1 INTRODUCTION

1.1 Objectives and scope

This study started in 1987 with an apparently innocent question: "is there any peat in South Africa that can be used for the preparation of activated carbon?" At the time it was also assumed that, since there is basically no peat in this country, the completion of this little exercise would take but a few weeks.

Therefore, the reason for this thesis is primarily the fact that there were far too many questions on South African peat with no ready answers. I soon discovered that this was in fact the case for the entire continent. Thus began the quest for knowledge on peat in South Africa in particular and Africa in general.

In the development of this thesis I will analyse, dissect and discuss the peats and peatlands of SOUTH AFRICA *sensu latu*. Towards the end of this manuscript (chapter 7), I will also briefly discuss some aspects of other African peats for the purpose of comparison and to further support a proposed peat classification system for Africa.

The objectives are as follows:

- to determine the extent and nature of peats and peatlands in South Africa,
- to study peat sedimentology and palaeoecology,
- to characterise peat types,
- to classify peatlands,
- to delineate management constraints.

Precious little information exists on South African mires (peatlands). In fact, shockingly few people in this country know that peatlands exist here, let alone realise their significance in the ecosystem or their economic importance. With the increased pressure on mires from agriculture and industry for the supply of raw materials and from urban development for more land, it was discovered that there were no answers to many of the questions being asked by developers, conservators and law-makers. This project will supply some of the basic scientific information needed to make correct and environmentally responsible management decisions regarding peatlands. It will also enable energy policy makers (Department of Mineral and Energy Affairs), conservators, natural resource conservation officers (Departments of Agriculture and of Environmental Affairs and Tourism), developers and entrepreneurs to base their decisions and actions on scientific facts. The results will also be used in popular format to educate the public as to the importance of peat and peatlands and their conservation and sustainable exploitation management.

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2 PEAT AND MIRES

Peat genesis is influenced by drainage, climate, hydrology, geomorphology, basement geology and nutrient status. Peat deposits form in localities of impeded drainage and/or high rainfall. Any freshwater wetland ecosystem in which autochthonous peat accumulates is termed a mire (Gore, 1983; Maltby and Proctor, 1996). This is a general term which includes all the following ecosystems - bog, fen and swamp. These terms are defined as follows:

bog is confined to ombrotrophic peat forming ecosystems ("nutrition from rainwater" synonym for ombrogenous (Stach *et al.* 1982; Bates and Jackson, 1987)). Precipitation is essentially the only input of water to the system and thus also the source of nutrients entering the system) (Gore, 1983);

bog forest is the same as above but the dominant vegetation is trees (Esterle *et al.*, 1989; Roggeri, 1995);

fen refers to rheotrophic peat forming systems in which the dry season water table may be below the peat surface (a rheotrophic system is one in which both precipitation and ground water/surface run-off play a role in affecting that system hydrologically. Synonym for topogenous (Stach *et al.*, 1983; Bates and Jackson, 1987));

swamp is a rheotrophic wetland in which the water table is almost always above the surface of the substrate;

floating swamp often develops around the fringes of lakes, especially common in tropical and sub-tropical African lakes where these platforms can be thick and extensive (Howard-Williams and Gaudet, 1985);

swamp forest is a specific swamp type (also rheotrophic in nature) in which trees are the dominant plant constituent in sub-tropical and tropical climates (Smuts, 1992), temperate swamp forests have been referred to as "carr" in earlier publications (Martin, 1959).

The above is merely a brief overview of some peat and peatland defenitions and should not be seen as an attempt at entering the discussion on semantics. Mire types can be found in all except the most hot and arid climatic areas of the world.

The principle prerequisite for the formation of peat is that the rate of production and accumulation of organic material must be greater than its decay.

Peat is the progenitor of coal. It consists predominantly of loosely compacted, partially decayed, semicarbonized plant material in a water saturated environment. It is generally more or less fibrous (structures of the vegetal matter can be recognised) and contains between 75% and 97% water in the natural state.

Organic material falling onto a mire surface may decompose completely in the acrotelm (aerobic peat layer) or it may pass down into the sulphide zone (catotelm) where decomposition rates and chemical changes are extremely low (Clymo, 1965; Latter and Cragg, 1967; Ingram, 1978). Once inside this anaerobic reducing environment of the catotelm, plant and animal remains will remain virtually unchanged for a long time (Ingram, 1978). The only notable changes being vertical compaction under the weight of further accumulation of organic matter.

Two types of material are dominantly preserved in peat, namely:

- those parts of plants and animals made up of materials resistant to microbial breakdown, (suberin, lignin and chitin) and
- those plant organs which penetrate the peat to be closer to the sulphide zone on death (roots and rhizomes).

The following peat components are recognised:

Organic matter

- identifiable due to its organised state of preservation.
- cell structure still visible but much decomposition has taken place.
- decomposed to below cellular level, forming humus or peat matrix.

Inorganic matter

- either blown or washed into the mire, or from plant cells, e.g. silica phytoliths from reeds and grasses, and diatomaceous tests.

Mires can be classified into bog and fen and any mire can essentially be categorised according to these two terms. More elaborate classifications have been devised, their nature largely dependent on the origin and purpose of the particular system. The criteria used in such systems have to be easily accessible; hence shape, chemistry, plant species composition and vegetative structure are all common criteria used in various parts of the world (Gore, 1983).

Gore (183) recognises two mechanisms are recognised as being responsible for mire formation.

Terrestrialization - formation of a mire by infilling of a shallow water body by organic matter. This is usually caused by progressive extension of peat-forming communities from the shoreline into a lake.

Paludification (swamping) - formation of a mire over previously forested land, grass land, bare rock or river flood plains. This can be caused by climatic, autogenic (processes internal to the mire) or tectonic processes.

Modifications by man to the natural environment may also activate either of these mechanisms into mire formation.

It is often not easy to distinguish between mode of formation when dealing with large, well established mire systems that have undergone a complex hydroseral succession. It is more the rule than the exception that complex mire systems will exhibit proof of both terrestrialization and paludification in its formation history both in time and in space.

2.1 Peat formation and templates of mire development

2.1.1 Peat Formation

2.1.1.1 Nutrient cycling and hydrology

Mire nutrients enter and leave the system mainly in solution or in suspension in the mire waters. Nutrients also enter the system via rainfall and dust precipitation. The underlying soil/bedrock has very little impact on the mire nutrient cycle as the peat layer largely isolates the mire from the underlying formations. Mire nutrient cycling is represented schematically in Fig. 2.1. The supply of elements to mire vegetation is a function of ionic concentrations and the rate of water flow through the system. Thus nutrient poor, oligotrophic waters may be able to support nutrient demanding vegetation if there is a sufficiently rapid rate of water movement (Moore, 1987). This process results in richer vegetation developing close to stream courses in valley mires (Moore, *op. cit.*).

Hydrology and nutrient cycling in mires are thus closely related; hence it is meaningful to classify mires in terms of their hydrology. Ombrotrophic mires (purely rain fed) are termed "bogs" and rheotrophic mires (fed by both precipitation and groundwater) are labelled fens, swamps or forest swamps.

More often than not it is rather difficult to separate ombrotrophic from rheotrophic mires as they are often found in close association and may in fact be derived from different segments of the same hydrological unit, hence the use of the term "mire complex". Moore (1987) put forward a modified model relating the precipitation/ evaporation ratio (P/E ratio) of mires to groundwater influence (Fig. 2.2). Ombrotrophic mires are confined to the upper left of the diagram, where there is no groundwater influence and precipitation is in excess of evaporation. Rheotrophic mires, in the centre, receive water from both sources. In the lower right part of the diagram groundwater represents the most important hydrological factor and peat was found not to accumulate in the wetlands that exist under these conditions.

Figure 2.1 Nutrient flow patterns in a mire (after Moore, 1987)

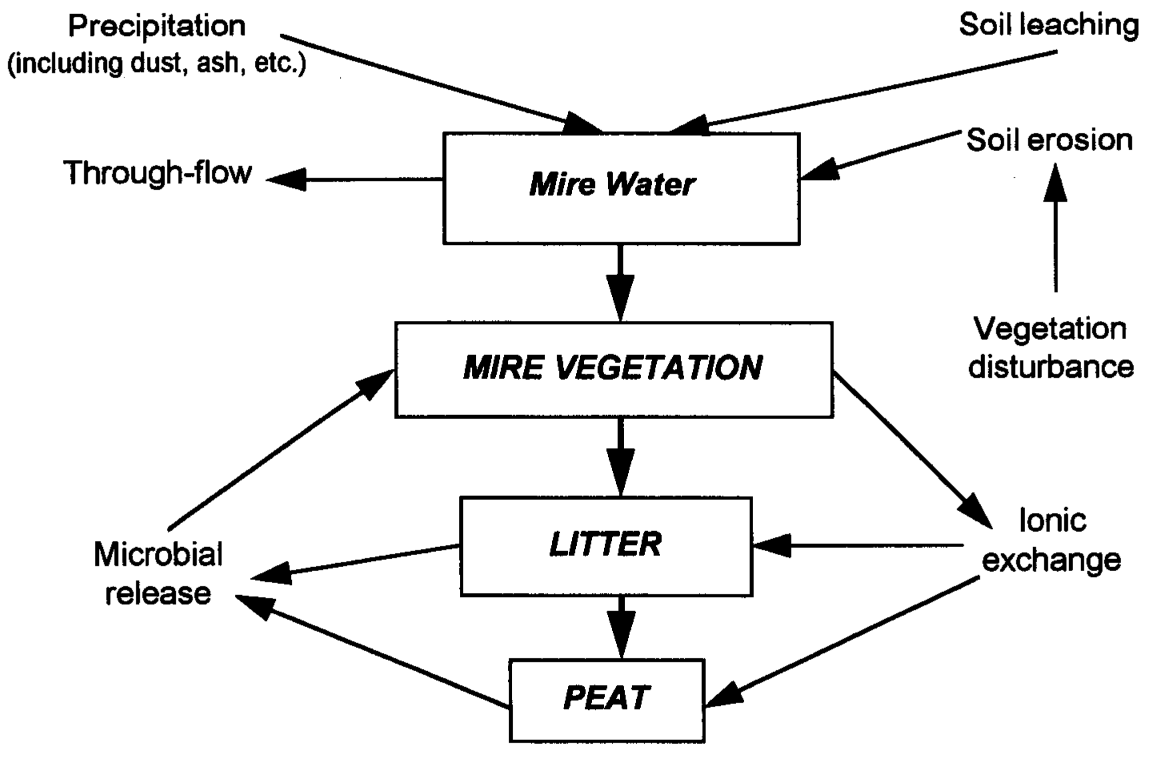
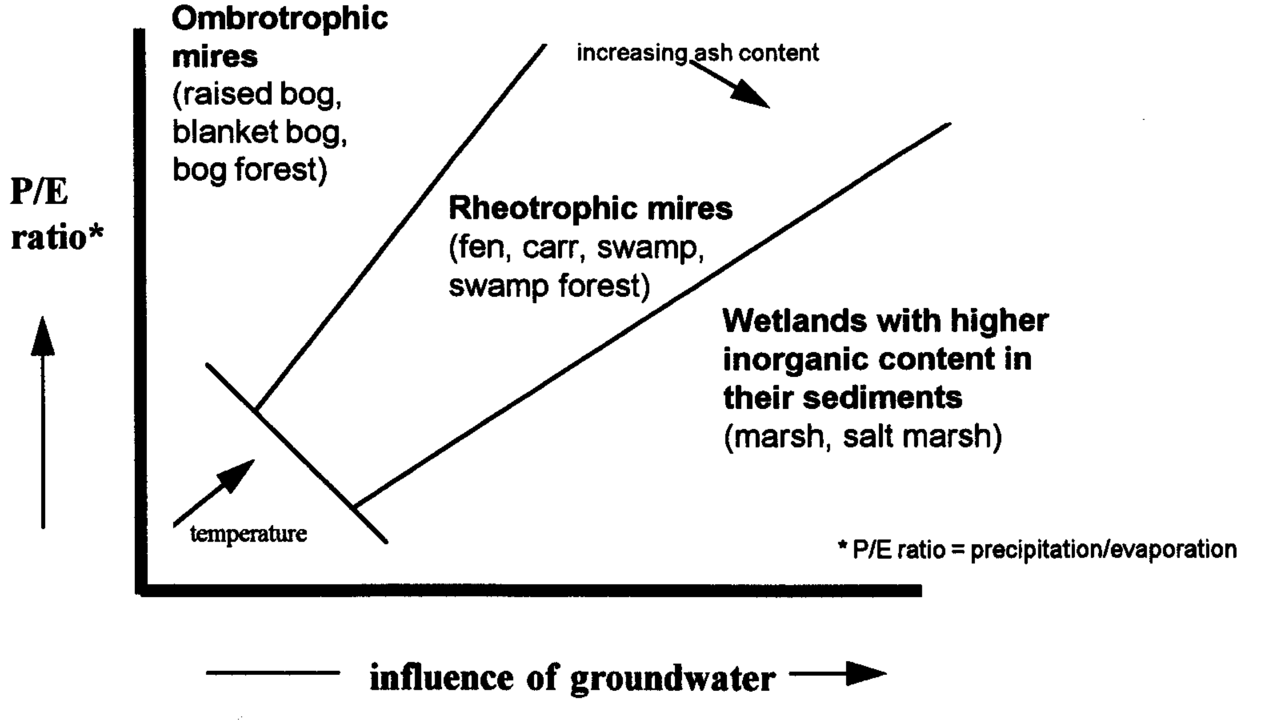


Figure 2.2 Relative influence of rainwater and groundwater on hydrological input of mires (after Moore. 1987)



Estimates of losses due to elutriation, rain and decomposition account for approximately two-thirds of the total nutrient accumulated in a tropical sedge swamp. The remainder is deposited in the peat (Gaudet, 1977). According to Moore (1987) rheotrophic mires could not have been responsible for our present-day coals as their initial inorganic content is too high. It has however been shown by Kosters *et al.* (1987) that peats in the Mississippi delta undergo leaching during early diagenesis, reducing ash values by 20 to 33%. This leaching and possible silica mobilisation reduces initial high ash contents to levels acceptable for coal formation (Cohen *et al.*, 1987; Kosters *et al. op. cit.*). This phenomenon has also been observed in South African peatlands.

2.1.1.2 Climate

Climatic factors affect wetlands and peat formation in a number of ways through modifications of the prevailing nutrient cycle and energetics of the system. A temperate peatland will have lower production and respiration rates than one in a tropical setting because of the higher temperatures in the latter. Similarly precipitation in a temperate wetland has little effect on primary productivity (net positive productivity starts at 1000 mm/yr.), whereas increased rainfall in a tropical wetland has a very marked effect on primary production, increasing rapidly with increasing rainfall (Moore, 1987). However in the tropics net positive production only occurs at rainfalls of 2000 + mm/yr. but then at higher production rates than in the temperate zones. Thompson and Hamilton (1983) maintain that at least 2000 mm/yr. precipitation is necessary to sustain peat formation in primary mire positions (valleys and basins). Under dry climatic conditions peat will only form where temperatures are low enough to reduce microbial activity significantly.

Peculiar hydrological conditions may result in the presence of mires in localities which would in terms of climate not be able to sustain peat formation, eg. the Hula valey in Israel (Cohen *et al.,* 1987) and the dolomitic spring mires of the arid Western Transvaal.

2.1.1.3 Energetics

The initial energy input in almost all terrestrial ecosystems is photosynthesis by green plants. Part of this energy is used up in the plant's metabolic process and the remainder becomes available as an energy source to higher life forms or is taken up into the litter layer where it is either attacked by detrivores or microbially decomposed. In mires some of this excess energy produced in the ecosystem is retained and accumulated as peat. Thus the entire system is gradually increasing its energy content as peat builds up. Energy can be stored in a system as increased biomass (plant material) or as litter and soil organic matter. In peatlands the detrivore and decomposer food webs are severely curtailed by waterlogging and consequential oxygen shortage, resulting in preferential accumulation of organic detritus. The continued build-up of energy in a system implies that system is in the course of succession and has not reached a state of equilibrium. From extensive work on UK blanket mires it appears that only 15% of the net primary production remains in the system as peat (Moore, 1987).

Productivity and peat accumulation exhibit a great deal of variation in different parts of the world and in different mire types (Moore and Bellamy, 1972). *Typha* swamps are reported to be amongst the world's most productive ecosystems with figures quoted in excess of 2 kg m^{-2} a^{-1} for above ground production (Moore, 1987; 1989). Thompson *et al.* (1979) and Gaudet (1979) measured production rates in African tropical papyrus swamps ranging from 1.1 to 3.4 kg m^{-2} a^{-1} (above ground production). When we examine peat accumulation rates we find that tropical swamps are not that far ahead of temperate bogs as might be expected from the large difference in production rates. Moore (1987) cites figures of 1 - 3 mm.a^{-1} for swamps and 0.2 - 0.5 mm.a^{-1} for *Sphagnum* bogs.

However, as Moore *(op. cit.)* also points out, rates of peat accumulation quoted in the literature are very difficult to interpret since they are often derived from incomparable data from various peat types and unrelated peat depths. Given adequately high rainfall and/or permanent water levels, mires (notably reed/sedge mires) in southern Africa generate large volumes of plant matter annually with the potential to accrue much of this primary production in the peat layer, leading to significant recent accumulation rates. Recent accumulation rates from 50 mm.a^{-1} (Okavango swamp, McCarthy *et al.*, 1989) to 100 mm.a^{-1} (eastern Transvaal reed/sedge/algae spring bog, Mr.. Du Plooy pers. comm. 1988) are quoted for southern Africa. This latter figure is based on peat accumulation after hand cutting of sod peat at this locality 10 years earlier.

2.1.2 Templates of Mire Development

"Anywhere water collects on its way down from the catchment to the sea, constitutes a template for peat formation"

(Bellamy, 1972).

Bellamy (1972) proposed two templates of peat formation, namely a hydrological template and a climatic template.

2.1.2.1 Hydrological Template:

The type of mire which forms in a particular area depends on the hydrological balance of the basin and quantity of dissolved nutrients. The hydrological balance for this template is as follows:

$$\text{INFLOW} = \text{OUTFLOW} + \text{RETENTION}$$

Accumulation of peat occurs within the volume of retention. This type of peat accumulation is limited to the level of drainage from the reservoir. Beyond this point the peat mass becomes an active reservoir capable of holding a certain volume of water against drainage. This can occur in two ways, (1) peat accumulating upwards under suitable conditions can create a perched water table in the peat. Capillary action holds the peat water table at a higher level than the ground water table. This process often leads to flooding of new ground upstream of the peat, giving rise to lateral paludification. Bellamy (1972) defined three terms for peat and mire description in terms of the hydrological template:

Primary mire systems are formed in basins or depressions, their development reducing the storage capacity of the reservoir.

Secondary mire systems develop beyond the confines of the basin, the peat acting both as reservoir and dam, increasing the storage capacity of the landscape unit.

Tertiary mire systems develop above the physical limits of the ground water table. The peat acts as a reservoir holding a volume of water by capillary action above the level of the ground water. This perched water table is fed directly by precipitation.

Primary mires can be found in all except the most arid and hot climatic zones of the earth, whereas secondary and tertiary mires are only found in areas were the macroclimate is favourable. These mire types exhibit a distinct zonation with respect to macroclimate on a world-wide scale. Bellamy (1972) does not include spring mires (mires which form over artesian spring heads) in his definitions. Upward accumulation of the peat is limited by the height of the hydrostatic head of the spring within the containing peat and vegetation. A spring mire has the appearance of a tertiary mire but the hydrological characteristics of a secondary mire.

2.1.2.2 Climatic Template

From examining peat formation in various climatic regions it becomes clear that to give an accurate rendition of the hydrological equations valid for mire types, precipitation and evaporation should also be included:

INFLOW + PRECIPITATION = OUTFLOW + EVAPORATION + RETENTION

Extensive lowland primary mires in southern Africa in drier sub-tropic and tropic areas are restricted to deltaic and estuarine positions, merging with coastal mangrove swamps.

Where rainfall is higher, mires extend further up-river and inland into lake, interdune and other low lying enclosed areas. Cooler more humid regions facilitate peat formation in a wider range of basin types, following the order, estuarine/deltaic, river flood plains, open lake basins, closed lake basins, valley heads and springs. Bellamy (1972) and Moore and Bellamy (1972) recognise 9 mire zones for Europe and Asia. Although some South African mires (any mire for that matter) can probably be classified very broadly according to similar zones, it will be necessary to fine-tune and modify a zone system (with special reference to climate and vegetation types) to really be applicable to southern hemisphere conditions and mire types.

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3 METHODS

3.1 Field methods

Wetlands were identified on 1:50 000 scale topographic maps and aerial photographs after which a number of potential peatlands were selected for preliminary investigation.

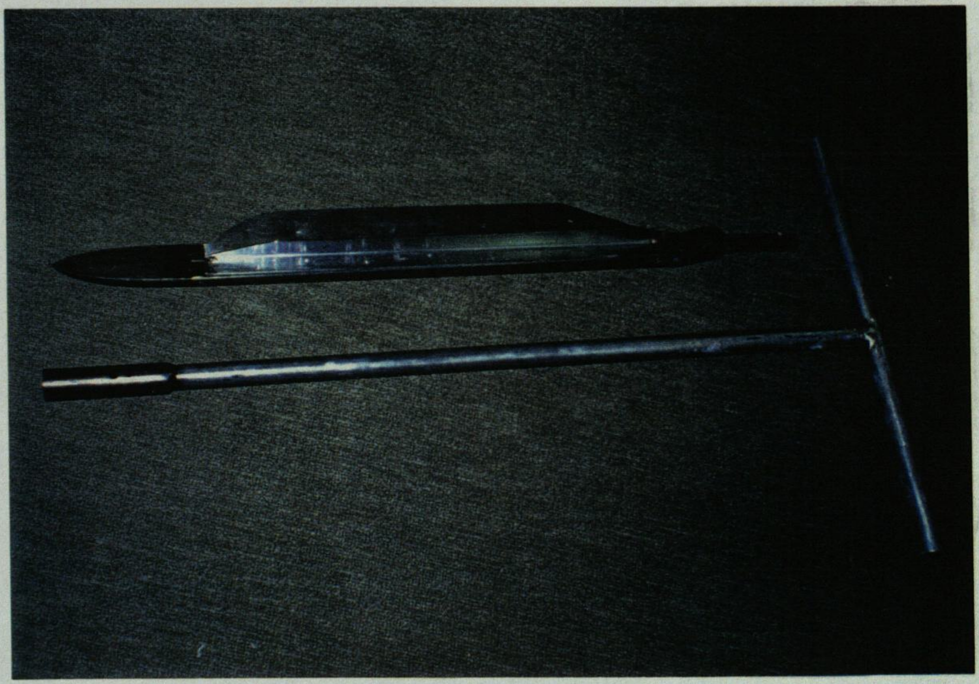
All samples were taken with a hand-operated Russian peat sampler (Fig.3.1) (Belokopytov and Beresnevich, 1955; Jowsey, 1966) unless otherwise specified. This device allowed the collection of undisturbed samples in 50 cm increments from the top to the bottom at each sampling site. Sampling sites are indicated on Figure 4.1. The shape of the sampler and the plastic nature of the peat facilitate the closure of the sampling hole almost immediately after extraction. It is thus possible to sample continuously from the top down the same hole or to take incremental samples at random depths and places. Each core increment was inspected in the field and sub-sampled.

Samples were placed carefully into labelled, 120 ml plastic bottles, closed with an airtight cap, and carried out in back packs. Samples were kept closely packed and upright to prevent disturbance or compaction. At each sample site the surface vegetation was recorded as well as the maximum thickness of the peat profile and the position of the water table (Fig. 3.2).

Some preliminary descriptions and analyses such as colour, texture and Von Post humification determinations were done in the field immediately after extraction of the cores (Fig. 3.2), the reason being that these values often change soon after exposure of the peat to the atmosphere. This is especially true for peats from the catotelm. The Von Post system is a simple and handy method for field classification of peats (Fig. 3.3).

Samples destined for petrographic/botanic investigation were sealed with a few drops of formalin to inhibit any biogenic activity subsequent to sampling. Samples for radiocarbon dating were carefully cleared of any living roots and other material which may adversely influence the determinations, and sealed.

Fig. 3.1 Russian peat drill



Drill (open position) with handle.

A freshly extracted peat core.

Sampling bottles.

Figure 3.2 An example of the log sheets used in the field to describe peat cores.

MAP NAME

DEPOSIT No.

SITE No.

VEGETATION

SAMPLE No.	LOG	XF	F	H	COLOUR	pH	DESCRIPTION

XF - expressed fluid
- **N - clear**
- **Y/R - yellow/red**
- **T - turbid**
- **V - very turbid**
- **S - strongly turbid**

F - fibre content
- **1 - 0 to 33%**
- **2 - 33 to 66 %**
- **3 - 66 to 99 %**

H - Von Post humification (see Fig. 3.3)

Figure 3.3 Von Post's Humification Scale for describing peat samples in the field. (modified after Bélanger *et al.*, 1988)

Humification	Description
H1	Completely undecomposed peat which, when squeezed, release almost clear water. Plant remains easily recognisable. no amorphous material present.
H2	Almost completely undecomposed peat which, when squeezed, releases almost clear or yellowish/reddish water. Plant remains still easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat which releases muddy brown or red water when squeezed.
H4	Slightly decomposed peat - releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of its identifiable features.
H5	Moderately decomposed peat - releases viscid water with a very small amount of amorphous granular peat escaping between the fingers. Only certain features of plant remains can still be recognised. The residue is strongly pasty.
H6	Moderately strongly decomposed peat with very indistinct plant structure. When squeezed about one third of the peat escapes between the fingers. The residue is strongly pasty but shows the plant structure more distinctly than before squeezing.
H7	Strongly decomposed peat. Contains a lot of amorphous material with very faintly recognisable plant structure. When squeezed about one-half of the peat escapes between the fingers. The water, if any, is very dark and almost pasty.
H8	Very strongly decomposed peat with a large quantity of amorphous material and very dry indistinct plant structure. Two thirds of the peat escapes through the fingers when squeezed, a small amount of pasty water may also be expressed. Plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.
H9	Practically fully decomposed peat in which there is hardly any recognisable plant structure. When squeezed almost all the peat escapes through the hand as a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed all the wet peat escapes between the fingers.

3.2 Laboratory methods

The following analyses were carried out:

1). Field moisture/bulk density/water holding capacity and fibre content,

2). semi quantitative mineralogical composition by means of X-ray diffraction analysis,

3). calorific value (MJ/kg) (on air-dried samples),

4). pH,

5). proximate analysis (moisture, ash, fixed carbon, and volatile matter) (on air-dried samples),

6). petrographic/botanical analysis,

7). major and trace element analysis,

8). ^{14}C age determinations,

9). Hydrogen, carbon, nitrogen, sulphur analysis (air-dried samples),

10). Fischer assay.

Field moisture (bed moisture in coal), bulk density and water holding capacity were calculated from wet volume, wet weight and dry weight, viz

- field moisture (bed moisture) is the moisture content at 100% relative humidity (ie. before drainage under gravity takes place)

$$FM = \frac{\text{mass of wet peat - mass of dry peat}}{\text{mass of wet peat}} \times 100\%$$

- water holding capacity (field capacity) is maximun moisture content before drainage under gravity takes place;

$$WHC = \frac{\text{mass of wet peat - mass of dry peat}}{\text{mass of dry peat}} \times 100\%$$

- the bulk density is the ratio between the dry mass and the volume of the water saturated samples.
- The fibre content of peat is defined in terms of fibres with a lenght of more than 0.15mm ie.

$$\%\ \text{fibre} = \frac{\text{mass of dry fibres (>0.15mm)}}{\text{total dry mass of peat}} \times 100$$

Sulphur, carbon and hydrogen analyses were carried out using Leco Induction Furnace Analysers. Proximate analyses were carried out according to ISO standards.

Calorific value determinations were done in a Minical Automatic Calorimeter and ashing was carried out on approximately one gram samples in a Carbolite CSF furnace for 3 hours at 815^{0}C in open ceramic crucibles. Proximate and ultimate analyses were carried out by Enertek of the CSIR, Pretoria.

The CV is essentially determined by the contents of carbon, hydrogen, nitrogen and sulphur, whereas moisture, oxygen and mineral matter act as diluents and hence lower the CV. The CV of organic materials can be calculated according to Boie's formula,

viz. **CV (MJ/kg) = 0,34 . %C + 1,162 . %H + 0,062 . %N + 0,1 . %S - 0,111 . %O**
(Van Krevelen and Schuyer, 1957),

In this study it was found empirically that CV (MJ/kg) = 0.34 FC + 0.18 VM (standard error = 0.7 MJ/kg), where FC = % fixed carbon and VM = % volatile matter. These equations were found to be useful to check on the quality of analyses and to calculate an approximate calorific value in cases where it had not been determined (Appendix 2 and 3), e.g. in sample 2732 BB20/3 at 50cm (appendix 2) the CV was determined as 22.4 MJ/kg (27.9 MJ/kg on a dry, ash-free basis). This value is more typical of a low-rank bituminous or sub-bituminous coal than of a peat. The calculated value is 18.3 MJ/kg (air-dry basis). In Appendix 3 several examples are given where the elemental composition is not in agreement with the proximate analysis and the determined calorific value (eg. RIK 200). By assuming that the percentages of minor elements (hydrogen, nitrogen and sulphur) are basically correct, adjustments can be made to the contents of carbon and oxygen by making use of Boie's formula:

$$
\begin{aligned}
CV &= 0.34\,C + 1.16\,H + 0.062\,N + 0.1\,S - 0.111\,O \\
23.6 &= 0.34\,C + 1.162\,H + 0.062\,N + 0.1\,S - 0.111(100 - H - N - S - C) \\
&= 0.34\,C + 6.21788 - 0.111(92.6 - C) \\
0.451C &= 27.66072 \\
\therefore C &= 61.33\% \text{ and } O = 92.6 - 61.33 = 31.27\%.
\end{aligned}
$$

It can also be assumed that the carbon is correct. In this case the calculation is as follows:

$$23.6 = 1.162\,H + 17.48062 - 0.111\,(46.83 - H)$$

$$1.273H = 11.31751$$

$$\therefore H = 8.89\% \text{ and } O = 37.94\%$$

As these adjustments are obviously not unique it is important that chemical analysts and geologists working in the coal/lignite/peat field should ensure that the analytical data are reliable before any interpretation is attempted.

A combination of calorific value and air-dry moisture (both on an ash-free basis) can be used to distinguish South African peat from South African hard coals of Permian age (Fig. 3.4).

Moisture analysis were done by weight loss in a Optolab Term-o-mat 321 oven at 105^{0}C for 12 hours. Major inorganic element analysis was done by the Geological Survey Laboratory by means of a Phillips PW1480 XRF Spectrometer and trace elements by means of a Phillips PW1400 XRF Spectrometer following the method of Feather and Willis (1976). Both major and trace element analysis were carried out on ash. The analytical results are listed in Appendix 4.

Samples for petrographic analysis were either processed using standard methods (with minor modifications) to obtain oriented microtome sections (Cohen and Spackman 1972, 1977, 1980; Cohen 1983), or prepared as standard polished sections. Some microtome sections were also stained to further elucidate possible changes in the peat during humification. Most petrographic work was carried out on a Zeiss UEM transmitted and incident light microscope with an incident ultraviolet light (UV) facility. Botanical analyses were done with the aid of a stereomicroscope.

3.3 Maceral description.

Macerals are, very broadly speaking, to coal what minerals are to rock and consist of humified plant remains (of which form and/or structure is preserved) and degraded structureless vegetal remains. The path to macerals is not merely one of breakdown into smaller pieces. It also involves chemical / biochemical reactions, precipitation, migration, staining, impregnation, dissolution, etc.. The nomenclature of the International Handbook of Coal Petrography (1971, 1975) and Stach *et al.* (1982) have been used as the basis of this module (Tables 3.1 and 3.2).

It is accepted that different plant organs (and different plants) contributing to peat, and ultimately to coal, differ in their response to humification and coalification (ie. biochemical degradation and organic metamorphism) (Styan and Bustin, 1983, Cohen and Spackman, 1980, Ting, 1989). Humification is regulated by the climate and the physical restrictions of the peatforming environment, while coalification is controlled by temperature and pressure within the coal-forming strata. In this study I will deal with the effects of humification, plant types and ecological conditions on plant material in the peatforming environment and the resultant petrographic fabric of the peat.

Fig. 3.4 Calorific value versus inherent moisture

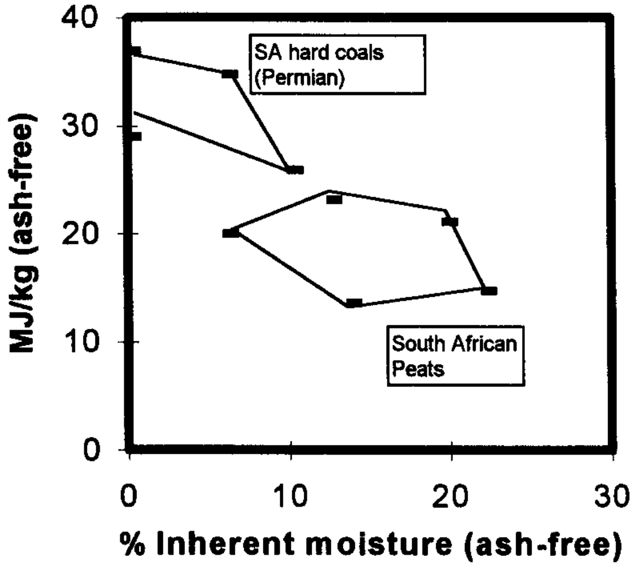


TABLE 3.1 MACERAL CLASSIFICATION OF BROWN COALS AND LIGNITES (International Handbook of Coal Petrography 1971, 1975).

	Maceral Subgroup	Maceral	Maceral Type
huminite	humotelinite	textinite ulminite	texto-ulminite eu-ulminite
	humodetrinite	attrinite densinite	
	humocollinite	gelinite corpohuminite	porigelinite levigelinite phlobaphinite pseudo-phlobaphinite
liptinite		sporinite cutinite resinite suberinite alginite liptodetrinite chlorophyllinite bituminite	
inertinite		fusinite semifusinite macrinite sclerotinite inertodetrinite	

TABLE 3.2 ORIGIN OF VITRINITES AND INERTINITES (after Stach et al., 1982).

MAIN PLANT SUBSTANCE	Phlobatannin	Lignin and Cellulose		Chitin + Melanin	Phlobatannin Resins	Lignin - Cellulose ?+ Melanin and/ or Phlobatannin	Lipoid Substances + Cellulose	+Lignin and Cellulose
STRUCTURAL ELEMENTS	cell fillings	intact cell walls (tissues) humification cell detritus	intact cell walls (tissues) cell detritus	dark fungal mycelia and fungal spores	cell fillings (cell secretions)	dark cell walls (tissues)	1)amorphous 2)wax squamae 3)incorporated in exines, algae, etc.	incorporated in cell walls
Lignite and Peat	Corpohuminite Phlobaphinite Pseudo-Phlobaphinite	mobile, amorphous humic subst humification biochemical gelification gelification humification Textinite B Attrinite Porigelinite biochemical gelification Ulminite B Densinite Eu - Gelinite geochemical gelification vitrinitization	amorphous humic subst by charring by oxidation fusinitization (Pyro-)(Oxy-) Semifusinite Fusinite Inertodetrinite Macrinite coalification	(Fungi-) (Secretion-) Sclerotinite coalification		(Primary-) Semifusinite Fusinite coalification	Resinite Bituminite coalification bituminization	Textinite A coalification bituminization
Bituminous Coal	Corpocollinite	Telinite Telocollinite | Vitrodetrinite Desmocollinite Gelocollinite	(Pyro-) (Oxy-) Semifusinite Fusinite | Inertodetrinite Macrinite	(Fungi-) (Secretion-) Sclerotinite		(Primary-) Semifusinite Fusinite	Micrinite	(Rank-) Semifusinite Fusinite
	Vitrinite Group			Inertinite Group				

3.3.1 Huminite (Vitrinite precursor)

This maceral group comprises a number of organic components, namely:

• humotelinite - plant tissues with recognisable cell structures partly decomposed and intact.

• humodetrinite - mixed detritus derived from the fragmentation and dispersion of cell walls in a fine matrix.

• humocollinite - gelified organic matter in masses or filling cell cavities, in which case it is called phlobaphinite.

3.3.2 Liptinite (exinite)

Liptinites originate from hydrogen-rich vegetal materials (e.g. cutin, suberin, resin, sporopollenin, waxes, fats and oils) as well as bacterial degradation products of cellulose and proteins. The following components are found in South African peats:

• cutinite - cuticles from the outer layers of the epidermis of aerial plant parts. In ultraviolet light they are fluorescent in the yellow to yellow-brown range and are common in all peats.

• sporinite - microspores and pollen occur in varying numbers in all peats, fluorescing in the yellow to yellow-green range. Many pollen types are easily decomposed and are found very rarely (Stach *et al.*, 1982).

• resinite - resinous, fatty and waxy vegetal secretions that are common in many sub-tropical and tropical plants, e.g. *Ficus*, *Phragmites, Typha, Cyperus, Scirpus* and many others. Resinites are fluorescent in yellow.

3.3.3 Inertinite

Chemically and botanically the precursors for inertinite and vitrinite are virtually the same. Inertinite can also be derived from liptinites (e.g. mictinite). However, inertinites experienced a very different formation history, described as "fusinitization", producing substances with relatively high carbon contents and low hydrogen contents. For the same H/C ratio, fusinite has a higher O/C ratio than vitrinite. This characteristic enables the structural parameters of macerals to be calculated from ultimate analyses (Van Krevelen and Schuyer, 1957). Most fusinitization is caused by charring, oxidation, mouldering and fungal attack in the standing crop or before deposition on the peat surface.

• fusinite and semifusinite generally have the same origin and are distinguished primarily on their degree of fusinitization. For this reason these two macerals are considered together. Three types of fusinite can be distinguished in the peat: pyrofusinite, degradofusinite and primary fusinite.

- pyrofusinite is related to peat and/or vegetation fires. The conditions in a mire during a fire (abundance of moisture in the system and an oxygen deficiency due to either the severity of the fire itself or the position of the fire within deeper levels of the peat profile) frequently result in incomplete combustion and incineration so that charring often occurs. Depending on the degree of charring, fusinites or semifusinites of varying reflectivity will form during fires in forest mires (Cohen *et al.,* 1987). The charcoal is deposited *in situ* around the burnt trees along with all particles transitional to uncarbonized wood to form lenticular fusinite layers. With the warm, periodically dry climate experienced in tropical and sub-tropical regions, vast fires frequently occur in sedge/reed mires. Cohen (1974) also reports a strong correlation between pyrofusinite and sawgrass peats in the ancient Everglades and coastal swamps of southern Florida. During such fires all plant parts projecting above the water may be burnt, explaining the high fusinite contents reported in reed/sedge peats (Stach *et al.*, 1982; Chateauneuf *et al.* 1991). The fusinites are typically thin walled and deposited as fine splinters.

During extreme drought periods, surface and sub-surface burning of the peat also occurs, leading to the formation of thick ash layers on surface and also to the formation of peat coke at depth as described by Teichmüller (1961) from a Dutch peat fire. Once started, such peat fires have been recorded to burn for many years until the peat is finished or the burning front is drowned by rising water levels. One such fire, at the town of Lichtenburg in the western Transvaal, has been constantly burning at depth since approximately 1941 when it was accidentally set on fire during peat extraction operations for domestic fuel.

- degradofusinite. The burnt stumps that remain on surface (sometimes for years) are often only burnt on the outside with the result that the dead wood in the unburnt core is also exposed to oxidation and fungal attack resulting in the formation of degradofusinite. Papyrus, reeds, sedges and grasses in dense stands will spend at least one season, often more, caught up between new growth before being incorporated in the peat layer. Trees that die in a dense forest are often caught in the canopy and spend a long time mouldering and oxidising before being incorporated into the peat. Oxidation and dehydration of surface peat layers during dry spells may also lead to the formation of degradofusinite.

- primary fusinite is the result of a number of peat forming plants (e.g. *Acrostichum aureum* and *Thelypteris* spp.) that have cell walls that are naturally dark brown to black in thin section and accordingly show relatively strong reflectivities. Cohen and Spackman (1980) also describe plant tissues which yield dark residues in the peat.

• sclerotinite formed from both dark fungal spores and mycelia and cell fillings or secretions. The dark fungi are most commonly observed in sedge/reed peats which is in keeping with the reports that they mainly attack sedges and grasses (Stach *et al.*, 1982).

• inertodetrinite consists of redeposited debris of various inertinites and small plant fragments. Inertodetrinite is most abundant at the top of peat profiles and in the lowest parts of the peat profile which was deposited under water. Some of the inertodetrinite is blown into depositional sites by wind. In many inland valley mires in central South Africa inertodetrinites are concentrated into low lying areas on the peat surface by the first heavy rains after the dry winter. Humus on dried-out peat surfaces and charcoal particles (particularly from sedge/reed mire fires) are easily blown away. The carbon-rich dust settles in ponds and lakes.

3.3.4 Matrix

The matrix consists of microscopic organic particles, various clays and other mineral fragments, phytoliths and sponge spicule fragments. In sedge/reed peats a large proportion of the matrix may consist of inertodetrinite.

3.4 Palynological composition.

Pollen and spores were liberated from the peat using standard methods as described in Faegri and Iverson (1989) and Mazus (1992), and classified according to spore and pollen characteristics only, or where possible, in terms of specific plant families or genera.

♦ ♦ ♦

4 SOUTH AFRICAN MIRE TYPES

Under favourable conditions mires occur in South Africa in widely different climatic systems, from the Antarctic blanket bogs of Marion Island to the tropical palm and hardwood forest swamps of Maputaland (Fig. 4.1). However, those of economic consequence tend to be located in certain broad geomorphological settings in the higher rainfall, eastern half of the country. Geomorphological expression of the geology of an area is extremely important to peat accumulation as it provides the template required for mire development. The local geomorphology is therefore considered to be a primary classification parameter. However, climate (and hence, vegetation) may have a strong modifying influence on mire development.

4.1 Vegetation

As far as vegetation is concerned, four main mire types can be distinguished, viz. sedge/reed, hardwood forest, *Raphia* palm and mangrove. However, different hydroseral assemblages under different climatic conditions lead to a number of transitional types.

4.1.1 Sedge/reed (grass)

These mires are the most common in southern Africa and most likely in Africa as a whole. They display a hydroseral zonation which has important implications for the eventual peat types preserved in the wetland. Plants which are particularly widespread throughout the continent are, *Cyperus papyrus, Phragmites australis* and *Typha capensis.*

4.1.2 Hardwood mires (Swamp forests)

Hardwood mires include all dicotyledonous woody peat-forming communities in freshwater environments, eg. Mgoboseleni (27^{0}32'S/32^{0}39'E) and Siyadla (27^{0}03'S/32^{0}48'E) (No 1 and 2 on Fig. 4.1). It is the next most important mire type after sedge/reed mires in the Natal Mire Complex (NMC). Approximately 3 986 ha of swamp forest occur in Maputaland (Wessels, 1991). Swamp forest represents the final mire stage in the natural hydroseral succession from open water to dry ground (first characterised by *Nympheae* in open water, then by sedges and reeds and finally by hardwood trees). Relict clumps of swamp forest or large dead/burnt trees along with woody layers in the peat are found in some sedge /reed mires in the NMC, indicating a reactivation in the mire succession due to a sudden change in water level. Such water level changes are most often related to fires were the vegetation is burnt off along with the upper peat layers (cf. Teichmüller, 1989).

4.1.3 Raphia palm.

These wetlands in southern Africa today only occur on the western shore of Lake aManzamnyama (27^{0}01'S/32^{0}49'E) (part of the Kosi system) (No 3 on Fig. 4.1). The vegetation of this mire type is virtually monotypic *Raphia australis* with some climbing ferns (*Stenoclaena tenuifolia*) present where more light is available. Exploratory drilling near Lake aManzamnyama has shown that this mire type used to have a much wider distribution.

4.1.4 Mangrove mires

These occur at 14 important localities from Kosi Bay in the north to Kabonqaba north of East London (Fig. 4.2, after Berjak *et al.,* 1977). Mangroves only occur in the intertidal zone along the coast. The most common of the South African mangrove trees are *Avicennia marina* and *Brugueira gymnorrhiza* compared to *Rizophora* and *Avicennia* spp. in other mangrove mires in Africa and Tropical America (Hesse, 1961; Cohen and Spackman, 1977, 1980). Mangrove swamps represent the most seaward (and topographically lowest) component of coastal unbound mires such as the Greater Mhlatuze wetland and Mfolozi Swamp (Fig 4.3 and 4.4).

4.2 Mire classification based on geomorphology

4.2.1 Extensive mires

Extensive mires are only limited by macro-scale topography and thus occur over extended areas, often with an undulating character with respect to the land surface. This results in expansive wetlands of varying depth. The thickness of the peat is to a large extent governed by the covered topography at any particular locality. Because of their extensive nature (usually >10 000 ha) these mires typically have a complex hydrology, resulting in rather intricate mosaics of plant communities and corollary peat types. Extensive mires are further subdivided into coastal and inland mires.

4.2.1.1 Extensive coastal mires

These mires only occur from northern Natal northwards and within 30 km from the coastline (Fig. 4.1). Mires that answer the above description are the Greater Mhlatuze wetland (28^{0}48'S/32^{0}03'E) (Fig. 4.1, No 4 and Fig. 4.3), Mfolozi Swamp (28^{0}28'S/32^{0}25'E) (Fig. 4.1 No 5) (only 43 % of this wetland still exists as such, the rest has been taken over by farming (Begg and Carser, 1990) (Fig. 4.4), Greater Mkuze Swamp (27^{0}45'S/32^{0}32'E) (Fig. 4.1, No 6 and Fig. 4.5A), Muzi Swamp (27^{0}10'S/32^{0}30'E) (Fig. 4.1 No 7) (Fig. 4.5B) and the Southern Maputo Bay Swamps in Mozambique. Figures 4.3 to 4.5 are based on Begg and Carser (1990). All but the Muzi swamps drain directly into the sea, so that conditions range from saline to fresh water with the resultant spectrum of mangrove to fresh water forest swamp to reed/sedge swamp to meadow communities.

Figure 4.1 Distribution of major mire types in southern Africa

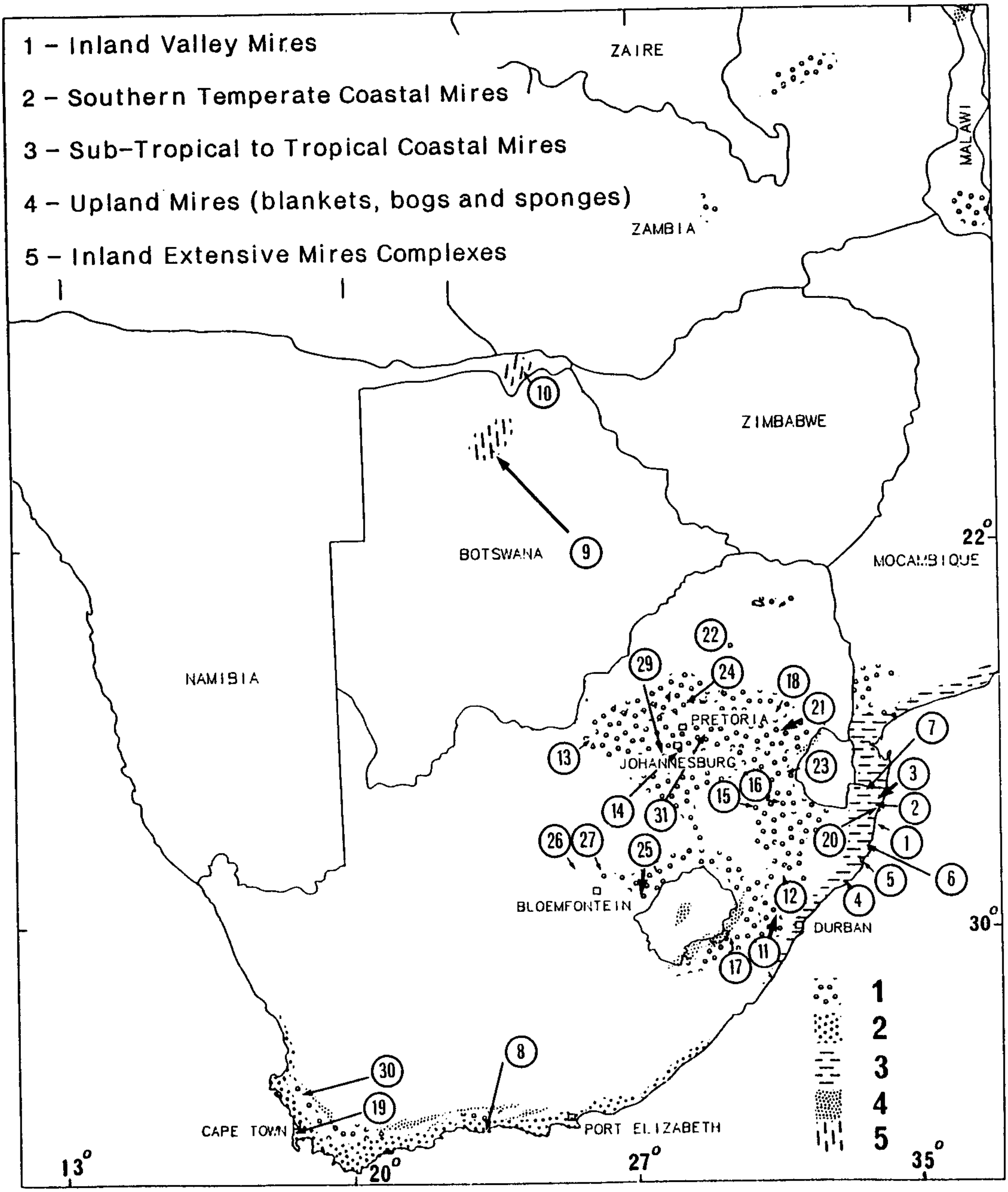


Fig. 4.2

Mangrove Communities of Southern Africa

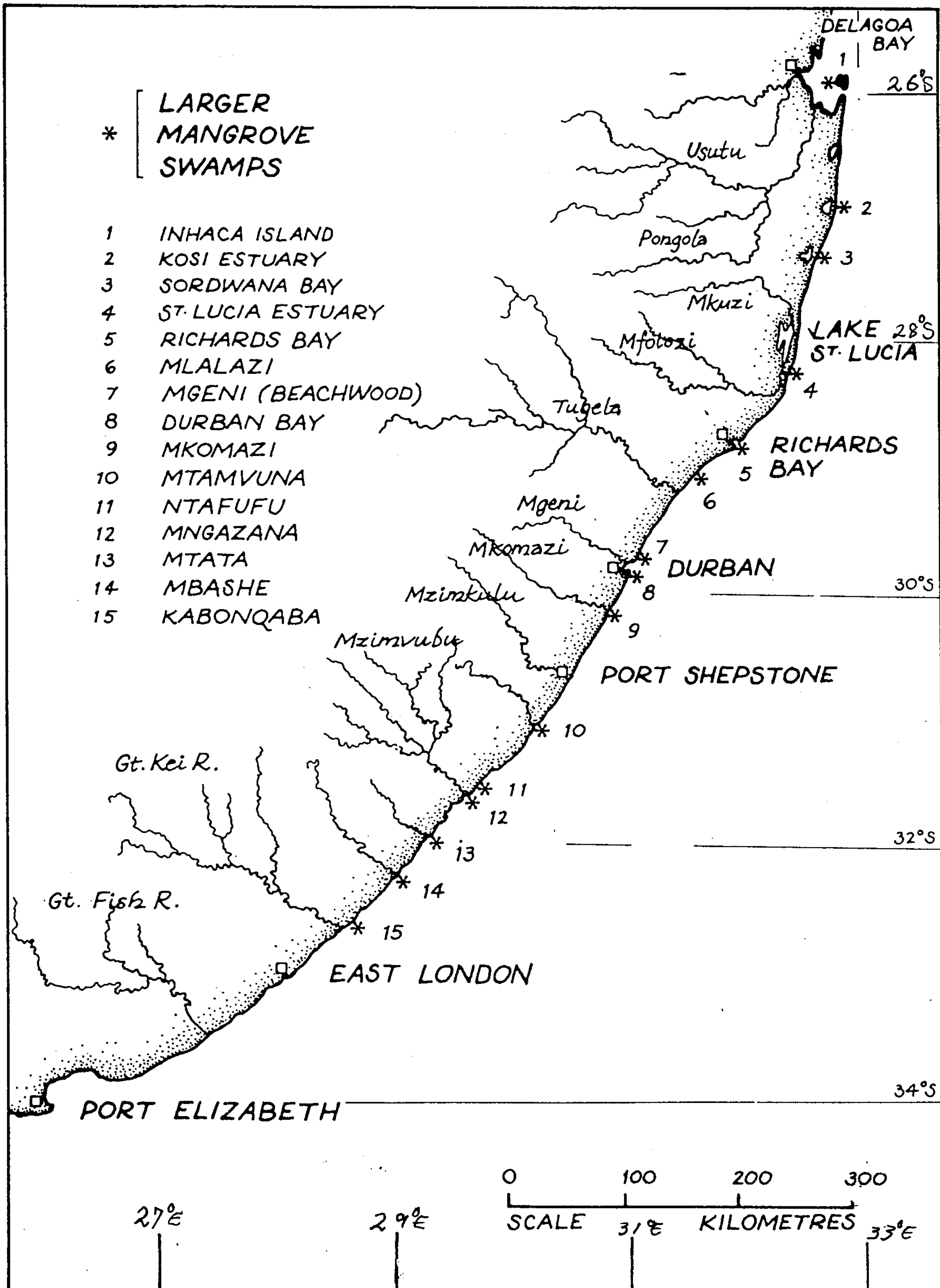


Figure 4.3 The Mhlatuze Mire System that surrounds the port city of Richards Bay in northern KwaZulu/Natal.

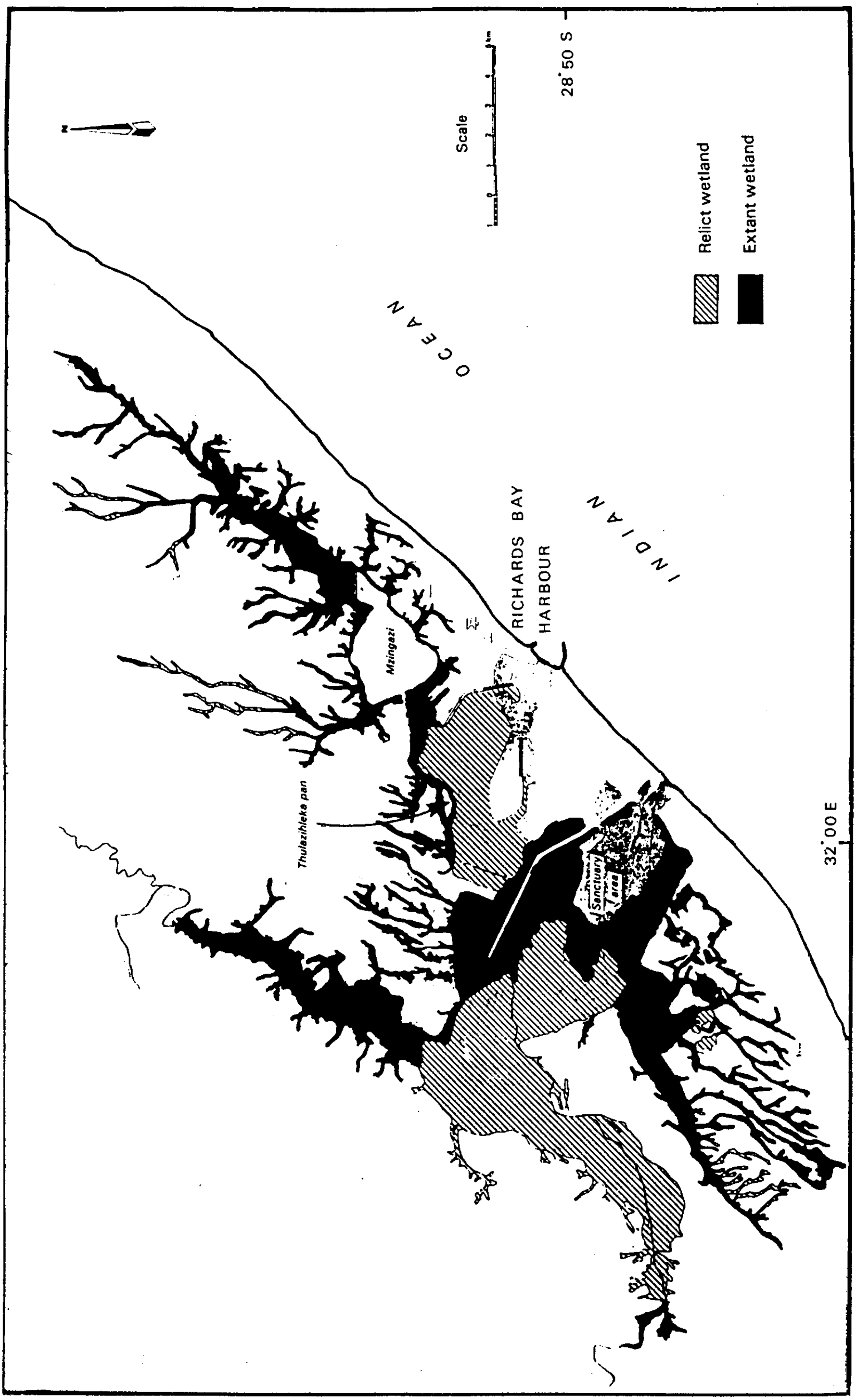
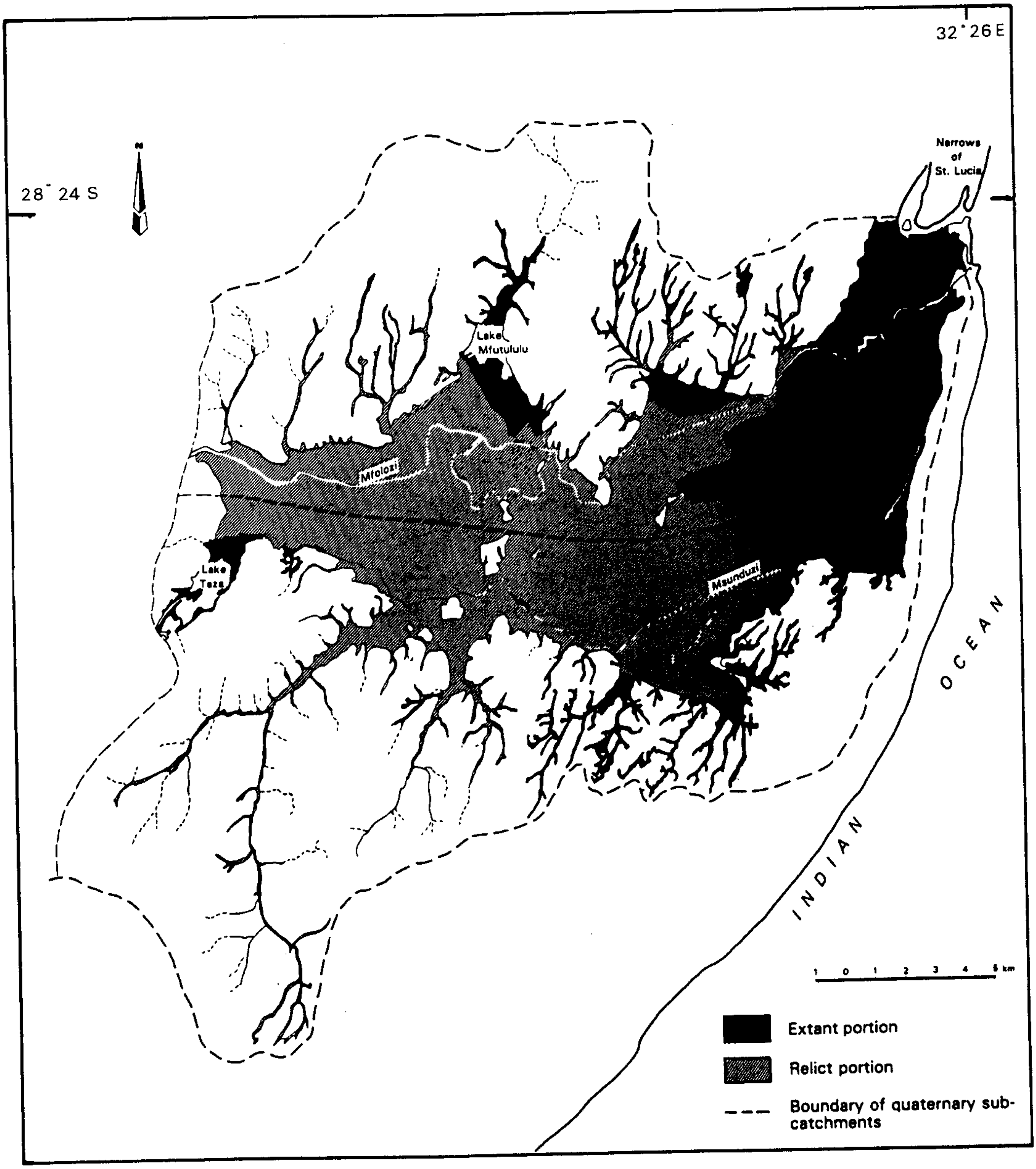


Figure 4.4 The Mfolozi Swamp south of St. Lucia. A large portion of this mire has been drained for agriculture and forestry.



Coastal mires also occur along the southern Cape coast. However, due to the very different climate, these mires are characterised by plant communities that differ from those in northern Natal. Two tropical mire types (mangrove and swamp forest) are absent from the southern temperate coastal mires. In the reed/sedge peatlands *Phragmites* spp. and *Typha capensis* are still co-dominant as peat formers but the other peat formers are replaced by different species. At Groenvlei in the southern Cape ($34^0$01'S/$22^0$53'E) (No 8 on Fig. 4.1) the hydroseral succession end member (fen carr) comprises shrubs and small soft wood trees such as *Rhus* spp., *Rhamnus* spp. and *Myrica* spp. (Martin, 1956, 1959).

4.2.1.2 Inland mires

The Okavango Swamp Complex (Fig. 4.1 No 9) is the largest example of an extensive inland mire in southern Africa (Fig.4.1). This vast mire is situated in the semi-arid Kalahari desert of Botswana. The swamp complex occurs in an active north-easterly striking half graben and is fed by the Okavango River draining the highlands of central Angola (McCarthy *et al.*, 1989; McCarthy and Ellery, 1993) (Fig. 4.6). The system consists of permanently inundated (6000 km^2) and seasonal (7000 to 12000 km^2) swamps. The dominant peat forming species in the swamps is *Cyperus papyrus*, a plant which under tropical conditions exhibits high rates of primary production (Moore, 1980; Thompson, Shewry and Woolhouse, 1979) with the consequent potential of producing large volumes of peat annually. Peat volumes in these vast mires are however kept in check by regular drought/fire cycles which are a common aspect of African ecosystems (Grobler and Ferreira, 1990; McCarthy and Ellery, 1993; Smuts, 1993). The Kwando-Linyanti-Chobe wetland system in the eastern Caprivi (Namibia) (Fig. 4.1, No 10) is similar to the Okavango in many respects except that its water supply is less stable with the result that Lake Liambesi has dried up twice this century resulting in spontaneous extensive peat-fires that burn for years until the next good rains eventually extinguish the burning fronts (Grobler and Ferreira, 1990).

Figure 4.5 A The Mkuze Swamp immediately north of Lake St. Lucia.

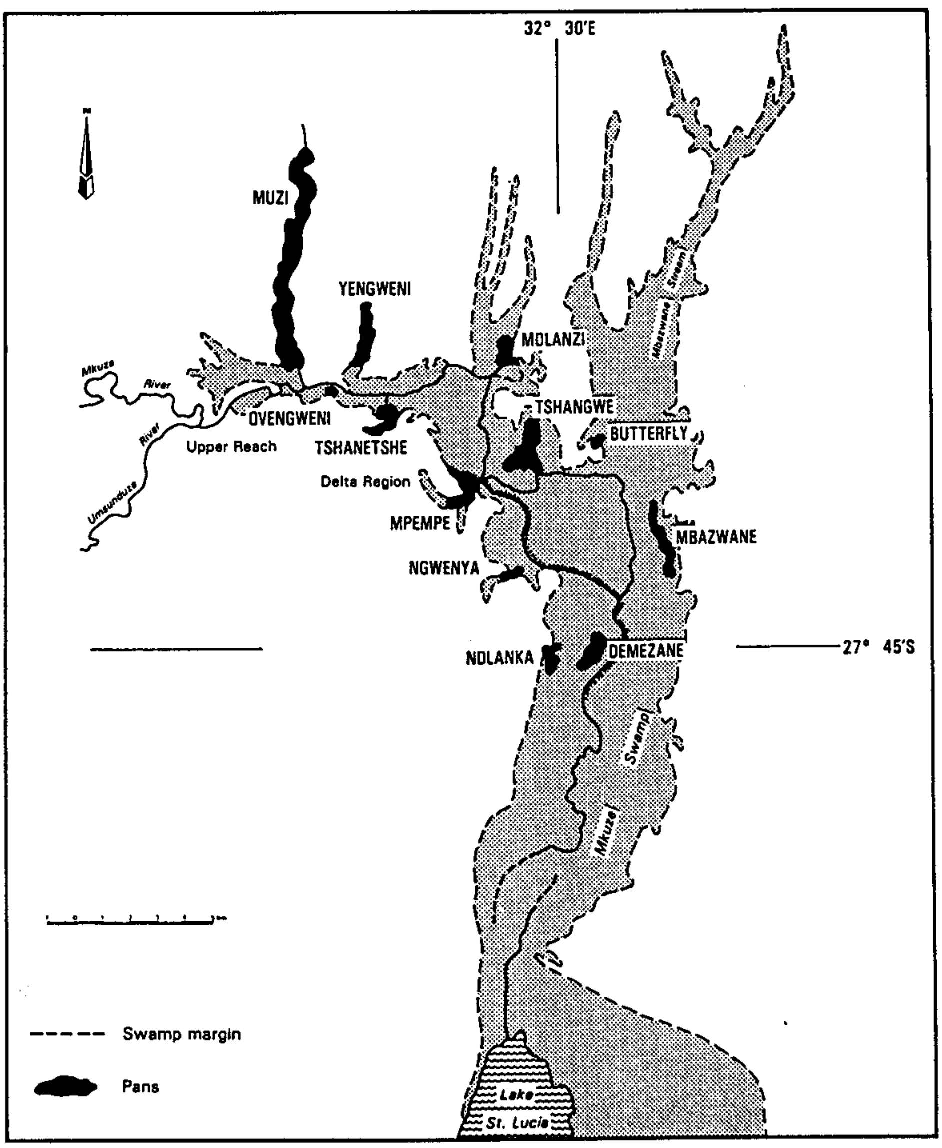


Figure 4.5 B The Muzi Swamp just south of the South Africa/Mocambique border. Note that the swamp does extend into Mocambique.

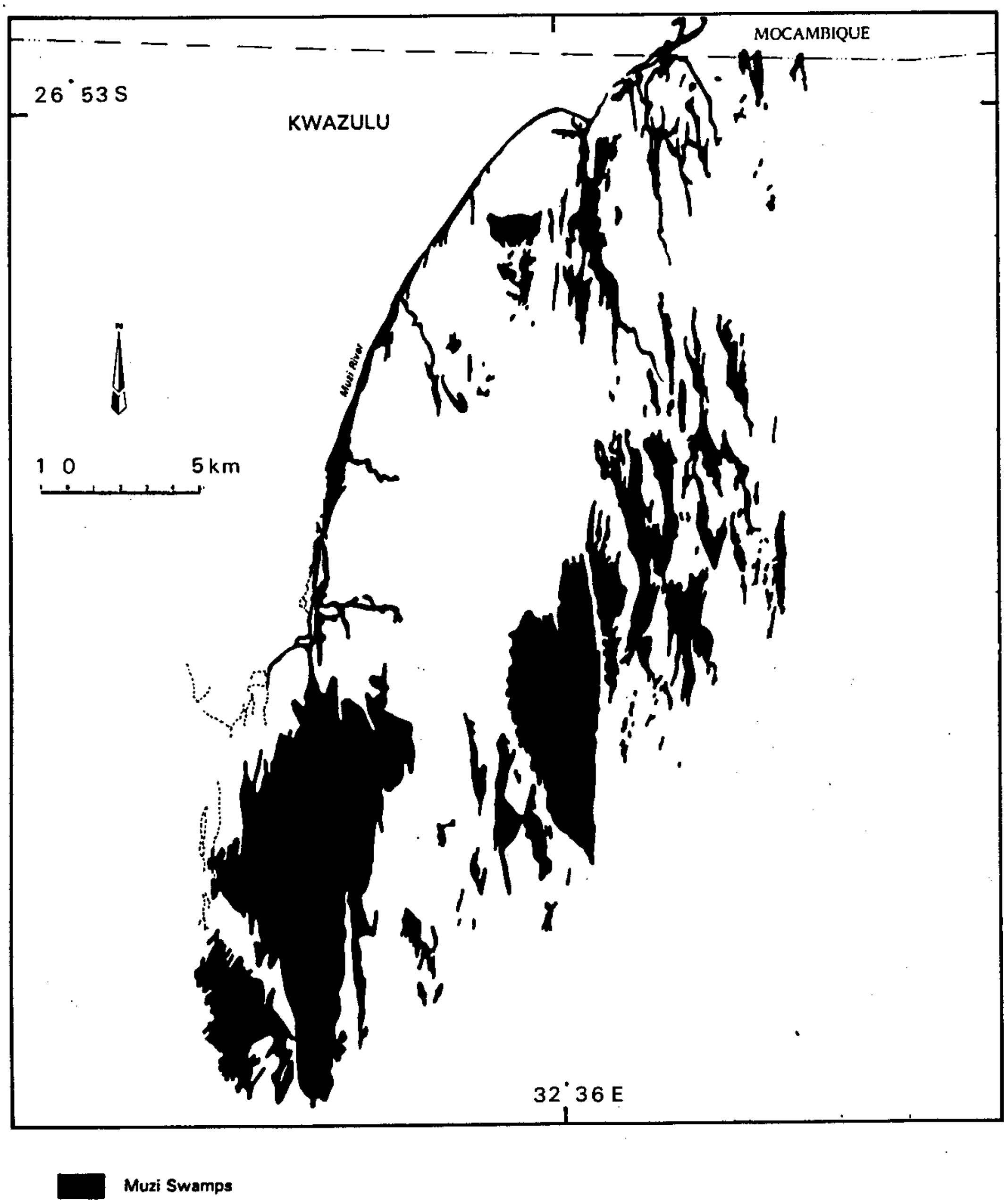
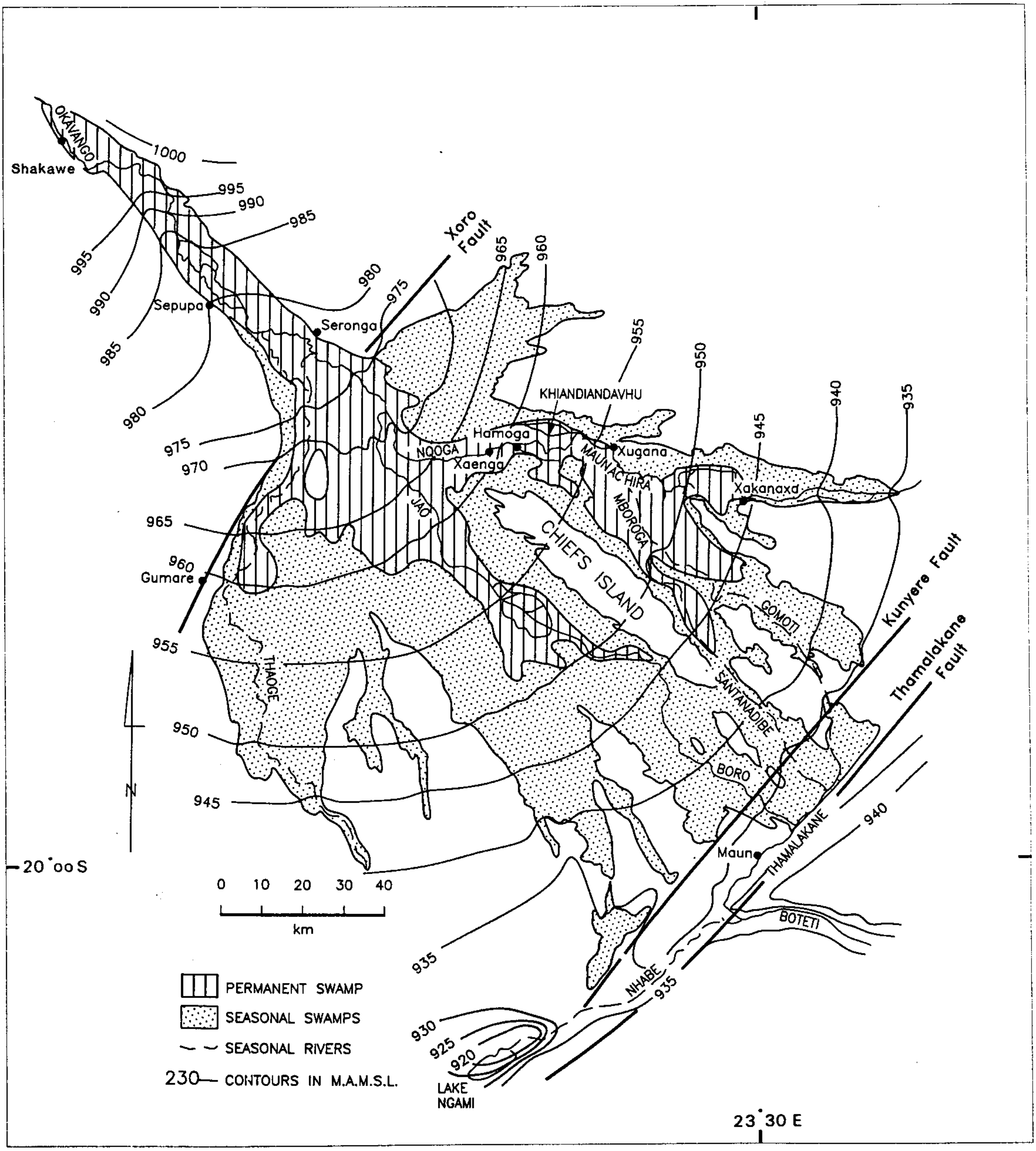


Figure 4.6 The Okavango Swamp complex in northern Botswana. Diagram after McCarthy and Ellery (1993).



4.2.2 Bound mires

As opposed to extensive mires, bound mires are strictly controlled (and bound) by local topography and geomorphological features. Bound mires are by far the most common in southern Africa. Bound mires, because of their smaller size and confined nature, tend to be much more sensitive to climatic changes than unbound mires. The unbound mires of Natal exist successfully through a much wider climatic and topographic range than the bound mires which are confined to a narrow topographic and rainfall band along the coast.

4.2.2.1 Valley mires

Valley mires occur widely in the Transvaal, Orange Free State, Natal Midlands and also in the Cape Province in a wide variety of unrelated geological settings, the only requirements being a valley in which the natural water flow is impeded by some sort of an obstruction (natural or man made) creating a template for mire formation. Valley mires can range in size from a few hectares to thousands of hectares (Mvoti vlei ($29^0$09'S/$30^0$35'E) (No 11 on Fig. 4.1), 2800 ha and Blood River vlei (No 12 on Fig. 4.1) ($27^0$49'S/$30^0$34'E), 6540 ha).

As the name indicates these deposits occur in valleys which form part of the natural drainage patterns. The geometry of these mires is determined primarily by the drainage pattern which in turn is determined by the geomorphology of the area. The Molopo (No 13, Fig. 4.1) and Malmani mires occur on dolomitic karst, whereas the Klip River mire (Fig. 4.1, No 14) south of Johannesburg is situated along the contact between different geological units (Fig. 4.7).

Karoo dolerite sills or other resistant rocks causing impeded drainage due to the obstruction of the natural flow, resulted in several mires, for examples; Wakkerstroom (Fig. 4.1, No 16) and Fig. 4.8 after Begg and Carser, 1990), Groenvlei (Fig. 4.1 No 15) (Natal), Ntsikeni vlei (No 17 on Fig. 4.1) and Lakenvlei mire (Fig. 4.1, No 18 and Fig. 4.9).

Fig. 4.7 Part of the Klip River, an example of mire formation along geological contacts due to differential weathering. The mire is flanked on the northern side by resistant quartzites of the Black Reef Formation (Vbr) and overlies weathered dolomites of the Malmani Subgroup (Vm) with some intrusive diabase dykes and sills.

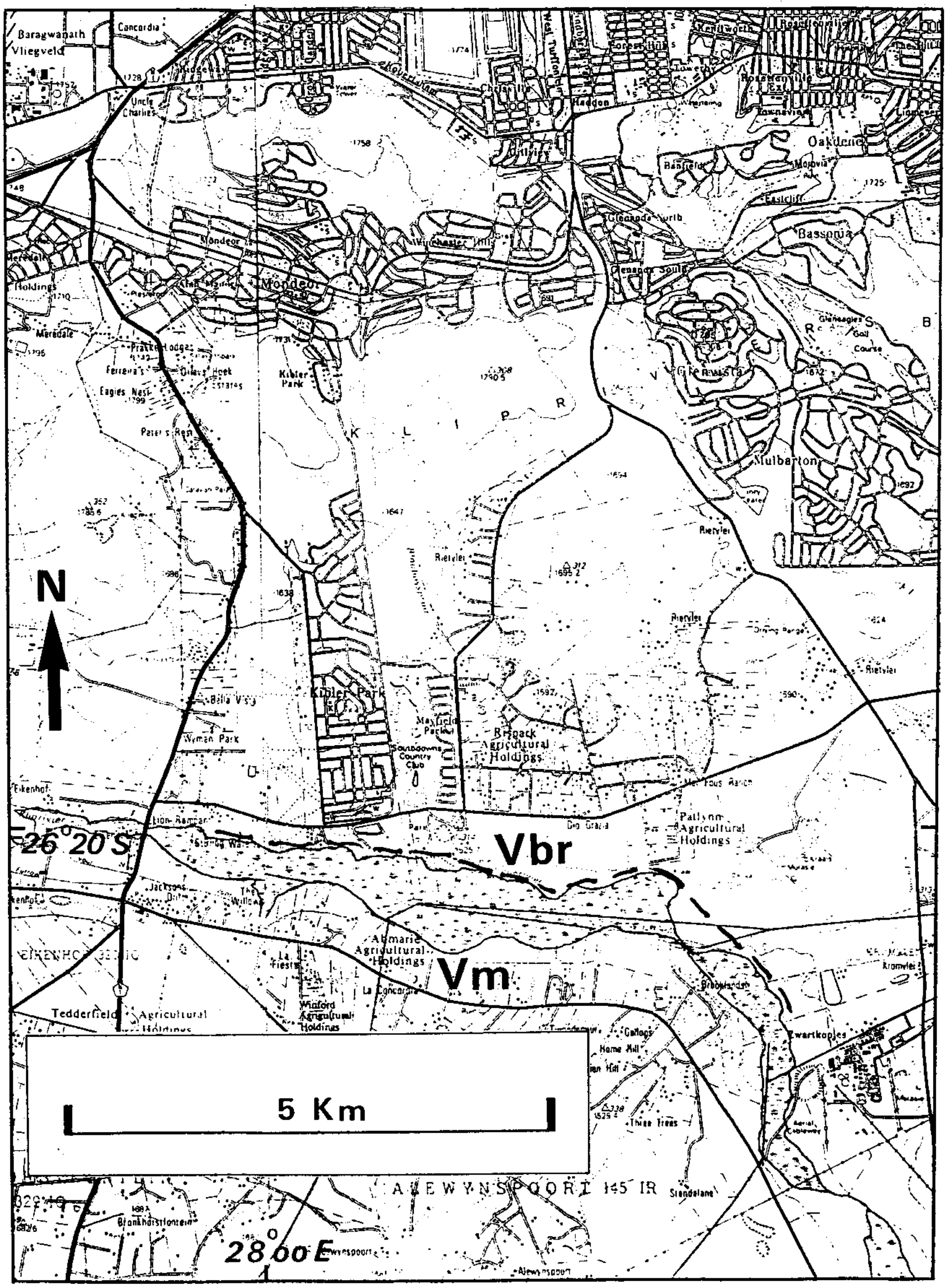


Figure 4.8 Two examples, Wakkerstroom and Ntsikeni, where mire formation resulted from Karoo dolerites impeding drainage. The arrows indicate the knick point in both diagrams.

A. WAKKERSTROOM

4.8 B. NTSIKENI

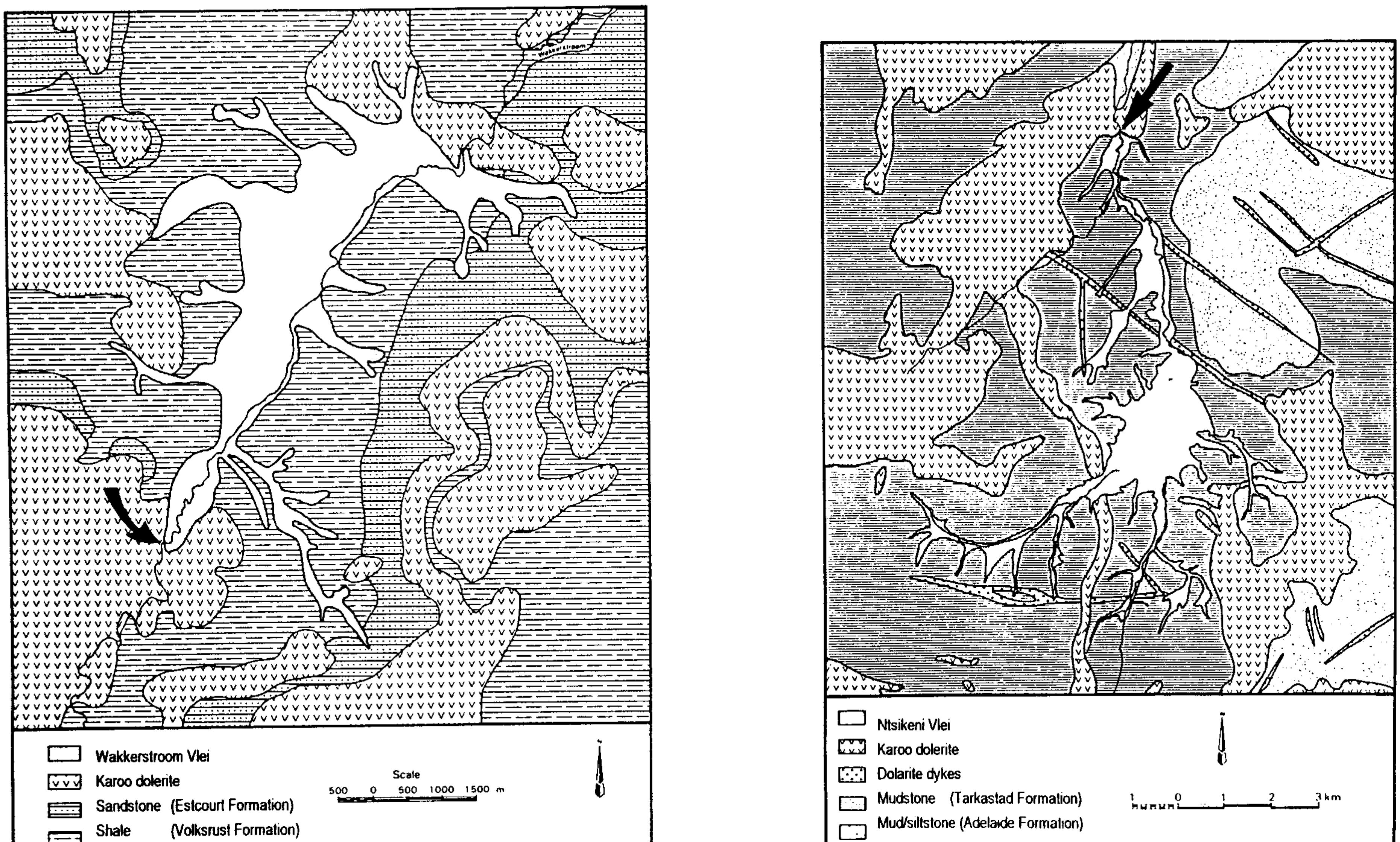
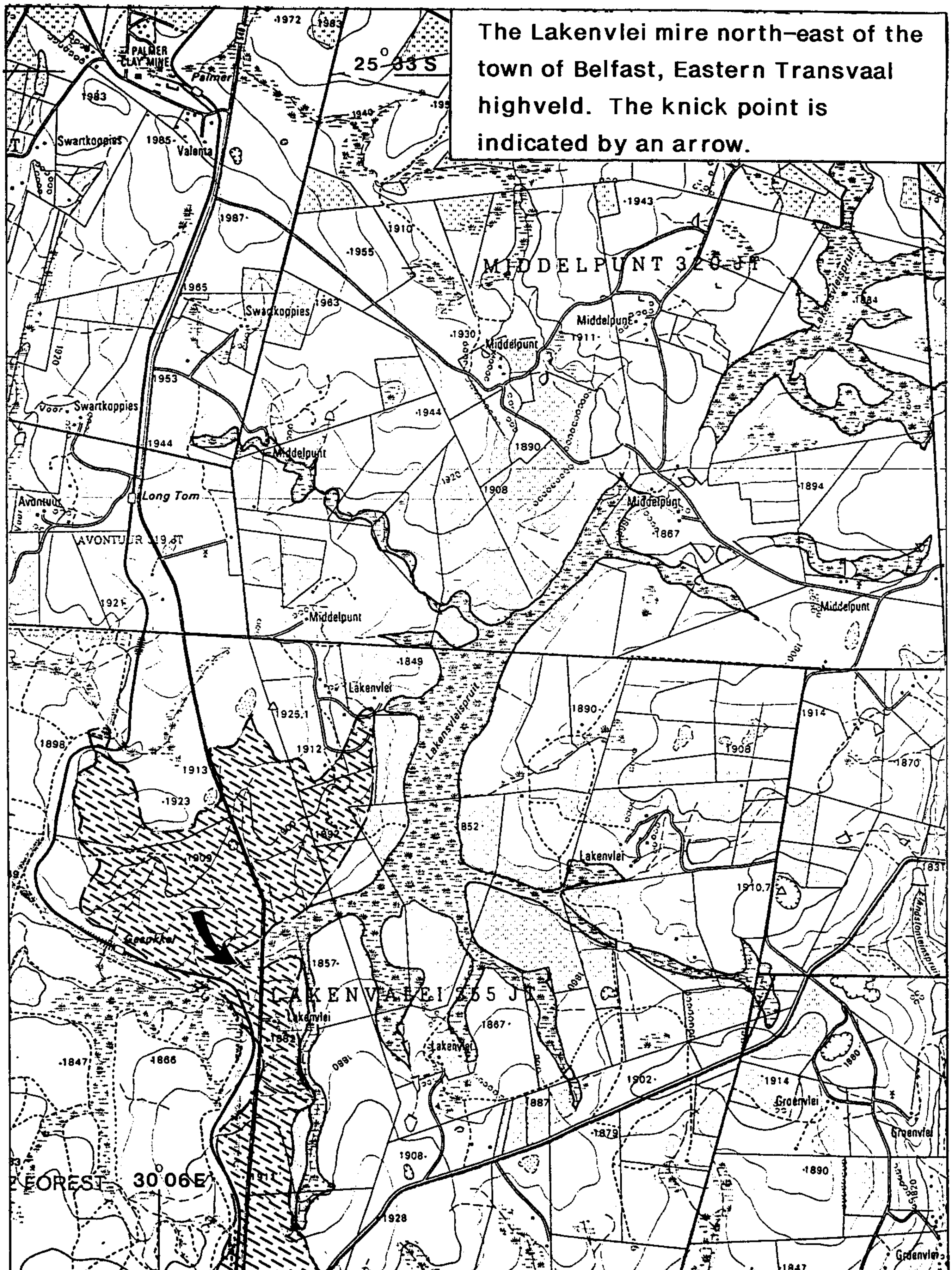


Fig. 4.9



The Lakenvlei mire north–east of the town of Belfast, Eastern Transvaal highveld. The knick point is indicated by an arrow.

scale 1:50 000

Lakenvalei Quartzite

4.2.2.2 Upland mires

Upland mires are found at higher levels in mountainous terrain were the local topography causes an impediment resulting in peat formation (Jacot-Guillarmod, 1962; Van Zinderen Bakker and Werger, 1974). The resultant mires are generally small in extent and the peat seldom exceeds thicknesses of one metre. A classical example occurs on Table Mountain between Plattekloof Gorge and Maclears Beacon (Fig. 4.1 No 19). The peat forming plants comprise sedges, *Erica* and *Restio* spp. and various mosses. This is the only mire type in southern Africa that contains notable moss peats. The climate at these mires is cool to alpine, moist with seasonal rains which tend to come down in showers. The mires can be classified as hanging bogs, valley-head raised bogs and blanket bogs. Upland mires all occur in the very sensitive upper regions of catchments, are excellent water retainers and are extremely susceptible to erosion. Hence they are not regarded as potentially exploitable peat resources and indeed should be protected at all cost.

4.2.2.3 Interdune mires

These occur between coastal dunes (27^{0}07'S/32^{0}49'E) (Fig. 4.1 No 20) due to impeded drainage and consequent high water levels, providing ideal sites for peat formation. These interdune mires have been a feature of South African coastal dune fields since the Quaternary and most likely even before that (Smuts and Rust, 1989). The most common peatland type in the Natal Mire Complex is interdune mires ranging in length from a few tens of metres to a few kilometres. They are generally oriented parallel to the coastline and have a typical elongated shape (Fig. 4.10). The long axes of these peatlands can be applied quite usefully to interpret palaeo-dune field orientations with respect to the coastline.

4.2.2.4 Pan mires.

Certain pans in the eastern Transvaal Highveld (26^{0}16'S/30^{0}16'E) exhibit interesting examples of mire formation within their confines (Fig. 4.1, No 21 and Fig. 4.11). The dominant peat formers in these wetlands are the common reed, *Phragmites australis* and the bull rush, *Typha capensis*. Peat thickness of up to 2 m have been recorded.

4.2.2.5 Spring mires.

Wonderkrater, the oldest known extant peatland in South Africa is a spring mire ($24^0$30'S/$28^0$45'E) (Fig. 4.1 No 22), i.e. a mire fed and controlled by an artesian spring (Scott and Thackeray, 1987). The size and height of spring mires are dependant on the hydraulic head of the spring(s) and the volume of water that is delivered to the mire. These mires are typically small (between 2 and 6 ha) with a clearly recognisable dome around the eye of the spring(s). Wonderkrater dome is about 4 m high while the Bankplaats (No 23 on Fig. 4.1) ($26^0$35'S/$30^0$23'E) domes are not higher than approximately 0.5 m. The typical peat forming vegetation assemblage comprises filamentous algae, diatoms, reeds, bulrushes and hygrophilous grasses (Kent and Rogers, 1947). The Bankplaats mire has been harvested since 1909 for its diatomaceous peat which produces a high quality kieselguhr (Kent and Rogers *op. cit.*). Spring mires have the ability to exist even under unfavourable regional climatic conditions as long as the spring is flowing. Scott and Thackeray (1987) indicate at least two periods of Kalahari-type conditions during the last +- 34 400 years and the current climate at Wonderkrater is also less than ideal for peat formation, yet the spring keeps its mire going. Some other famous South African spring mires (both fossil and extant) include Warmbad (Fig. 4.1, no 24) ($24^0$53'S/$28^0$45'E), Aliwal North (Fig. 4.1 No 25) ($30^0$41'S/$26^0$43'E), Florisbad ($28^0$46'S/$26^0$04'E) and Baden-Baden (Fig. 4.1 No 26 and No 27).

Figure 4.10 Typical NMC interdune mires. (outlined in black). Note also numerous areas (white) of wind erosion activated by human intervention. Scale = 1:50 000.

Figure 4.11 Pan mires of the Eastern Transvaal (Chrissiesmeer area) during the dry season with low water levels.