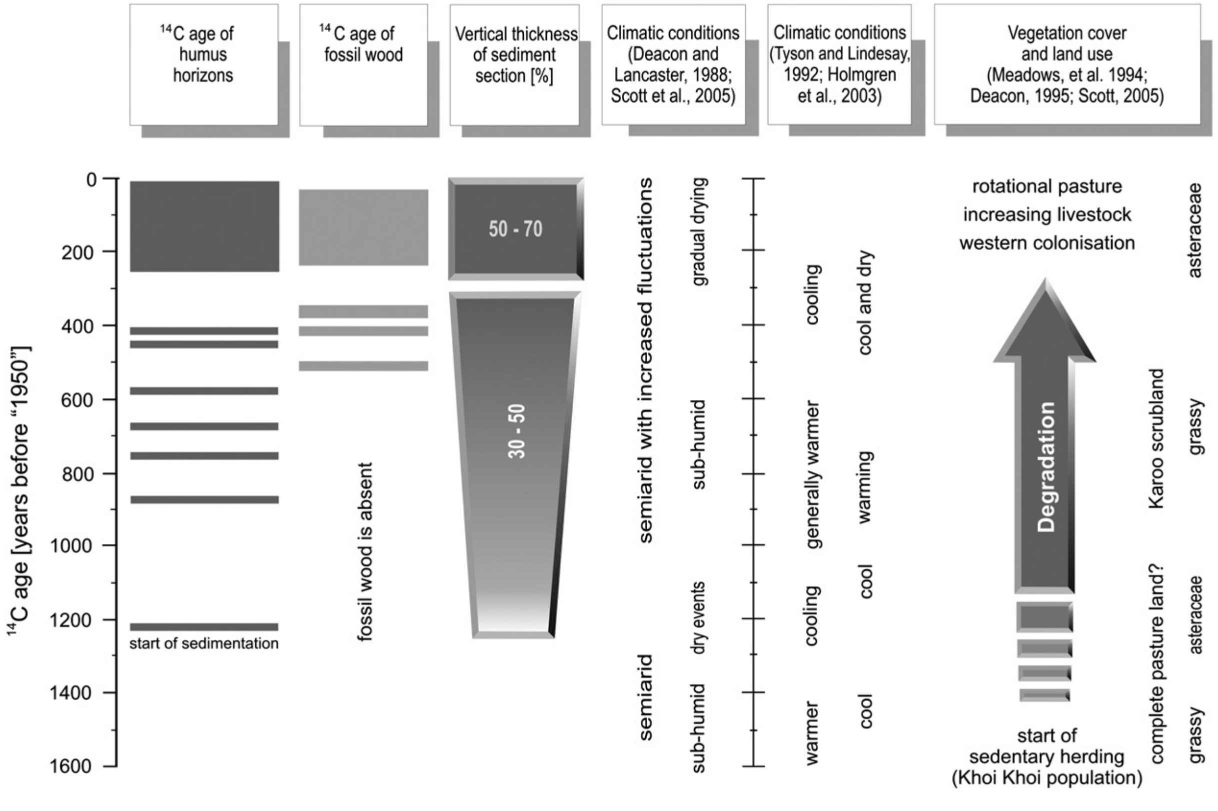


**Fig. 6.** Present state of knowledge of climate change, vegetation cover and land-use change in the Cape Province in connection with radiocarbon dating of organic sediments, fossil wood, and mean vertical thickness of sediment sections in the Gourits River basin (according to the present study and data from other authors; see text).

before the 8th century, based on the radiocarbon dates obtained. For now, a temporal and process-related interplay is assumed between fluvial dynamics, alluvial sedimentation and settlement history and the intensification of the land use.

## Acknowledgements

The authors would like to thank the German Research Foundation (DFG) for funding this research (Ha 506/21-1). We thank Dr. Becker-Heidmann, Institute of Soil Science of the University of Hamburg for the radiocarbon datings. Our thanks are also due to Prof. Dr. Eckstein, at the Department of Wood Science at the University of Hamburg, for determining the fossil wood samples. For scientific references and logistic help on site, the authors would like to thank Prof. Dr. W.S. Barnard, Geographical Institute of the University of Stellenbosch, South Africa.

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