A landscape-based model to characterize the evolution and recent dynamics of wetlands in the Umzimvubu headwaters, Eastern Cape, South Africa

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ABSTRACT: This study presents a landscape model approach to characterize the evolution and recent dynamics of palustrine wetlands within a landscape perspective in the semiarid headwaters of the Umzimvubu catchment, South Africa. Geophysical methods and sediment analyses have been combined to provide information in order to evaluate whether the evolution of wetlands was predominantly climatically driven or influenced (if not even caused) by human impact. Results indicate a late Holocene formation of the wetlands due to the increased sedimentation of fine grained sediments in the valley floors starting at about 3400 BP. At this time human activities remarkably increased in this area and thereby might have influenced vegetation and sedimentation dynamics. A subsequent formation of an impervious soil layer is addressed to a relatively stable phase enabling recent wetland conditions. This is much more important for management and conservation purposes, since noticable afforestation activities in the basin headwaters since 1989 indicate significant changes with effects on recent wetland dynamics.

1 INTRODUCTION

The landscape of the semi arid headwaters of the Umzimvubu catchment (Eastern Cape Province, South Africa) is characterized by the occurrence of several types of palustrine wetlands which vary in extent, topographic position, and functioning. Those wetlands are very complex regarding their hydrological, bio-ecological and geomorphological functioning, and dynamics. They have been utilized by farmers in terms of drainage and annual burning for stock-farming for hundreds or even thousands of years. Since 1989 greater parts of the upper reaches of the Umzimvubu basin have been afforested with pine and eucalypt and thereby caused remarkable changes of the landscape. About 60,000 ha have been planted for commercial forestry and, moreover, additional areas are supposed to be planted during the next years. As a consequence, an interdisciplinary research project was initiated to provide knowledge about the impact of past and recent landscape changes on the formation of these wetlands and their hydro-geomorphological dynamics within a basin perspective. While some progress was achieved regarding the study of hydrological dynamics of those wetlands (Helmschrot et al. 2005), only little knowledge is available regarding the formation of these wetlands. Many South African scientists emphasize that the present landscape of the Eastern Cape was basically formed by climatic and geologic processes and remained stable during the entire Holocene. Wetlands are assumed to be relics of the late Pleistocene and thus older than 10,000 years (Beckedahl, pers. comm.). In addition, it is indicated that grassland is predominant since many thousands of years because there is no potential for the growth of higher vegetation. This is usually related to limiting factors like altitude, humidity, or soil conditions.

On the other hand, there is some indication that the area was covered by higher vegetation than grassland (Acocks 1988) over several periods during the Holocene, whereas relics of indigenous Podocarpus forest can still be found in steep valleys. These patches of indigenous vegetation as well as the successful establishment of commercial forestry indicate the potential of the landscape to support the growth of higher vegetation. In addition, land management like annual burning, which is proved for hundreds of years for this region and is assumed to be used for farming activities for even thousands of years, have led to a reduction of biodiversity and the growth potential for other vegetation than fast growing grass species (Everson et al. 1985, 1989, Everson & Tainton 1984, Mentis & Bigalke 1981, Short et al. 2003, Trollope 1974, Smith & Tainton 1985). Thus, the disturbance of the natural vegetation induced by human activities during the Holocene needs to be taken into account when developing a model which characterizes the formation of the present landscape and wetlands.

Assuming that the formation of wetlands is strongly linked to sediment transport (deposition of wetland sediments) and hydrological dynamics, changes in vegetation pattern on the slopes surrounding wetlands supported (if not even caused) recent wetland systems.

The presented study provides a model describing the formation of the wetlands during the Holocene as a combination of climatic trends and anthropogenic activities in the study area. In this context, this paper contributes to the controversial discussion on the formation and development of the landscape of the Eastern Cape Province during the Holocene.

2 STUDY AREA

The study area (Figure 1) is located in the semiarid headwaters of the Umzimvubu catchment (Eastern Cape Province, South Africa) and can be seen as representative for the eastern slopes of the Great Escarpment. It covers an area of about 816 km² and is divided into three meso-scale subcatchments: Mooi (307 km²), Wildebees (364 km²) and Gatberg (145 km²). The altitudes range from 1200 m asl. to 2700 m asl. along the catchment boundary at the border to the Kingdom of Lesotho.

The geology is dominated by Triassic sediments belonging to the Karoo Sequence, often intruded in place by dykes of Jurassic dolerite. The manifold geological base results in a scarpland with wide valleys, numerous canyons, and series of sloping plateaus (De Dekker 1981, Karpeta & Johnson 1978). Soil types depend on the muddy or sandy parent material and the hydrological conditions.

Regarding the climate the region lies in a summer rainfall area that is characterized by rainfalls and higher temperatures from September to April (MAP: 750 mm/year, MAT: 14.1 °C). Temperature and precipitation show a high inner- and inter-annual temporal and spatial variability (Helmschrot 2006).

According to Acocks (1988) the vegetation is characterized by a grassveld type namely *Highland Sourveld* in the upper parts and *Dohne Sourveld* in the warmer and drier lower elevations. The grassveld becomes scrubby on steeper slopes as a savannah of *Protea multibracteata*. Relics of indigenous forest dominated by *Podocarpus latifolius* occur in the sheltered canyons (kloofs) along the escarpment.

Presently, the land use is mainly characterized by rangeland grazing, dryland agriculture and some small scale irrigation patches. Several environmental problems which have been induced by lacking land use management schemes over years are predominant in this area. Extensive stock farming and annual burning led to the degradation of the natural grassveld and to areal soil losses caused by erosion. Since

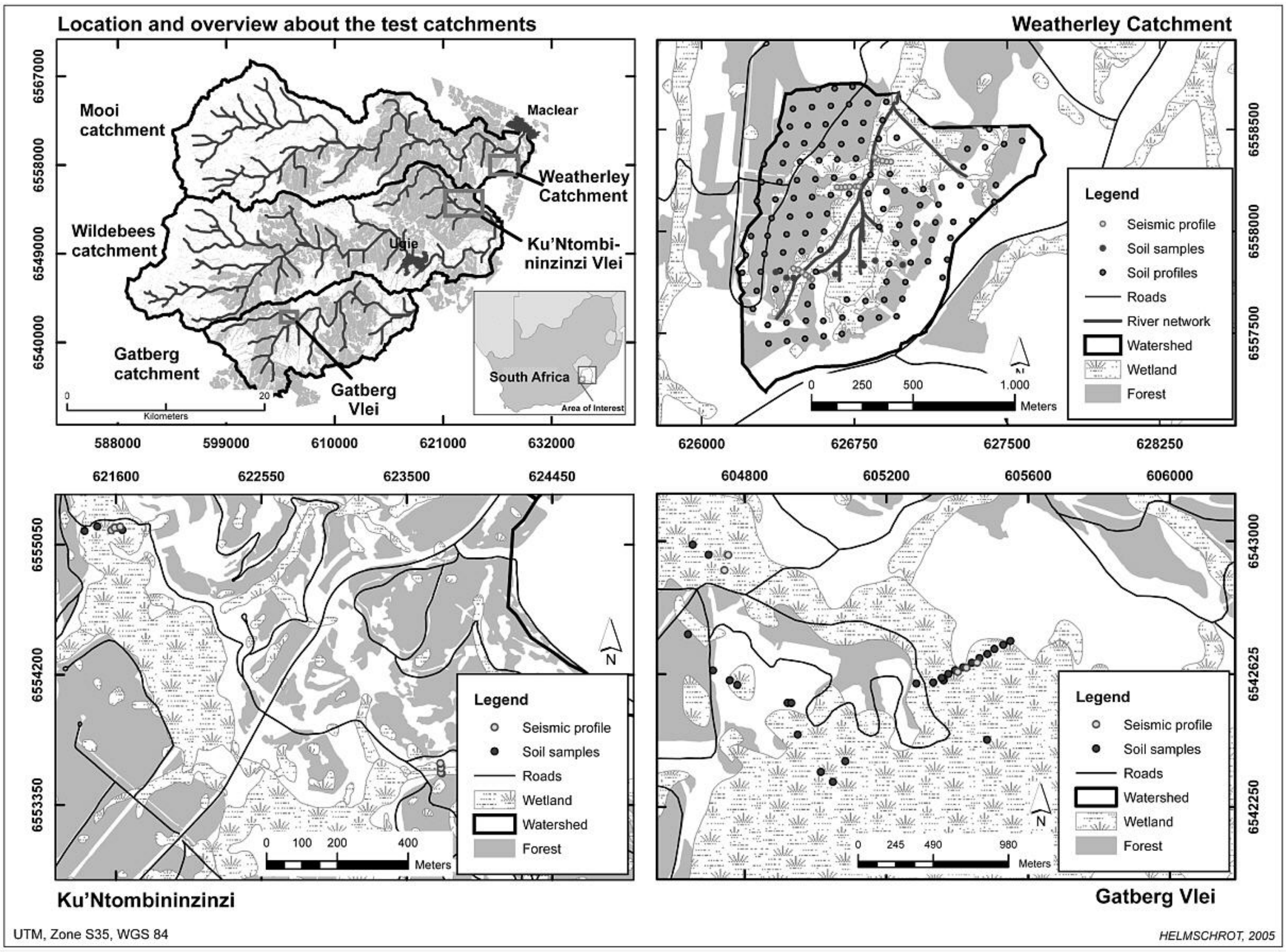

Figure 1. Location and characteristics of the study area.

the establishment of forest industries in 1989 large scale afforestation have resulted in significant changes in land use especially in the headwater catchments of the Umzimvubu River. During the last 15 years forest industries owned some 120,000 ha and afforested rather 60,000 ha of the former range land with various pine species and eucalypt. As a consequence, the large plantations are assumed to cause both changes in the hydrological system (run-off reduction, interception losses, etc.) and ecological changes (dry out of wetlands, biodiversity issues, destruction of natural habitats, etc.).

3 PALAEO-ENVIRONMENTAL CONSIDERATIONS

Since this study is based on the assumption that the formation of palustrine wetlands in the Eastern Cape is strongly linked to landscape and land use dynamics during the Holocene, palaeo-climatological and palaeo-ecological studies as well as research concerning historic land use dynamics in the study area have been reviewed in detail.

3.1 *Palaeoclimate*

Only few studies have been published relating to historic climate conditions in Southern Africa in the past. Tyson (1987) presented a state-of-the-art of the climatic change and variability in Southern Africa within the historic context. In general, little evidence is given for significant southern Africa climate changes during the Holocene, but a few studies indicate that longer periods of the Holocene seemed to be slightly wetter and cooler than at present. Based on an oxygen isotope temperature curve for the Southern Cape (Figure 2), two significant cooling phases during the last 5000 years have been identified (Tyson 1987). The first set in 4700 years BP with a minimum temperature at 4300 years BP. An intermediate warm phase found its maximum at 3500 years BP followed by a second cooling phase that set in after 3500 years BP. The steepest decline was found between 3200 and 2900 years BP. This

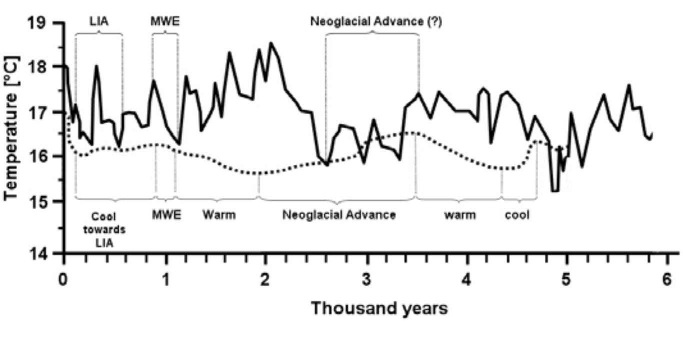

Figure 2. Temperature sequence of the Cango Caves stalagmite derived from $\delta^{13}C$ and $\delta^{18}O$ (line; mod. after Scott & Lee-Thorp 2004) compared to Holocene oxygen isotope temperature for the southern cape from Cango Cave (dotted line; mod. after Tyson 1987).

Table 1. Climatic summary refined by calibrated radiocarbon and dendro-chronologial data (mod. after Huffman 1996, Tyson & Lindesay 1992).

Age	Conditions
1850-1750 BP	Cool
1700-1350 BP	Warm/wet (Early Iron Age)
1350-1050 BP	Cool
1050-650 BP	Warm/wet (Medieval Warm Epoch)
650-450 BP	Cool/dry (Little Ice Age)
450-275 BP	Warm/wet
275-70 BP	Cool
70-40 BP	Warm/wet

cooling phase reached its temperature minimum at about 2000 years BP (Tyson 1987).

More recently, Scott & Lee-Thorp (2004) summarized numerous palaeo-climatological studies from different places in Southern Africa (Figure 2). According to the authors temperature principally tended to be higher over the last 6000 years than published by Tyson (1987) and climate records indicate greater temperature fluctuations. Similar to Tyson (1987), Scott & Lee-Thorp (2004) suggest a warmer trend after 4300 years BP and the beginning of a cooling phase (Neoglacial Advance ?) after about 3500 years BP. Nevertheless, the comparison of climate data presented by Tyson (1987) and Scott & Lee-Thorp (2004) shows, in particular, differences regarding the duration and end of this cooling phase, and thereby opposite temperature trends from 2500 years BP until the beginning of the Medieval Warm Epoch (MWE: 1100 years BP). This controversial discussion on sub-saharan climate variability during the middle Holocene, however, results from the lack of reliable records concerning the palaeo-climatic evolution (Tyson 1987, Scott & Lee-Thorp 2004).

A more detailed picture of the last 2000 years with additional hygric information on climate trends is given by Huffmann (1996) and Tyson & Lindesay (1992). Huffmann (1996) compared archaeological studies concerning migration dynamics and early farming activities in southern Africa to climatic data summarized by Tyson & Lindesay (1992) to reconstruct climate conditions during the last 2000 years. According to Huffman (1996), a warm and wet phase between 1700 and 1350 years BP motivated early Iron Age people to scatter over a wide area of southern Africa. A second warming period in the middle Iron Age has been related to 1050 - 650 years BP (MWE), since comparable migration activities as a consequence of higher rainfalls were proved. The Little Ice Age (LIA) set in at 650 years BP and was interrupted by a warmer and wetter episode between 450 - 275 years BP. Around 1850 AD temperatures and precipitation increased again continuously.

Phases of cooling and warming in the Iron Age (Table 1) widely coincide with data presented by

Scott & Lee-Thorp (2004). Based on studies of wood anatomy of *Protea* species along a rainfall gradient of the eastern Drakensberg mountains, February (1994) suggested a general decrease in rainfall from 2300 years BP to the present with a slight counter trend to increased rainfalls between 600 and 200 years BP. Nevertheless, he summarized similar rainfall conditions with some fluctuations in terms of variability and intensity over the last 2000 years.

3.2 *Palaeoecology*

Since wetland formation is mainly influenced by relief position as well as sediment and water input from the surroundings, the Holocene vegetation dynamics on the slopes can be seen as an important component to develop an understanding of wetland formation.

It is being postulated that prehistoric man, particularly early pastoralists and Iron-Age populations, had considerable impacts on the Holocene vegetation in South Africa (Avery 1987, February 1994, Ellery & Mentis 1992, Feely 1987, Hall 2000, Meadows 2001). Time and extent of these prehistoric human influences, however, are hardly to identify owing to the incompleteness of the archaeological and palaeo-ecological records. The assumptions of Acocks (1988) regarding the replacement of indigenous forests by grassland within the Eastern Cape are controversially discussed by South African ecologists. For example Feely (1987) hypothesized that no evidence has been presented that farming activities were responsible for more than the diminution of the present extent of forest patches in Transkei, and thereby that grassland is older than 1500 years BP. But he also concluded that earlier destruction might have been caused by hunters or herders burning down forests to enhance grazing for wild or domestic ungulates earlier than 1700 years BP. Meadows & Meadows (1988) found that the cooler and drier late Pleistocene provided the basic conditions for grassland establishment, but montane forest expanded somewhat in the mid-Holocene from 8000 years BP as moisture and temperature conditions improved. However, they also highlighted that montane forests never dominated the escarpment or the plateau in the area. According to Ellery & Mentis (1992) the grassland biome, as it is presently mapped, has been in existence for at least 1000 years, probably for much longer.

February (1994) studied the anatomy of recent and archaeological plant samples from charcoal findings along the eastern Drakensberge. He identified more than 70 % of the charcoal as signals of *Protea* species and even *Podocarpus* forest in different depths of the profiles, indicating their occurrence for at least 2000 years, although no *Protea* and *Podocarpus* forest grow in the vicinity of the sample sites at present. The reason for the absence of other plant species in the modern environment is rather seen in the veld management practice (annual burning, grazing, etc.) than in climate variations within the last 2000 years (February 1994).

Studies assessing the effects of long term burning treatments on species composition of the grassland (Everson et al. 1989, Everson & Tainton 1984, Mentis & Bigalke 1981, Short et al. 2003), on shrub regeneration (Smith & Tainton 1985) and canopy recovery in shrublands and woodlands (Everson et al. 1985) give evidence that there is a landscape potential to support higher vegetation like shrubs and trees. Those studies indicate that the significant loss of biodiversity within high altitude grasslands, shrublands and forests is strongly associated with the type of fire management (frequency, intensity and season) as well as grazing management.

3.3 *Historic land use dynamics*

Only few studies exist on historic land use dynamics in the Transkei and Lesotho highlands that provide information on the behavior of hunter-gatherers and early farmers and their environmental influence. Opperman (1996) highlighted early activities in the study area about hunter-gatherers that occupied Strathalan caves near Maclear at several times between 29,000 and 26,000 years BP. Archaeological studies at the Sehonghong cave in south-eastern Lesotho proved its recurrent occupation by hunter-gatherers at several times between 25,000 and 6000 years BP and in a series of marked pulses within the last 2000 years (Mitchell 1996). Feely (1987) reported on farming activities by early pastoralists in the Transkei since 1700 years BP, giving evidence that Xhosa speaking farmers settled in areas with woody vegetation formation avoiding grassland. At later times they were supposed to settle closer, since they utilized the land for grazing. He also found settlement locations occupied by farmers for more than 900 years BP along the middle reaches of the Umzimvubu. Their extent varied between 1.4 km^2 and 2.9 km^2 in size.

Summarizing the development of vegetation and land use, it was shown that the burning in the slopes for grazing and land management has a long tradition in the study area and its impact on vegetation is undisputable.

4 METHODS

Sedimentological and geophysical methods have been applied to selected wetlands in the upper Umzimvubu catchment to assess the formation and evolution of the wetlands in the Eastern Cape Province in general and the influence of human activities on landscape dynamics in particular.

Refraction seismic surveys provide information on subsurface material, depth to water table or to bedrock, respectively and thickness of sedimentary layers. Furthermore this method serves to retrace morphological structures in two-dimensional profile lines (Burger 1992, Pullan & Hunter 1999, Reynolds 1997). These surveys contribute to the evaluation of the water retention capability. A total of five seismic profiles (each consisting of up to five sub-profiles) were measured to investigate wetlands submorphology in three different valley bottom wetlands (Figure 1). Seismic surveys were designed with respect to a high resolution of the upper few meters of the wetlands in order to retrace certain sedimentary structures responsible for wetland formation. Profile lengths varied between 70 and 140 m, investigation depth was about 5 m.

Sedimentological studies comprised the assessment of the sedimentological characteristics (corings and outcrops) in the field as well as the extraction of sample material for laboratory analyses and radiocarbon dating. Based on extensive field surveys and visual inspection of numerous natural outcrops, altogether 11 coring positions in different valley bottom wetlands have been selected (Figure 1). Detailed analytical treatment included the determination of grain size distribution (by sieving and pipette analysis) and geochemical indicators like pH, and C, N, S (with Element Analysator Vario EL), exchangeable cations (Ca, Mg, K, Na), Al, and Fe (with Atom Absorption Spectrometry AAS).Basically grain size distribution has been considered to assess the sedimentological structure and therefore serves to reconstruct the formation and evolution of the wetlands. CNS- and AAS-analysis was intended in order to identify potential environmental changes, but provided only few additional information, since the variability of these parameters is mainly controlled by grain size distribution (content of clay and silt). An example of soil profile analysis with selected elements is given in Figure 4.

To evaluate a minimum age for wetland formation, two samples have been chosen for radiocarbon dating., They were extracted from the base of a sediment core in the Gatberg Vlei (Figure 1) in depths of 220 and 240 cm.

5 RESULTS AND DISCUSSION

5.1 *Refraction seismics*

Valley bottom wetlands with different wetland and catchment sizes in the Gatberg, Wildebees and Mooi catchment have been measured along longitudinal and cross sequences. The determined layer thickness of the sedimentary sequence, the structure and physical properties of the wetlands have been used to reconstruct their subsurface structures and serve to regionalize wetland characteristics.

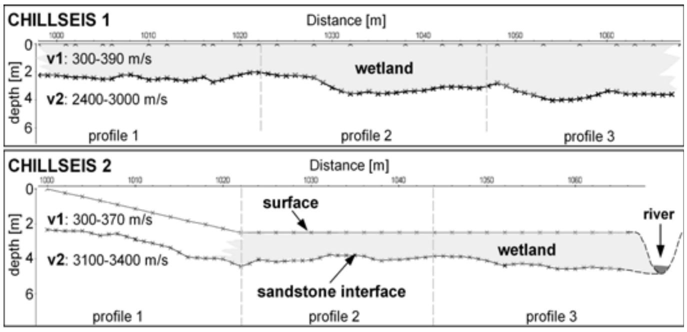

Figure 3. Refraction seismic profiles of 2 valley bottom wetlands in the Mooi basin (exaggerated). ChillSeis1 illustrates a valley floor situation (cross-profile) within the Ku'Ntombininzinzi Vlei, while ChillSeis2 characterizes a whole sequence from the river to the downslope. The wetlands are limited by seismic boundary at the interface derived from the model and the surface topography (topographic correction).

In general, data analysis revealed two distinct layers with differences in measured wave velocities between 300-500 m/s for the upper and about 2200 - 4800 m/s for the lower layer. The relatively small variation of the upper layer velocities indicates homogenous conditions in terms of the physical properties of the material. The low velocity values are typical for unconsolidated overburden sediments. Therefore relatively constant conditions during the deposition of these sediments are assumed. Thickness of this sediment layer is about 2 - 4 m in all profiles. Although it varies slightly due to topographic effects and wetlands submorphology, no indication was found that sediment thickness is related to a specific wetland size. Thus, the evolution and water dynamics of valley bottom wetlands seem to be less influenced by submorphological features.

The interface to the underlying seismic layer is characterized by a sharp increase of wave velocities up to 4800 m/s, indicating the presence of bedrock that is interpreted as the Triassic sandstones underlying the quaternary sediments in the study area. Its significant higher range of wave velocities is addressed to inhomogeneities due to weathered and fractured as well as non-weathered zones within the sandstone, which also could be surveyed at several outcrops.

The results of seismic measurements within two valley bottom profiles are presented in Figure 3. ChillSeis1 shows a sequence of a valley cross profile without a channel, while ChillSeis 2 represents a sequence from the channel up to the downslope.

5.2 *Sedimentological studies*

In order to characterize the processes that led to the deposition and development of the sedimentary sequence as prerequisite for wetland formation, selected cores have been analyzed in detail by laboratory treatment. Additional information arise from numerous field observations in the wetlands surroundings.

In general, the observed sedimentary sequence can be divided into three units overlaying the sandstone of the Karoo sequence. The base of the sedimentary sequence is built up by a thin layer consisting of grayish sands (which is assumed to be partially or completely eroded in some profiles). This is superimposed by a gravel layer, which is also restricted in thickness to about 0.5 m. The topmost layer of the sequence comprises about 1.5 - 2.7 m of fine sandy-silty material with a clay content ranging between a minimum of 10 % to a maximum of 60 %. An intermediary section enriched with clay and silt of about 0.5 m thickness can be found in the top layer of nearly all observed profiles with a horizon with Fe- and Mn-concretions underneath. Both features are expected to indicate soil-forming processes, which are in turn associated to a relatively constant phase during or after sediment deposition. Since the corings mostly did not penetrate the gravel layer, laboratory analyses are restricted to this upper and therefore youngest part of the sedimentary sequence to assess further features related to the sedimentary history of wetlands.

However, according to radiocarbon dating of organic matter, extracted slightly above the base of this upper layer, a maximum age of 3370 ± 51 (Erl-6949, $\Delta^{13}C$: -15.1) and 3384 ± 58 radiocarbon years BP (Erl-6950, $\Delta^{13}C$: -14.8) is given for this layer. Since wetlands have developed within this upper sequence their formation must consequently be placed into this time span that coincides with the beginning of human impact on landscape development in the late Holocene.

Within the wetland bearing sediments a slight fining upwards trend of grain sizes is visible in most profiles (Figure 4). Grain size distribution ranges from sandy material with a low clay and silt content of about 20 to 40 % at the lowermost 50 to 100 cm of the sequence to a clay-silt fraction of about 40 up to 95 % at the top. The above mentioned characteristic layer of clay and silt, which is visible in nearly all profiles in a similar depth and thickness, disturbs this trend by a sudden increase and afterwards a sudden decrease of grain sizes. So far it is assumed, that soil formation processes are responsible for its development, however, changing sedimentation processes cannot be excluded as another possible explanation. Significant amounts of Fe- and Mn-concretions associated with this layer support the first assumption. The development of this fine grained layer, whether driven by sedimentation dynamics or soil forming processes, however, forced a change in hydrological dynamics and thus enabled water retention in the uppermost part of the sediments. Its development is considered responsible for

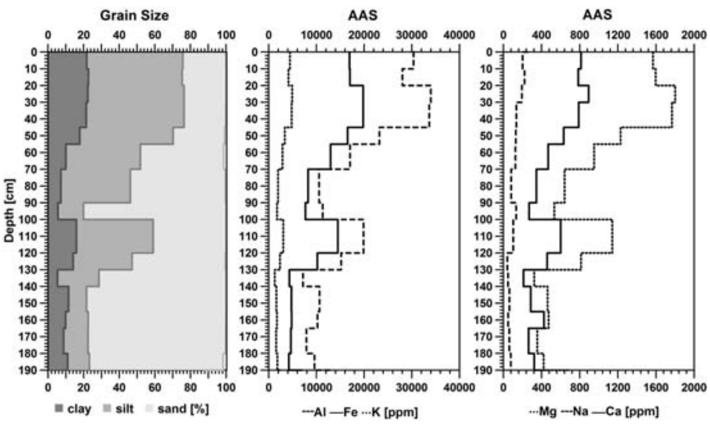

Figure 4. Results of laboratory analyses of 16 samples of core Chillingly 3 within a valley bottom wetland.

the formation of recent wetland conditions in the study area.

6 LANDSCAPE MODEL

Interpretation of all available data (including own investigations compared with results from Acocks 1988, Scott & Lee-Thorp 2004, Huffmann 1996 and Tyson & Lindesay 1992) were used to develop a landscape model, which describes the formation and evolution of the wetlands within the study area. As illustrated in Figure 5, the landscape model comprises five wetland formation phases, which differ in terms of geomorphodynamic processes, vegetation characteristics, as well as anthropogenic influences on landscape development.

Stage A: According to the model the sedimentary basis for wetland evolution is represented by deep incised valleys into the basement. The valley floors which are proved by several drillings and retraced by refraction seismic profiles formed the initial relief of the present floodplains. These deep valleys have been partly filled up with grayish sands and were partially eroded again later. The sandy sediments outcrop slightly above the present sediment level in terms of terraces fringing the valleys. A layer of coarse gravels has accumulated on the remaining sandy sediments in the valley bottoms. These sedimentation and erosion processes altogether provide the morphological basis for the further development.

Stage B: Along with the late Holocene cooling phases (Figure 2), intensified erosion and thus sedimentation of fine material in the floodplains is assumed, leading to a complete infilling of the valley bottoms up to the present level. As reported by Scott & Lee-Thorp (2004) who reviewed demographic responses on climate dynamics, hunter gatherers activities due to intensive resource exploitation (deforestation of riverine vegetation, hunting by burning) increased significantly after 5000 years BP in the interior landscape with a peak at 3100 years BP. A reason for higher demand on resources is hypothe-

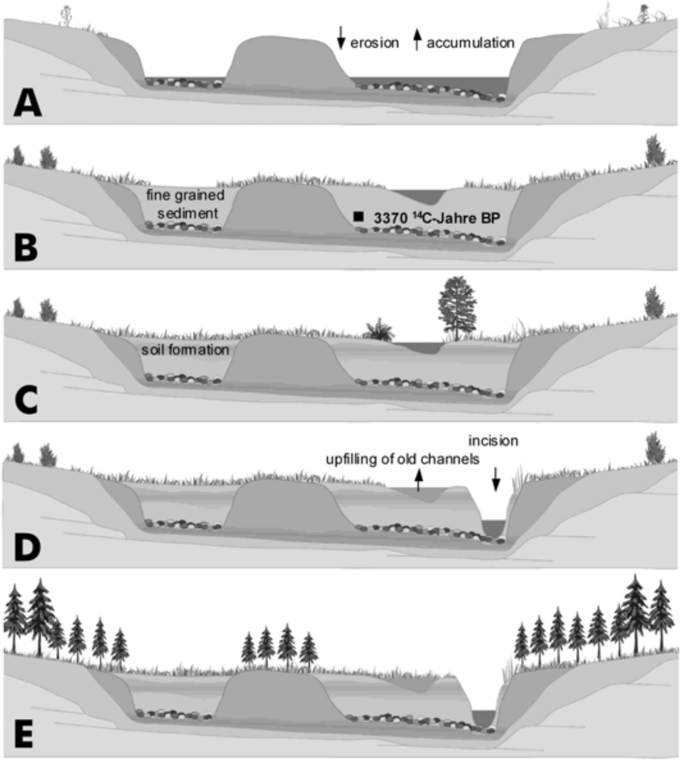

Figure 5: Illustration of the landscape model, which describes the reconstructed evolution of wetlands within the study area in terms of geomorphodynamic processes, vegetation characteristics and anthropogenic influence by land use in 5 consecutive stages.

sized to be related to the following cooling phase which set in abruptly about 3200 years BP. As a consequence thereof those activities may have affected sediment mobilization on slopes at this time. The corresponding sediments deposited in the valley floors and are interpreted as the initial substrate for the formation of wetlands within the study area. Consequently, climate conditions and human activities are assumed to be main drivers for sediment deposition and thereby wetland formation. Results from radiocarbon dating at the base of these sediments reveal a maximum age of 3370±51 ^{14}C years BP for wetland formation. Assuming that the given dating represents nearly the initial phase of the deposition of fine sediments found at the base and relatively steady conditions over the last 2000 years, it furthermore can be concluded that at least 2 m of sediment have been deposited within a relatively short time span of about 1500 years (3500 – 2000 years BP).

Stage C: Within these sediments an initial soil formation is visible in terms of a clayey-silty layer and Fe- and Mn-concretions underneath. This is attributed to a steady phase during or after deposition with neither remarkable erosion nor sedimentation. As a consequence, clay mineralization processes and the development of cemented Fe- and Mn crusts led to the development of an impervious layer in a depth of about 0.5 to 1 m that affects the seasonal hydrological dynamics and therefore enables recent wetland conditions. Since less evidence is given in terms of significant climate changes compared to recent conditions over the last 2000 years (Tyson 1987, Scott & Lee-Thorp 2004), it is assumed that soil development took place during the last 2000 years. As emphasized by Fey (pers. comm.), soil-chemical considerations indicate that these features developed under constant conditions regarding sediment dynamics and permanent water fluctuations for at least 600 years and thereby confirm the assumptions due to climate impacts on wetland evolution. During this steady stage a pronounced riverine vegetation developed. Anthropogenic land use is characterized by the transition of the hunter-gatherer culture into early farming activities, also pointing to a persistence of a grassy vegetation type.

Stage D: In recent to subrecent time scales a new incision into the valley fills took place, much more restricted to narrow channel beds than in stage A, but nevertheless 2 to 3 m deep, down to the basement or at least to the gravel layer. This incision is probably the result of anthropogenic influences due to efforts of drainage of the wetlands in order to use the land for pasture management. Drainage lowered the erosion level up to several meters, which is furthermore associated with the onset of deep gully erosion as a consequence of extensive farming management, i.e. (over)grazing and fire management during the last 600 years.

Stage E: In addition to the existing farm management, intensive afforestation attempts with pine and eucalypt started since 1989 within the Umzimvubu catchment. To some extent the plantations even reach into the wetlands. The impact on wetlands is currently studied in the context of extensive hydrological measurements, with first results pointing to a rising limitation of water supply from the slopes due to increasing water retention by the trees (Lorentz, pers. comm., Helmschrot 2006). However, long time studies are necessary to get further insights and to prove these assumptions.

7 CONCLUSIONS

Refraction seismic measurements and soil profile analysis indicate that wetland evolution was induced by a late Holocene infilling of former valley bottoms with fine materials. This process started about 3,370±51 radiocarbon years BP. Significant layers of clay and silt in upper parts of the profile are addressed to phases of increased sedimentation of fine materials associated to low fluvial dynamics and sparse vegetation cover. This might be a consequence of climate change to slightly cooler and wetter conditions intensifying anthropogenic activities (i.e. artificial fires that reduced vegetation cover and increased sediment delivery). Thus, wetland evolution is assumed to be related to both climate and anthropogenic influences. Following the sedimentation, soil formation processes, in conjunction with increased groundwater fluctuation, led to the formation of an impervious layer that affects the seasonal hydrological dynamics and therefore enabled recent wetland conditions.

The results show that there is an indication of changes in landscape dynamics during the Holocene and thereby support a new perspective on wetland formation. Addressing the controversial discussion of human and climatic impacts on Holocene landscape evolution in South Africa, this study provides an alternative model describing late Holocene landscape evolution within the semiarid headwaters of the Umzimvubu catchment. Further studies are necessary to prove the assumptions and refine the model.

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