

The “European Aeolian Sand Belt”: Geoconservation of Drift Sand Landscapes

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Abstract The aeolian geological record for Europe, as reflected in the “European sand belt” in the northern European Lowlands, which extends from Britain to the Polish–Russian border and beyond, is known in detail. Mainly in the western part of this sand belt, extensive Late Holocene moving sand areas developed due to overexploitation (deforestation, sheep and cattle grazing, cutting of heather sods for plaggen agriculture, etc.) of the sandy soils. In the past, these man-made deserts were considered as wastelands as moving sands threatened to cover arable fields and villages. However, the majority of these drift sand regions have now been stabilized by a natural or artificial vegetation cover. In the Netherlands, almost all dune fields were transformed into pine (*Pinus sylvestris*) plantations during the late nineteenth and early twentieth century. Of the originally approximately 950 km² of actively moving drift sand areas, only 15/16 km² remains today. It is increasingly realized that these small remaining areas represent a unique ecosystem characterized by current geomorphic (aeolian) processes, primary vegetation succession, and a special floral and faunal composition adapted to extreme environmental conditions. New perceptions in nature management and geoconservation led to the view that reactivating some of the formerly bare drift sand areas will strongly increase their geomorphological, ecological, and educational importance. Careful and efficient manage-

ment requires detailed knowledge of the interaction of the many geomorphological, ecological, and land use processes. After reviewing the distribution, origin, and geomorphic properties of drift sand landscapes, reactivation projects and plans in the Netherlands are discussed.

Keywords Drift Sands · Inland Dunes · Aeolian Processes · Dune Management · Geoconservation

Introduction

In all European countries, attention is given to landscape preservation; however, policy and practice in the past have mainly been based on specific biological, historical–cultural, and visual landscape qualities. Although the geological aspects are the essential foundation for these values, they seldom formed the primary basis for the preservation policy (Gonggrijp 2005). Therefore, many important geosites (or geotopes in German) have been lost or are still being threatened. The word geosite has been adopted for distinct parts of the geosphere of outstanding geological, geomorphological, and/or pedological interest. However, in the last two decades, this situation is changing, and valuing and conserving abiotic nature or geoconservation have increasingly become an accepted part of nature conservation and nature management (Gray 2004; Burek and Prosser 2008; Erikstad 2008). Geoconservation is defined as “action taken with the intent of conserving and enhancing geological and geomorphological features, processes, sites and specimens” (Burek and Prosser 2008).

In the Netherlands, geoconservation is particularly interested in those areas where active geological/geomorphological processes in marine, fluvial, and aeolian environments can be seen and studied. Examples of these are (a) the preservation

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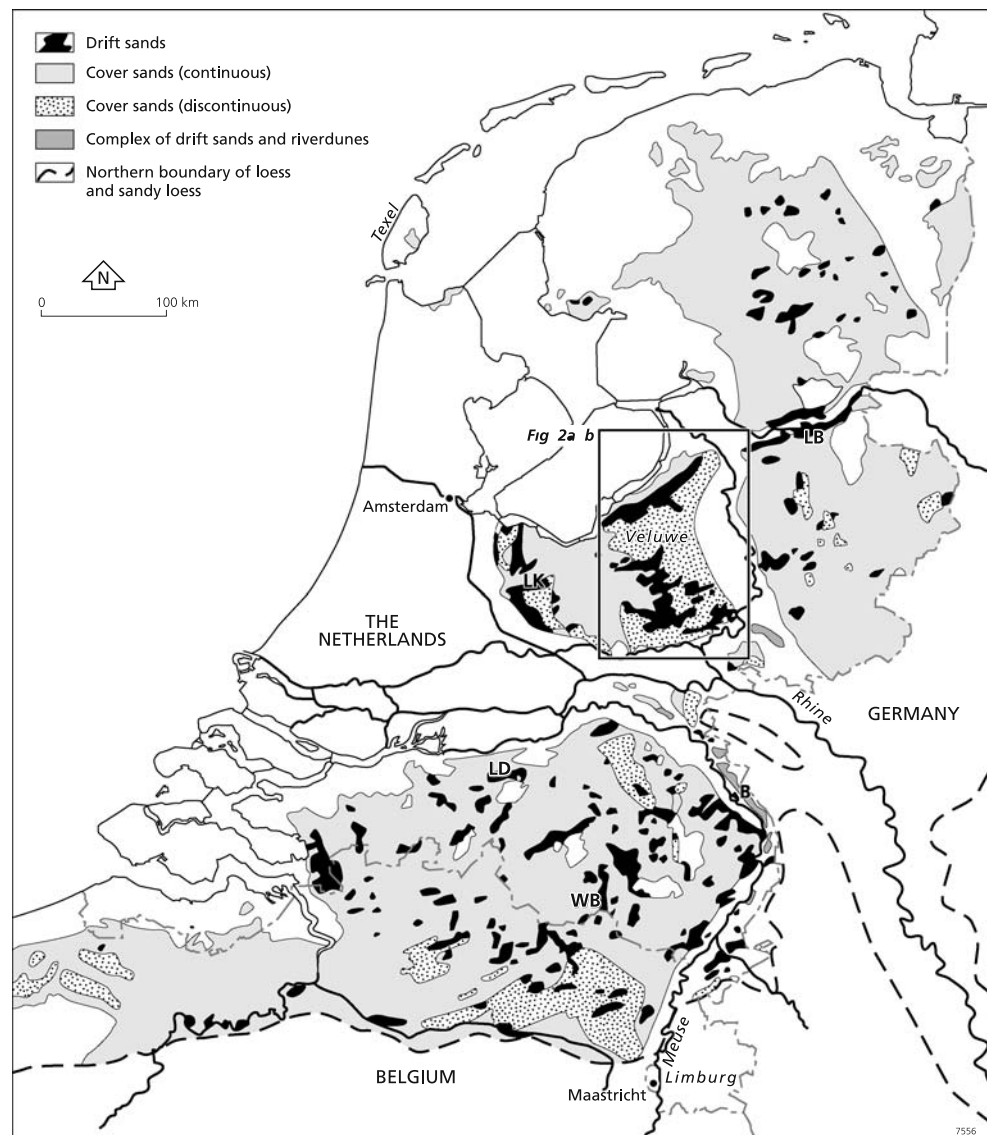
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of tidal flats in the Wadden Sea and other regions outside the river and coastal dikes; (b) rehabilitation of rivers and brooks to attain more natural patterns, flow conditions, and water quality; (c) reactivation of wind transport in coastal and inland dunes; and (d) preservation or rehabilitation of peat areas. Similar notions are the basis for the conservation and management of dynamic geomorphological sites in many countries, e.g., many examples of these have been identified in the UK (Stevens et al. 1992; Hooke 1994). Dynamic geomorphological sites are considered of particular importance: (a) for their scientific value, where processes of transport, erosion, and deposition can be directly measured and monitored, and consequently long-term development of landforms can be better understood, (b) their scenic and amenity value (the dynamism of such areas conveys a characteristic of “naturalness” and beauty), and (c) active

processes that create a range of ecological habitats and thereby maintain ecological diversity (Hooke 1994).

This contribution focuses on the origin, form, and sediment characteristics, ecological values, and potential for geoconservation of dynamic drift sand landscapes. In contrast to what most people believe, aeolian sediments cover a large part of this low-lying and flat country. More than half of the country is covered by coastal, river, and inland dunes as well as by gently undulating cover sand and drift sand sediments (Fig. 1). Aeolian deposits, irrespective of their form as sheets or dunes, resulting from resedimentation of sandy deposits by human impact since the beginning of the Neolithic, are called (aeolian) drift sands. These Late Holocene drift sands mainly consist of redeposited cover sands. Cover sands are essentially Weichselian aeolian deposits, which accumulated under

Fig. 1 The areal distribution of aeolian sands in the Netherlands and Belgium (after Koster 1978). Drift sand reactivation sites, mentioned in the text, are indicated: *B* Bergerheide, *WB* Weerter-en Budelerbergen, *LB* Lemelerberg/Beerzerveld, *LD* Loonse en Drunense Duinen, *LK* Lange en Korte Duinen



cold-climate or periglacial conditions during the last glacial period, not directly related to present or former coastlines or river courses. Moreover, cover sands are characterized by a relatively flat to gently undulating relief. As such, the terms cover sand and drift sand have a stratigraphical as well as a geomorphological meaning (Koster 1982, 2005a). The drift sands represent a typical man-made landscape as former overexploitation of sandy regions by man resulted in severe wind erosion and sediment transport. However, the overwhelming majority of drift sand regions in the Netherlands, but also in other countries in northwestern Europe, have become stabilized by reforestation, at some places since the end of the eighteenth but primarily since the end of the nineteenth and in the beginning of the twentieth century, as well as by spontaneous vegetation development. This development even accelerated during the last few decades due to air pollution, in particular due to increased nitrogen deposition. The Netherlands has a special obligation in this respect as it is estimated that more than three quarters of the remaining active drift sand fields in northwestern Europe is found in this country.

In this paper, at first, a short review is presented of the distribution, geomorphological and sedimentological characteristics, and the origin and age of drift sand landscapes because proper management of these aeolian environments must be based on a profound knowledge of the interaction of the many geomorphological, ecological, and land use processes. Secondly, attention is focused on recent projects and plans for reactivation of the sand drifting processes on suitable sites in the light of geoheritage and geoconservation.

Distribution

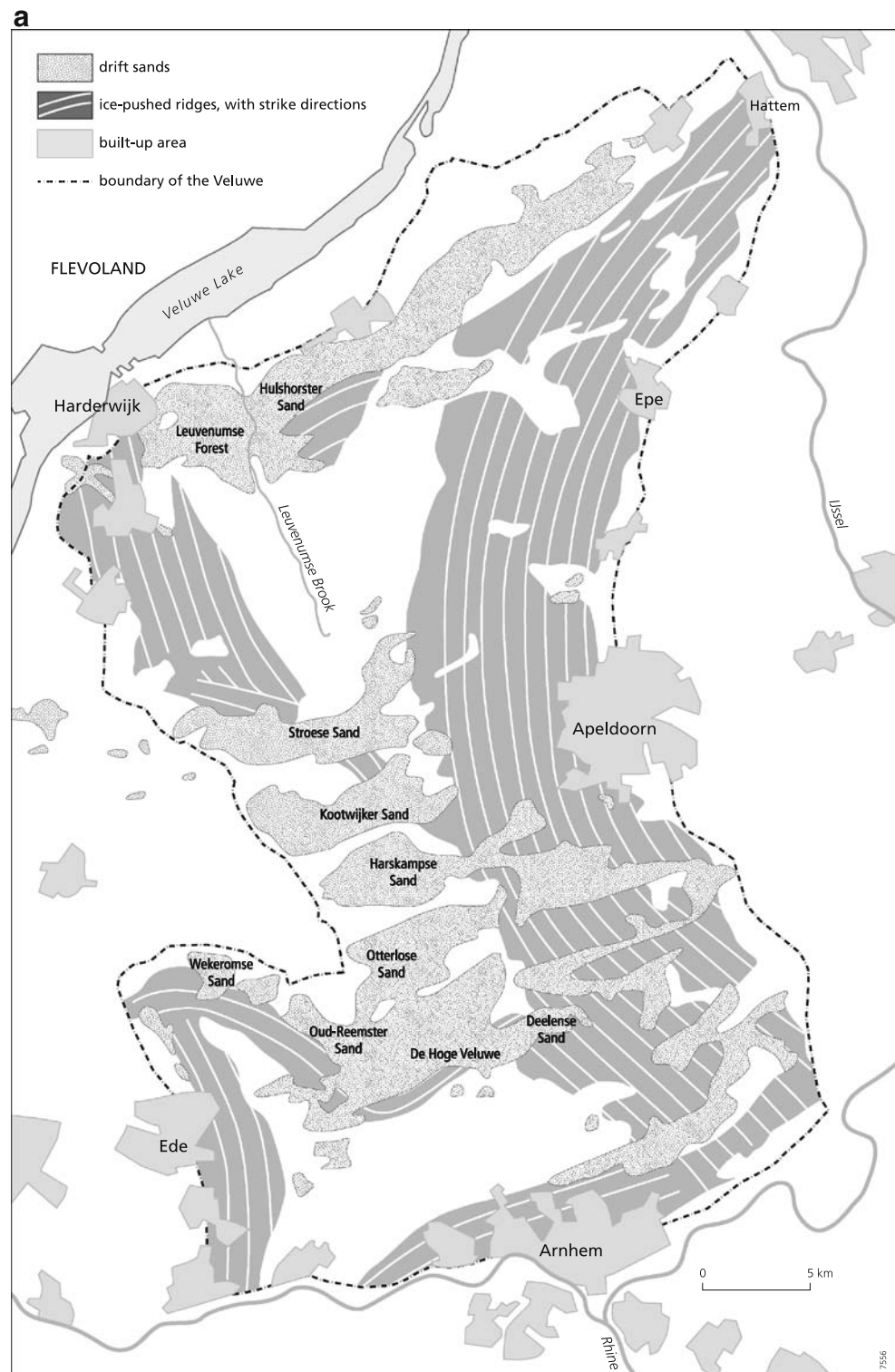
The aeolian geological record for Europe, as reflected in the “European sand belt” in the northwestern and central European Lowlands, which extends from Britain to the Polish–Russian border (and beyond), is known in great detail (Koster 1988, 2005a; Zeeberg 1998). The northern boundary more or less coincides with the maximum ice border lines of the last glacial period, whereas the southern boundary coincides with the maximum Pleistocene ice border lines and grades into cover loam and loess deposits. The westernmost occurrences of dune and cover sands are encountered in the UK in Breckland and parts of Lincolnshire, Yorkshire, and Lancashire (Bateman and Godby 2004; Koster 2005a). Zeeberg (1998) showed that extensive aeolian deposits even progress with two separate arms into the Baltic region and into Belorussia and northernmost Ukraine. The easternmost occurrences of the sand belt have been identified in the Pechora lowlands close to the northwestern border of the Ural mountain range. Although the majority of the “sand belt” deposits are of the last glacial (Weichselian) age, Ruegg (1983) already concluded that sandy aeolian deposits in the

Netherlands—a region of continued regional subsidence throughout the Quaternary combined with extensive delta building—originated in at least six glacial stages, forming stacked sequences locally up to 40 m thick.

The total area covered by surficial aeolian sands in the northwestern and central European Lowlands, including extensive sheets of late Weichselian cover sand and late Holocene drift sands not showing a dune relief, is of the order of several tens of thousands of square kilometers. Going from west to east in the European lowlands, the proportion of cover sands to dune sands changes. Cover sands are found mainly in the western part, whereas large dune fields predominate in the eastern regions. The extensive dune fields in western and central Europe attracted the attention of many German and Polish earth scientists, but the study of Pyritz (1972) is regarded as the first modern analysis of the origin, form, and sediment properties of inland dunes in Germany. Another comprehensive study of the morphogenesis of Older and Younger inland dunes in Germany is published by Alisch (1995). His observations on the anthropogenic factors leading to late Holocene reactivation of aeolian sands, the destruction of dune forms by excavations of sand, and the nature conservation value of those remaining deserve special attention. Overviews on the areal distribution of aeolian phenomena in Europe are presented by Kozarski (1991), Kasse (1997), and Koster (2005b).

The areal extent of drift sand fields in northwestern Europe alone is estimated to be 3,000–4,000 km². These fields are almost completely stabilized by reforestation and spontaneous vegetation development. Within the Netherlands and Belgium, aeolian sand sheets and dunes cover a large part of the countries (Fig. 1). Wind erosion mainly on cover sand regions resulted in extensive (anthropogenic) drift sands. The many, more, or less isolated drift sand fields in the Netherlands cover about 950 km². Of these, only about 2% (15/16 km²) is presently not stabilized by artificial or natural causes and is still actively moving. In 1980, approximately 40 km² consisted of actively moving sands, but since that time stabilization has accelerated mainly due to air pollution (Ketner-Oostra 2006; Riksen 2006; Riksen et al. 2006, 2008). The largest extent of drift sands is found on the Veluwe plateau in the center of the Netherlands. Surrounded by a system of large ice-pushed ridges of Saalian age and adjacent fluvioglacial units, a series of drift sand fields occurs: from south to north called Oud-Reemster and Deelense Sand, Otterlose Sand, Harskampse Sand, Kootwijker Sand, Stroese Sand, and a 30-km-long WSW–ENE-oriented drift sand region at the northern edge of the Veluwe plateau (Fig. 2a). Most of the research results presented in this paper refer to the drift sand regions in the Veluwe area. Together, the last remains of dynamic drift sands in the Veluwe area (Fig. 2b) are by far the largest occurrences in northwestern Europe.

Fig. 2 a The areal distribution of almost completely stabilized drift sand fields in the Veluwe area (central Netherlands); the average strike directions in the ice-pushed ridges are indicated. The locations of the drift sand fields mentioned in the text, including those where reactivation projects have been carried out, are indicated; **b** the decrease in actively moving sands between 1878 and 1966

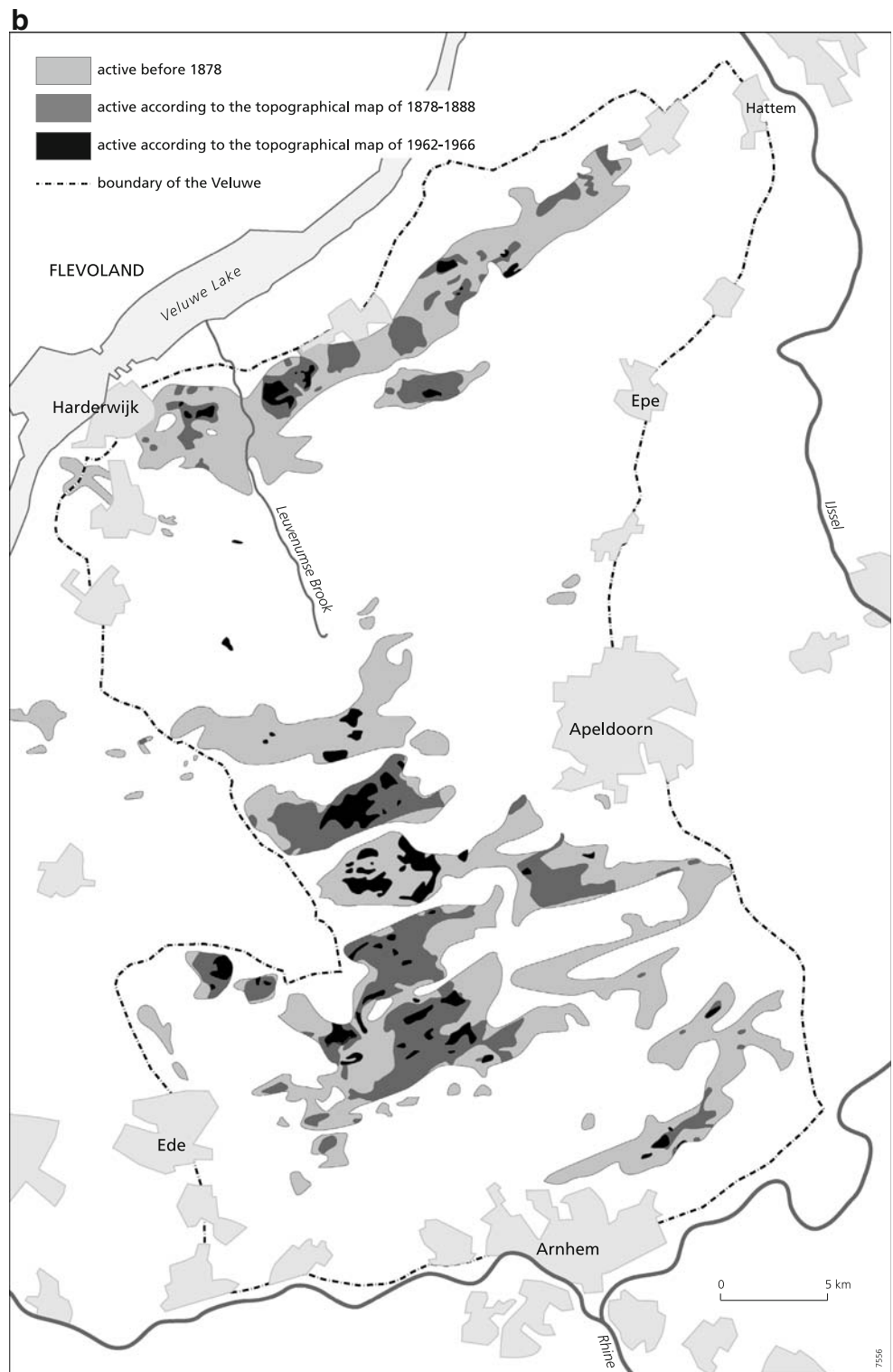


Landform, Sediment, and Soil Properties

Drift sand regions usually display a rather chaotic pattern of erosional and accumulative parts which strongly vary in outline and size. Individual, often isolated, hummocky

dunes vary in height (up to c. 20 m) and slope values (max. c. 15–33°, in extreme cases up to 47°). In contrast to most coastal or river dunes, drift sand forms often lack a system of distinct morphogenetic units in a downwind direction. Apart from parabolic and transverse dune forms, most dunes show

Fig. 2 (continued)



an irregular outline. Nevertheless, detailed morphometric analyses of seemingly chaotic dune forms have shown that there is a clear orientation of the longest axes of individual drift sand dunes, as well as of the extension of drift sand fields. Measurements of the azimuth of the

longest axis of more than 600 dune forms in the Veluwe and other areas in the Netherlands reveal a distinct orientation from WSW to ENE (Koster 1978). Not surprisingly, this orientation is also found in the frequency distribution of wind directions especially when regarding

the wind velocity classes of >5 m/s. This result clearly reflects the fact that dominant southwesterly winds of >5 m/s are responsible for most sand transport under present-day and former conditions. A secondary maximum of sand transport is caused by occasionally occurring dry northeasterly wind events.

The typical drift sand relief, consisting of an irregular alternation of deflational and accumulative parts together with the related soil and vegetation types, is shown in a schematic cross-profile (Fig. 3). It appears that there is a close relationship between the form elements of the drift sand landscape—e.g., accumulative or blown-over parts where the original podzolic profile in cover sand has been preserved and blown-out parts where deflation of cover sand continued until the underlying gravelly subsoil or the ground water level was reached—and the soil profiles that have developed and the vegetation succession that goes together. In the blown-on parts, deflation of the original cover sand was followed by accumulation of drift sand. The humus profile development starts directly after the stabilization of the drift sand by the plantation of Scots pine and

is related to the amount of litter input and quality and stand age (Emmer 1995; Dijkstra 1996). These very young soils, also called micropodzols, are characterized by a thick ectorganic layer and a limited development of the underlying mineral soil. More fully developed humic podzols are found in drift sand deposits of many centuries old. The profiles on the young drift sand hills and on the blown-out areas are classified as regosols, as illustrated in Fig. 3.

In several instances, a peculiar drift sand landscape resulted due to relief inversion (Fig. 4). The originally low-lying and wet depressions (“sand traps”) in the cover sand landscape preferentially became filled-in with blowing sands, whereas the originally higher and dryer parts of the cover sand landscape were subjected to strong deflation and therefore lowering of the surface. Thus, these areas presently show an alternation of plateau dunes of irregular outline (locally called “forts”) and very flat blown-out regions (Koster 1970). Moreover, as the plateau dunes contain their original, often impermeable, podzolic soil profiles at a certain depth, infiltrating rainwater stagnates in the dunes, and consequently the habitat conditions for tree

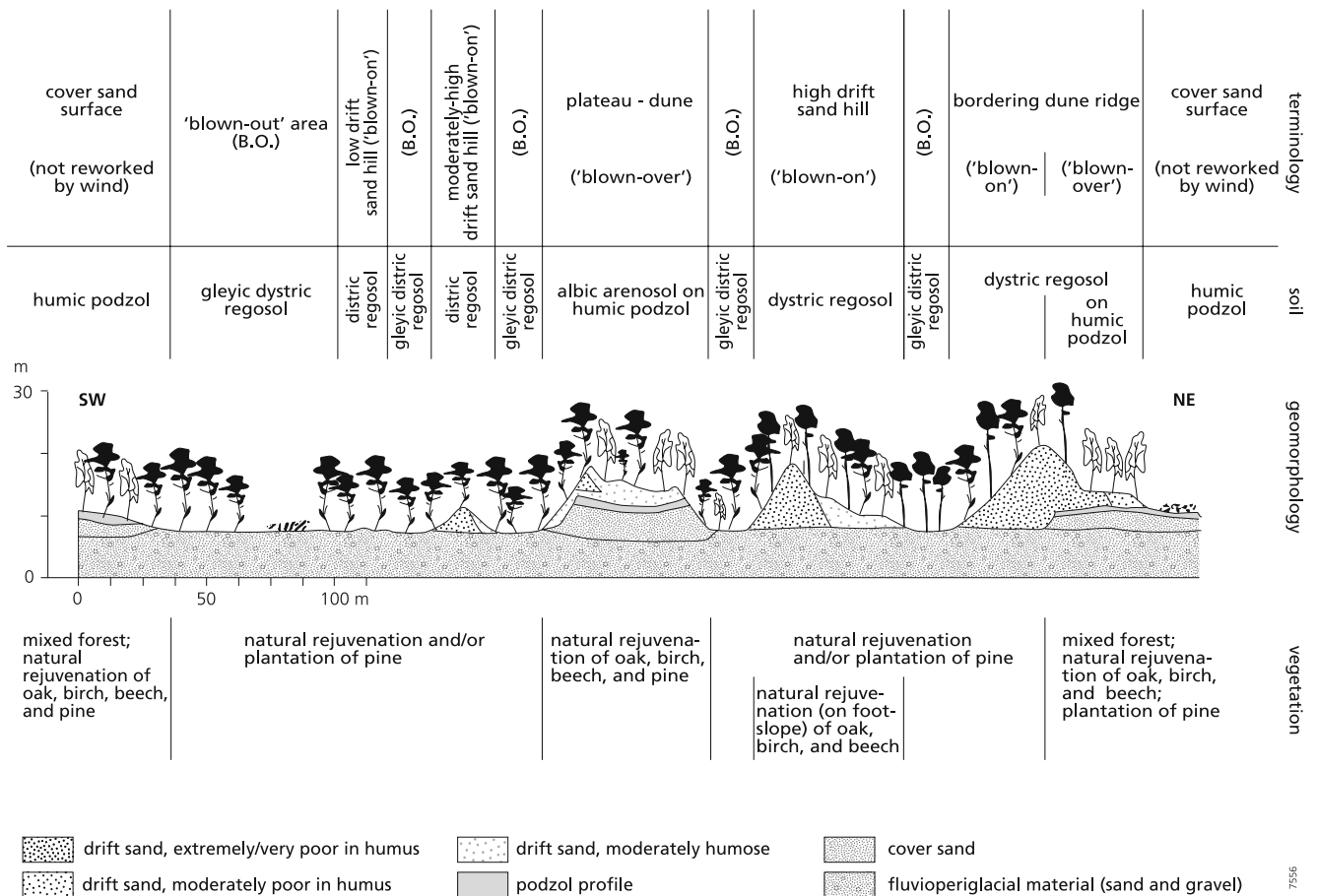


Fig. 3 Schematic cross section of a drift sand landscape (central Netherlands), emphasizing the interrelations between landform, soil, and vegetation development (after Castel et al. 1989)

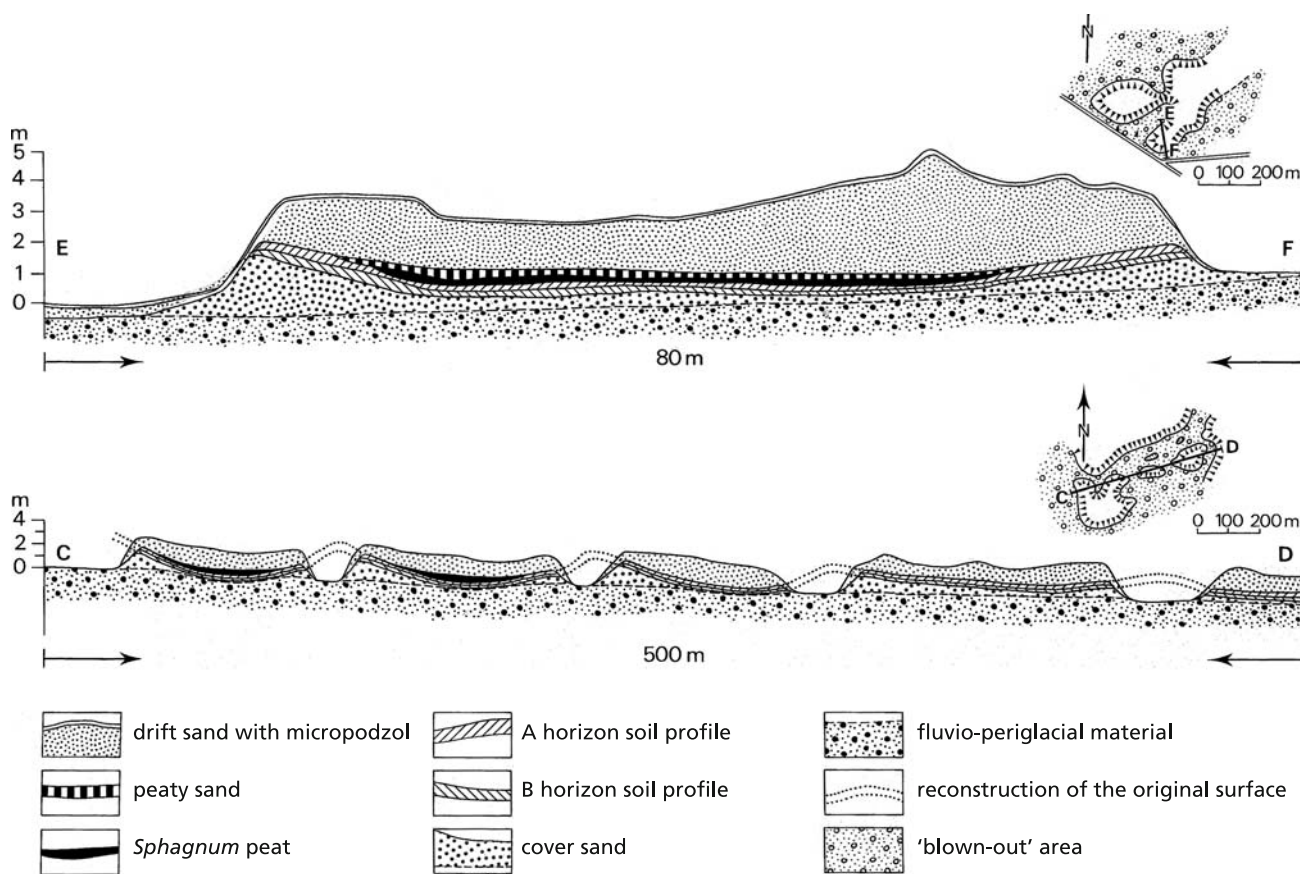


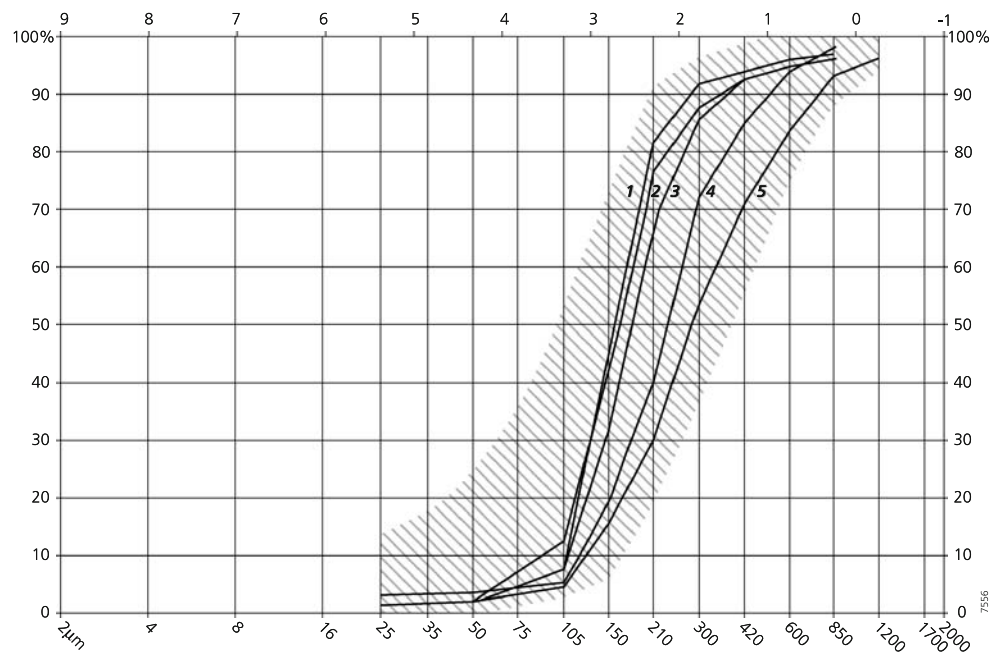
Fig. 4 Cross sections of plateau dunes (locally called “forts”) in the northern Veluwe area. These dunes originate by relief inversion of originally low-lying, relatively wet cover sand depressions (after Koster 1970)

growth on the dunes are much better than on the low-lying blown-out surfaces (Koster 1970; Castel 1986; Prach 1989; see also Fig. 3). Pine trees of almost 200 years old are found on top of some of these plateau dunes (Prach 1989). The complex origin and the distinct, in the field clearly visible, relationships between subsoil properties, soil moisture conditions, relief characteristics, and vegetation development make these stabilized drift sand landscapes part of the most valuable aeolian nature conservation areas in the country.

Although the sediment attributes of drift sands usually reflect their local provenance quite well, they mainly consist of very fine to moderately fine, nonloamy, well-sorted, and well-rounded unimodal sands. Moreover, they are characterized by an absence of carbonate, a dominance of quartz, and to a lesser extent feldspar particles, a variable but very low content of heavy minerals, an usually very low organic matter content (<1.5%), and finally a relatively loose grain packing (i.e., high pore volume). The grain size distribution of most aeolian sands in the Netherlands is fairly uniform; all coastal, river, and inland dune sediment are concentrated in the fractions between 105 and 420 μm , with an average median value in the fraction 150–210 μm

(Fig. 5). Koster et al. (1993) discussed characteristic primary sedimentary structures of drift sands indicative of tractional or grain fall deposition and secondary (post-genetic) structures. Specific combinations of these features are interpreted in terms of dry, moist, or wet conditions during transport and accumulation (Fig. 6). De Ploey (1977), in an experimental study on present-day wind transport in an unvegetated drift sand area near the Belgian–Dutch border, observed that deflation not only occurred during dry spells but also on wetted dune sands during or just after heavy rainstorms at wind speeds of more than 30 km/h or approximately 8 m/s. He also reported that gravel (2–5 mm) movement occurred by saltation up to a height of 50 cm during heavy winter storms. Similar observations were made, e.g., in the Kootwijkse Sand region, both during rainfall events but also during severe winter conditions. Due to heavy rainfall, surficially flowing water causes sediment transport even over slopes of only a few degrees. This process is strongly stimulated by the water repellency, i.e., hydrophobic properties of many dune sands (Witter et al. 1991; Riksen et al. 2004). During specific winter conditions, transport of small gravel particles by wind over a frozen sand surface has also been observed.

Fig. 5 Typical grain size distributions ($n =$ several hundreds) of aeolian sands, various locations in the Netherlands (after Koster 1982); 1 Late Holocene coastal dunes, 2 Weichselian cover sands, 3 Late Holocene drift sands, 4 Late Weichselian river dunes, 5 Weichselian inland dunes



During these conditions, granule ripples of fine gravel particles developed. The most common feature in Fig. 6 is the very fine (sub)horizontal lamination of the sediment. Sets of undisturbed parallel lamination (5–10 cm thick) alternate with sets consisting of crinkly (convoluted) laminae indicative of deposition during dry, moist, or wet conditions, respectively. Small gully-shaped deformations are the result of surficially flowing water possibly during rainstorm events. These features, however, should not be confused with the secondary nonaeolian (sharply defined) deformations, e.g., in the middle of Fig. 6, that are interpreted as footprint or hoofprint structures (Van der Lingen and Andrews 1969; Lewis and Titheridge 1978).

The degree of transformation of source sediments into aeolian ones may help to estimate the character and duration of aeolian transport. The best indicative values in this respect are combinations of sediment properties such as grain size distribution, quartz grain form and roundness, grain surface texture, and mineralogical composition (Pye and Tsoar 1990). In a particular region, it might well be possible to distinguish aeolian facies types only on the basis of grain size distribution (see, e.g., Siebertz 1988), but this certainly does not mean that grain size can be used as a diagnostic criterion in general. Nevertheless, there is an obvious relationship between grain size and the different modes of particle transport by wind.

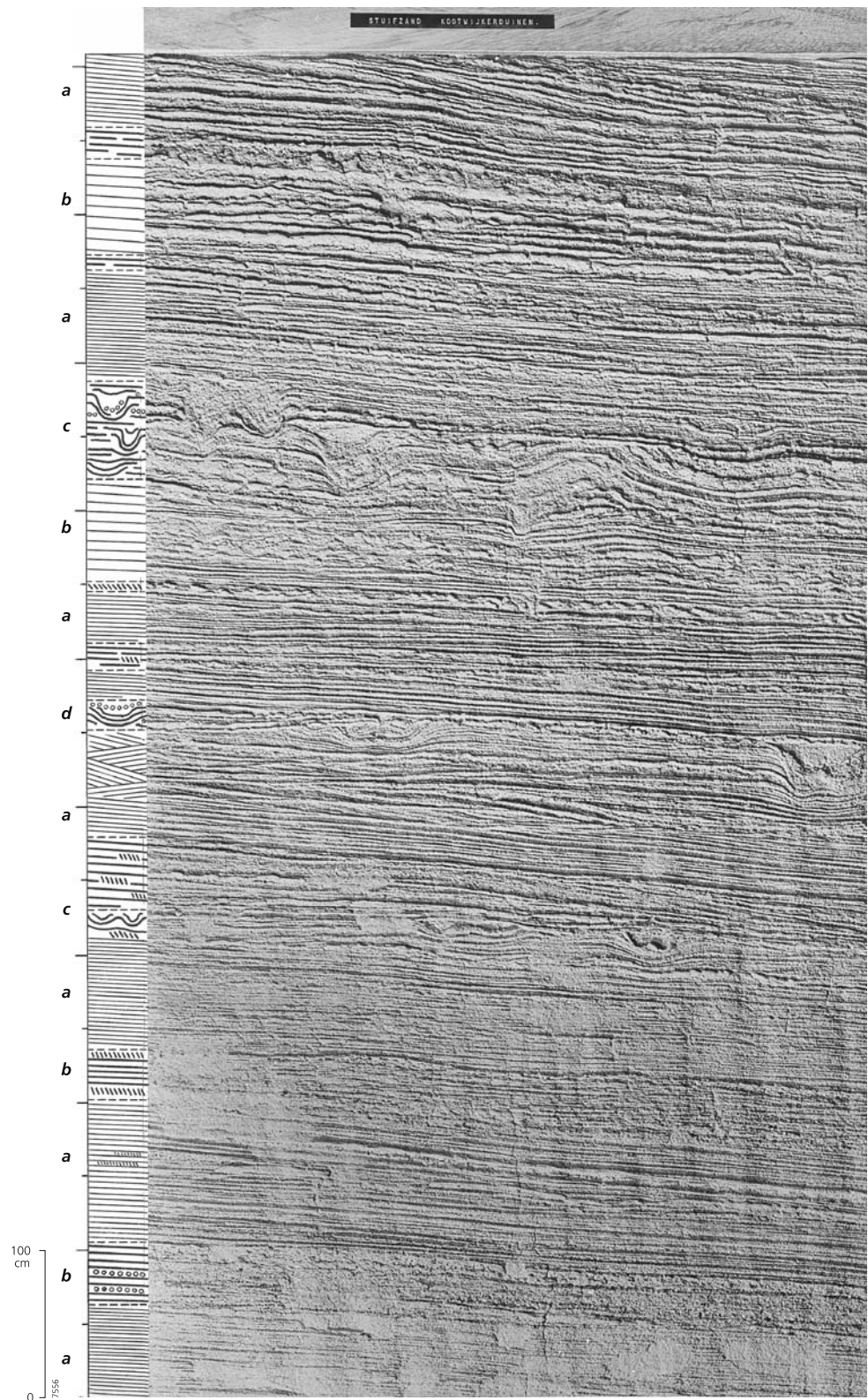
Cover sands and their redeposited counterparts, the drift sands, are often difficult to distinguish, especially when intercalated soil profiles are lacking. Both types of aeolian sediments are also more or similar in textural and mineralogical properties. Moreover, both cover and drift sand regions often show a gently sloping surface with only minor height

differences of a few meters. On the other hand, in those cases where the original soil profiles in cover sands have been preserved (Fig. 7a–c) and where drift sands display a typical dune relief, the distinction is easy to make.

Origin and Age

As mentioned before, drift sands are especially extensive in the western part of the European sand belt, i.e., in the Netherlands and adjoining parts of Belgium and Germany. In order to determine a “post quem” age of drift sand accumulation, radiocarbon ages of the topmost part of buried peat sections and humic podzol soils at many locations have been obtained (Castel et al. 1989; Castel 1991a, b; Koster et al. 1993). Although there is evidence for local sand drifts from Neolithic (since approximately 3500 BC) to Roman age, the beginning of really extensive sand drifting in northwestern Europe is thought to be related, both in time and space, to the rapid expansion of agriculture, together with grazing and burning practices of communal heathlands (overexploitation), the formation of roads and cattle/sheep drifts, and the use of plaggen fertilizer (Pape 1970), mainly after 950 AD. Some authors (e.g., Heidinga 1984a) have suggested a relationship between sand drifting and a drier climate in the “climatic optimum” in the Middle Ages (ca. 950 AD to 1250). However, no conclusive evidence for this climatic oscillation has been found in many peat sections, all of which encompass this period. Thus far, all available evidence seems to confirm the conclusion of Castel et al. (1989) that the majority of drift sand accumulation originated during the early part of the Late

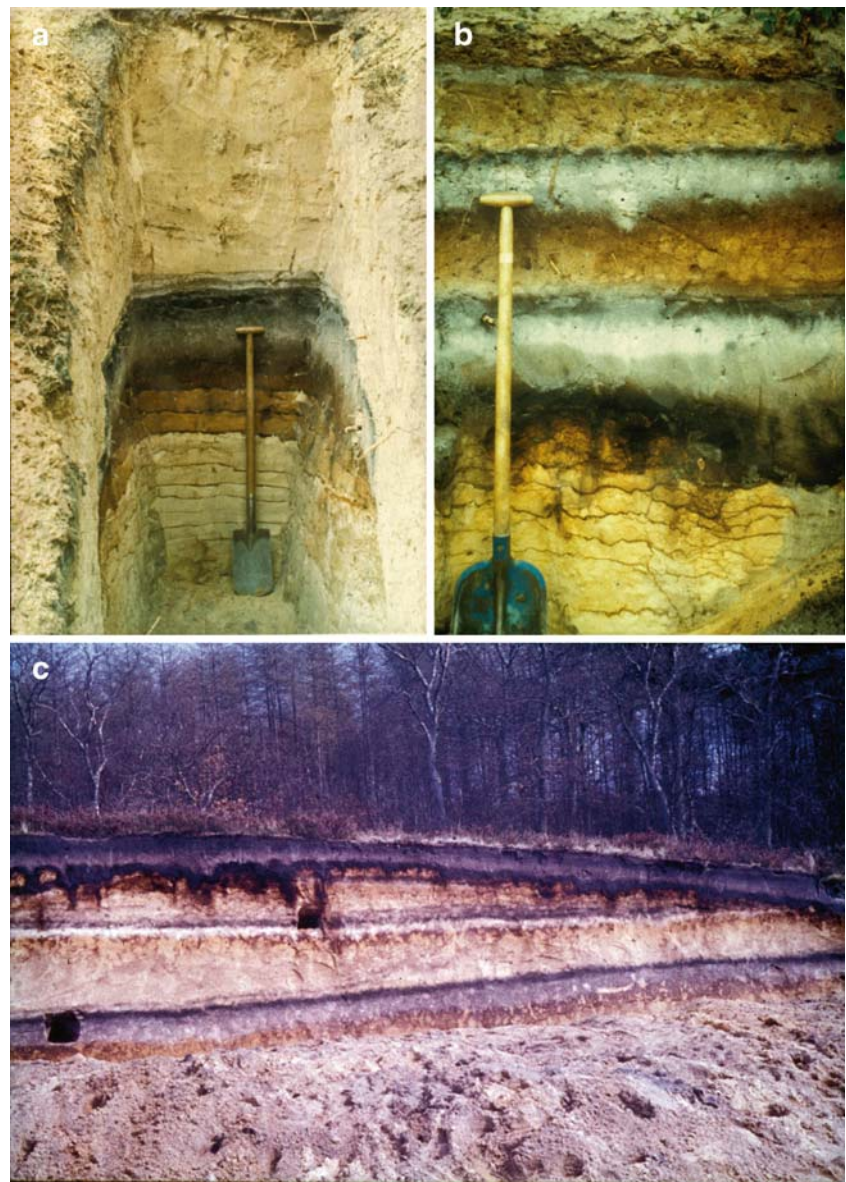
Fig. 6 Lacquer peel (approximately 1 m long) illustrating primary and secondary sedimentary structures, mainly parallel lamination reflecting dry conditions (e.g., sets *a*), crinkly laminae reflecting wet conditions (e.g., sets *b*), and distinct deformation structures (e.g., sets *c*) caused by flowing water in an interdune area and footprint or hoofprint structures that can be seen in set *d*; location Kootwijker Sand, Veluwe, central Netherlands



Middle Ages (after 950/1150 AD), but important sedimentation also occurred since the sixteenth century and even as late as the eighteenth and nineteenth century, as indicated by very young soil profiles (micropodzols).

In this respect, it must be mentioned that the reliability of conventional radiocarbon dates of bulk samples from organic remains in paleosols is inherently problematic, e.g., due to (a) large age differences obtained by dating the

Fig. 7 **a** Late Holocene drift sand on strongly developed humic podzol in Late Weichselian Younger Coversand II (location Ugchelen, Veluwe); **b** micropodzol and podzolic paleosol in drift sand on humic podzol in cover sand (location Geeste, Niedersachsen, Germany); **c** threefold Holocene podzolic profiles in a gently sloping inland dune (location Schoonoord, Drenthe, the Netherlands)



various organic fractions, (b) the possible inclusion of old carbon derived from deflation of older surfaces, or (c) the rejuvenation by contamination from younger roots (Castel 1991a; Koster et al. 1993). To overcome the difficulties of diverging age determinations resulting from the analyses of the different humic fractions contained in peat or soil samples, nowadays, accelerator mass spectrometry dating techniques on individual seeds or other organic particles are favored. Nevertheless, specific drift sand phases of more than local significance cannot yet be distinguished. Even in a small country like the Netherlands, a clear synchronicity in sand drifting phases in the central, southern, and northern parts of the country could not be established.

Until recently, it was thought that the practice of using heather sods for fertilizing nutrient-poor sandy soils, i.e.,

the forming of plaggen soils, already started in the Middle Ages. According to authors like Mückenhausen et al. (1968) and Behre (1980), the expansion of arable fields with the use of plaggen fertilization already started in the eighth or ninth century. In new studies, however, doubt has been cast on the early development of plaggen soils and consequently on the relation between sand drifting since the Late Middle Ages and the practice of plaggen fertilization. Spek (2004) in his exhaustive study on the influence of agriculture on the landscape development in the province of Drenthe (northern Netherlands) comes to the following conclusion:

after a critical analysis of all the datings carried out so far, it appears that manuring with mineral turf in the

Netherlands, in other words raising the level of the cultivated land with a humic plaggen layer (depending on the region concerned), dates from the late 15th to the late 17th century. That is much younger than the generally accepted datings for these layers, i.e. the end of the Middle Ages, which until recently was thought to be the case

Following this line of thought, the agricultural practice of plaggen fertilization is criticized as a cause for initiation of sand drifting, at least during the Middle Ages. Spek (2004) assumes on the basis of archeological and palynological indications that in the fourteenth to sixteenth century mainly plaggen was collected with a high organic content; only since the sixteenth century were plaggen soils raised because (heather) sods with a high mineral content were also used. Lascaris (1999) mentioned that, although in the early sixteenth century there were as much as 110,000 sheep in the Veluwe region, it was not until the sixteenth century that the pressure on the heath areas strongly increased because farmers changed to the plaggen agricultural system.

Moreover, there appear to be indications of natural causes of drift sand initiation (Koomen et al. 2004; Riksen et al. 2006). Although deforestation and agricultural practices may have triggered sand drifting in many instances, a natural geomorphological control also maintained the transport of aeolian sands. During periods of extreme wind erosion, possibly related to phases of increased storminess and or extreme droughts (groundwater lowering), oval-shaped drift sand cells with a length of 1.5 to over 6 km started to develop in the central Veluwe (see Fig. 2), which cannot be directly related to anthropogenic causes. Another factor that is sometimes mentioned as being of influence on sand drifting, e.g. in the Veluwe area, is charcoal burning for the local iron industry. Joosten (2004) rightly criticized this opinion as pollen diagrams of the region show that large-scale deforestation of the Veluwe area only started after the Early Medieval iron industry had ceased. The extensive Veluwe iron production stopped in the ninth century AD. However, in other regions, the situation is apparently very different. For example, Szczypek and Wach (1991) and Dulias et al. (2008), in their overviews on the influence of man on aeolian processes in southern Poland, report that “the activating of aeolian processes that ensued from the 12th and 13th centuries onwards can be related to the intensive thinning of forests for the use in ore mining and metallurgy.”

In paleoenvironmental reconstructions, one of the main problems that often remains is the accurate dating of aeolian sediments and landforms or more specifically the establishment of the duration of the aeolian “effective” periods. In most cases, age determinations of aeolian phases are still based on dating of intercalated organic (peat) layers

and paleosols that represent the nonaeolian phases (Koster 1988). Luminescence dating techniques might shed new light on this matter in the near future (Koster 2005b). However, until now, only few luminescence studies have addressed very young aeolian formations (Radtko 1998; Ballarini et al. 2003; Bateman and Godby 2004; Hilgers 2007). Hilgers et al. (2001) report on very young luminescence dates of only a few hundred years, which have been obtained from recently remobilized sands near the dune surface. It is considered that these young ages provide strong evidence that the resetting process in these aeolian sediments was complete and that the last mobilization of these sands probably took place towards the end of the Little Ice Age.

In conclusion, apart from locally occurring sand drifts of (much) earlier age, the first phase of extensive drift sand formation took place during the eleventh to thirteenth century AD, followed by a second phase during the sixteenth and seventeenth century. Locally, sand drifting continued until large-scale stabilization took place during the last two centuries.

Artificial and Natural Drift Sand Stabilization

The overwhelming majority of inland dune fields, including drift sand regions, in Europe has now been stabilized by a natural or artificial vegetation cover. Most dune fields in Belgium, the Netherlands, and Germany were transformed into Scots pine (*Pinus sylvestris*) plantations during the late eighteenth, nineteenth, and up to the early twentieth century (Alisch 1995; Koster 2005a; Riksen et al. 2006); Corsican pine (*Pinus nigra*) and Douglas fir (*Pseudotsuga menziesii*) were introduced to a lesser degree. Much of the wood was being used for the important coal mining industry in northwestern Europe at that time. Only few actively moving drift sand regions remain today. The dynamic part of the Kootwijker Sand dune field (Fig. 8) is one of the largest remaining active inland dune field in northwestern Europe. That drift sands formed a serious threat to farming in the Veluwe area, mainly since the fifteenth century, was frequently reported in historical documents (Lascaris 1999). An early example of this threat was found underneath the sands in the northeastern corner of the Kootwijker Sand (Fig. 8). Heidinga (1984b, 1987) excavated in this area the remnants of a Carolingian village consisting of more than 20 farmsteads during the eighth and ninth century. Somewhere in between 950 and 1000 AD, this village had to be abandoned as the local water wells began to dry out, and the farmland became increasingly covered by drifting sands.

In the Netherlands, the State Forestry Department was established in 1899 with the specific task to reafforest and

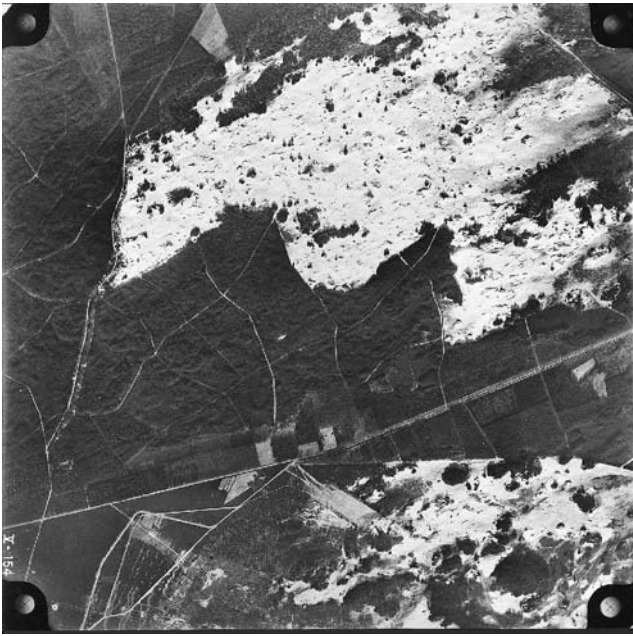


Fig. 8 One of the largest still actively moving drift sand regions in northwestern Europe (Kootwijker Sand and Harskampse Sand regions, *upper* and *lower part* of the picture, respectively, located in the Veluwe area, central Netherlands); the dune fields are surrounded by pine plantations dating from the beginning of the twentieth century (photo Topographic Survey of The Netherlands 1954). At present, the area of completely bare sands is significantly smaller (approximately 1.3 km² according to Riksen and Visser 2008)

cultivate wastelands, including the drift sand regions (Lascaris 1999). Of the originally approximately 950 km², some 60 km² still existed in the 1960s, whereas not more than 15/16 km² of actively moving drift sand regions remains today. The Hulshorster Sand region (Fig. 9) serves as a good example of the gradual change from actively drifting bare sand to stabilized dune surfaces covered by a variety of algae, lichens, mosses, grasses, heather, and pioneer pine trees during the twentieth century. Around 1900, the western and eastern active parts of the Hulshorster Sand were still united (surface area approximately 4 km²); around 1970/1980, the bare sand area had been reduced to less than 1 km², whereas in 2006 the bare sand area had shrunk to 0.35 km². The easterly active part of the Hulshorster Sand is shown in Fig. 10.

The increased nitrogen deposition caused by the expanded livestock farming since the 1960s results in further stabilization of bare sands. Ketner-Oostra and Huijsman (1998) mention a nitrogen deposition on the Kootwijker Sand in the 1990s of the order of 40–50 kg/ha per year. In combination with wet surficial conditions, nitrogen will stimulate algal growth. A few-millimeter-thick crust of algae can effectively stop wind erosion (van den Ancker et al. 1985; Pluis 1993, 1994). Factors like accelerated vegetation succession, increased algal crust formation,

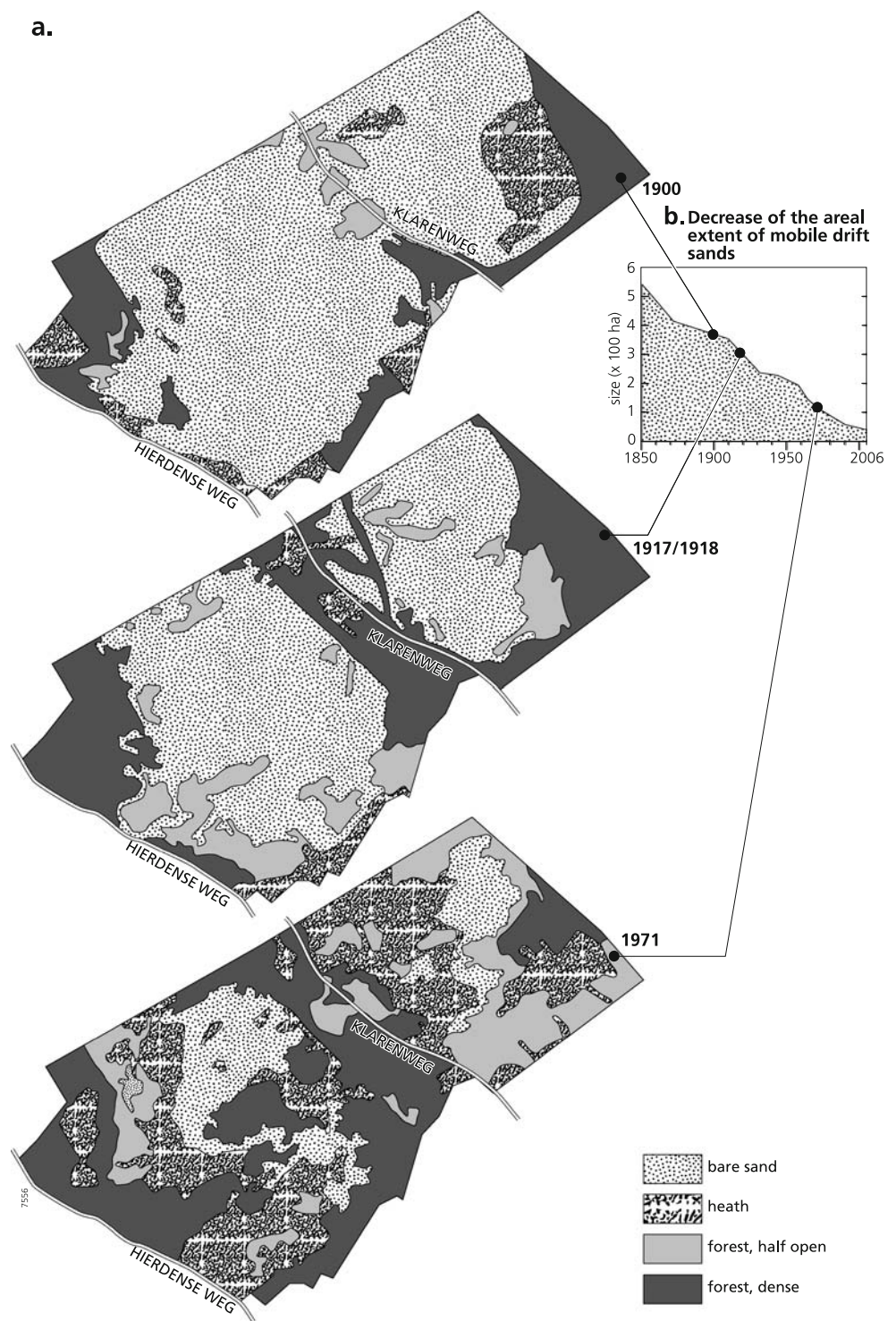
growth of lichen communities, pioneer (and exotic) moss and grass species, and a decrease in wind fetch all work together and result in rapid fixation of the sand surfaces (Fanta 1986; Prach et al. 1993; Ketner-Oostra and Huijsman 1998; Ketner-Oostra 2006; Riksen et al. 2006, 2008). It appears that lichens and soil algae appear first on mobile sand (Pluis 1993), soon to make place for a vegetation consisting of mosses, grasses, heather, and pine trees. Pioneer species like *Ammophila arenaria* (marram grass), *Festuca rubra* (red fescue), *Corynephorus canescens* (gray hairgrass), *Spergula morisonii* (Morison's spurry), and *Polytrichum piliferum* (hair cap moss) are part of a first succession stage.

Geoconservation by Management

In 1969, on the initiative of the Netherlands State Research Institute for Nature Management, the GEA Working Group was established. Its task was to assess the value and to make an inventory of all sites of interest to the earth sciences and to investigate the possibilities for conservation and management of such sites. The work was mainly based on scientific and educational parameters but also included ethical and esthetic aspects (compare, e.g., Harley 1994). Since that time, provincial inventories have been produced, resulting in the identification of hundreds of special sites and regions of geological/geomorphological and or pedological interest, more or less comparable to the Regionally Important Geological/Geomorphological Sites in the UK (Wilson 1994; Harley 1994; Gray 2004). In the 1990s, national surveys of “GEA sites” were undertaken, and criteria for the identification, selection, and evaluation of such sites were elaborated. To enable the evaluation of sites, a geogenetic or morphogenetic classification system, based upon a hierarchy of landforms according to the Geomorphological Map of the Netherlands, scale 1:50,000, was developed. In order to make the classification also suitable for international use, the geomorphological regions of Europe distinguished by Embleton (1984) have been used as a framework for the classification (Gonggrijp 2005). All sites were subsequently evaluated on a national scale according to the following criteria: (a) geogenetic distinctive characteristics or geogenetic representativeness, (b) rareness, (c) form characteristics or form representativeness, and (d) intactness, i.e., not damaged by man. Since the European Nature Conservation Year 1995, the provincial authorities in the Netherlands have designated a variety of sites of special geological/geomorphological interest as Earth Science Monuments, including several sites where active aeolian processes can be observed and studied, both in coastal and inland dunes.

Unvegetated drift sand areas constitute a very specific habitat for plants and insects due to (a) the very nutrient-poor substrate, (b) the continuously changing environmen-

Fig. 9 *a* Areal extent of bare sand, heath, and forest at 1900, 1917, and 1971, illustrating the decrease of actively moving drift sands (location Hulshorster Sand, Veluwe, central Netherlands; after Castel and Koster 1987); *b* the decrease of the areal extent of the active drift sand area from 1850 to 2006



tal conditions related to sand movement, and (c) the exceptional microclimate in which daily temperature ranges of more than 50°C and extreme changes in soil moisture content can occur (Stoutjesdijk 1959; van der Drift 1964). Under favorable daytime conditions, surface temperatures on bare sands may rise up to 30°C above the air temperature at 2 m height, whereas the sands cool very

rapidly in windless, bright nights because of the low heat conductivity (Stoutjesdijk 1959). Because of these extreme conditions, inland drift sands accommodate a species-poor but very characteristic fauna community (van der Drift 1964; Riksen et al. 2006). Alisch (1995) is one of the few authors who has explicitly paid attention to the mapping and evaluation of inland aeolian forms in Germany from the

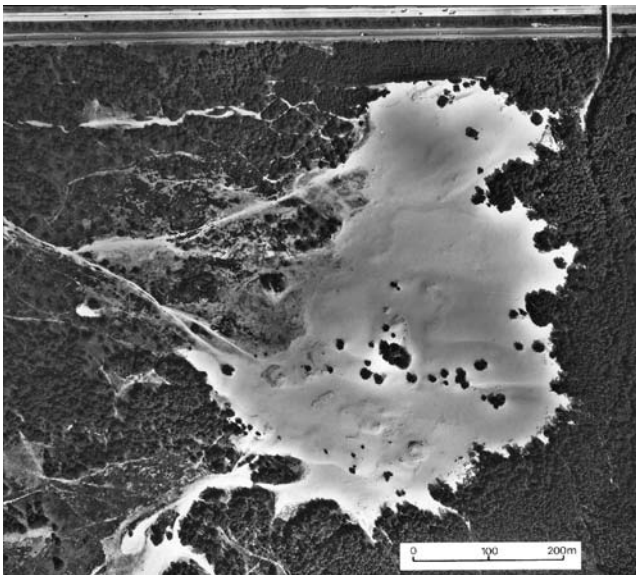


Fig. 10 Detailed aerial photograph of still actively moving drift sand in the Hulshorster Sand area (July 1985). The sand invades the pine plantation at the right-hand side of the photograph as the dominant transport direction is from left to right (SW–NE)

point of view of nature conservation. The ecological value of partly stabilized and partly actively moving drift sands is manifest. Prach (1989) stresses the fact that a spontaneous primary successional sere (i.e., ecological series) running from bare ground to 100- to 200-year-old forests can only rarely be seen in densely populated Europe.

Because of the scarcity and the geomorphological and ecological importance of drift sand regions that are still actively moving, elaborate and costly projects to reactivate sand drifting are executed by several organizations in the Netherlands (Provincial Authorities, the Nature Conservation Board, the State Forestry Board, the Provincial Landscape Conservation Boards, the National Park of The Hoge Veluwe). It is unfortunate that all the reports on

reactivations plans and on actual projects being carried out are in Dutch with the exception of a preliminary evaluation of former restoration projects in the Hulshorster, Wekeromse, and Kootwijker Sand areas (Ketner-Oostra 2006). Studies have been carried out in the following inland dune/drift sand regions; locations are indicated in Figs. 1 and 2: Hulshorster Sand, Veluwe (1995); Kootwijker Sand, Veluwe (1996, 2005); National Park De Hoge Veluwe (1999); river dunes on the Bergerheide along the river Meuse, province of Limburg (2002); drift sands on the Weerter/Boshoeverheide, province of Noord-Brabant (2003); Wekeromse Sand, Veluwe (2003); drift sand region Lemelerberg/Beerzerveld, province of Overijssel (2004); Loonse en Drunense Duinen, province of Noord-Brabant (2004); Lange en Korte Duinen, province of Utrecht (2005); and Hulshorster Sand, Veluwe (2006). Some of these projects are quite ambitious and drastic. For example, in the case of the reactivation project in the National Park De Hoge Veluwe, 15,000 pine trees in an area of 130 ha have been cut; the stumps, the undergrowth vegetation, and even the litter layer have been removed (Turnhout et al. 2004).

One of the first projects that addressed the potential of reactivation of drift sands concerning the Hulshorster Sand (Fig. 11a, b) was carried out by Castel in 1986. The direction and amount of future sand transport was quantified using a simulation program based on detailed geomorphological and vegetation mapping and measurements of sand volumes available for sand transport, in combination with meteorological data of nearby weather stations (Castel and Koster 1987). The results show that under present-day climatological conditions migration rates of sand bodies are small. This means that the mobility of these inland dunes can only be guaranteed by special management measures like locally removing all vegetation. To enable the prediction of sand transport rates and directions under present-day climatic conditions, Castel (1988) calculated drift potentials and developed a simulation model for sand



Fig. 11 Landscape of the Hulshorster Sand: **a** bare sands; **b** completely stabilized surface

transport. The only way to reactivate sand drifting and restore natural processes is to remove all vegetation, trees, shrubs, stumps, grass, and moss layer, and even the top soil (A-horizon) at the upwind side of active areas, of course, under the provision that locally sufficient sandy material susceptible to wind erosion is available, e.g., blown-out areas are unsuitable for reactivation because surficial material is usually either too coarse or too wet for deflation to be effective. However, serious problems were envisioned, like the high costs of such measures, legislation which tends to prohibit deforestation, the presence of infrastructural works or private ownership, and the (unnecessary) fear that wind erosion processes can run out of control.

The most elaborate study on the interactions between vegetation dynamics, aeolian sediment transport, potential for reactivation measures, and the efficiency of tilling techniques to achieve renewed sand transport was carried out in the Kootwijker Sand (Riksen 2006; Riksen and Goossens 2005; Riksen and Visser 2008; Riksen et al. 2004, 2008; Ketner-Oostra 2006). The remaining bare sandy part of the originally much larger Kootwijker Sand is only c. 300–350 ha, but the surface of bare sand is rapidly declining. The objective of the State Forestry Board, the owner of the region, is to maintain about 300–400 ha as an active drift sand landscape (Riksen 2006). To attain this objective, management is necessary, which means complete removal of vegetation including a thin layer of top soil. It has been determined that sediment transport by wind and or splash erosion in this drift sand area virtually stops already when the vegetation cover reaches values of more than 40%. Therefore, to remobilize the sands, this vegetation must be removed, but the bare sand patches must also be large enough for the wind force to build up. In other words, the wind fetch effect after a vegetation boundary, e.g., a row of trees, must be sufficient to enable sand transport. The fetch effect is the increase of sand flux with distance downwind of a barrier. As a rule of thumb, it can be assumed that the wind velocity in the shadow of a barrier, depending on its permeability, will attain its original value after a distance of 15 to 20 times the barrier height. Consequently, in small drift sand areas, <100 ha, wind erosion cannot fully function as a landscape-differentiating process. Obviously, good management of these areas requires monitoring of sand transport and changes in the vegetation cover and repeated deployment of suitable measures. Under the present-day wind regime in the Netherlands, most sediment transport takes place during extreme erosion events, which only occur a few days per year. During the intervening period, if it is long enough and if growing conditions are good, a pioneer vegetation and or algae crust may soon develop and protect the sand again against deflation. Riksen and Goossens (2005) and Riksen and

Visser (2008) have also investigated several tilling techniques by which a good balance between bare sand areas and areas covered with a low pioneer vegetation can be achieved. Only a thin layer of some 10–20 cm of the top soil has to be removed. Experiments have shown that, of the four tilling techniques tested, the beach sand cleaner and the rotary cultivator are the most recommendable methods to reactivate sand stabilized by gray hairgrass and algae crusts.

In summary, it may be said that the originally extensive drift sand areas mainly resulted from uncontrolled exploitation of the land and have therefore been looked upon as “man-made deserts.” After several centuries of unsuccessful attempts to stabilize the bare drift sand areas, these wastelands probably reached their maximum extent in the eighteenth and nineteenth century. Due to large-scale reforestation during the last two centuries as well as by natural vegetation development, these areas have become very rare. Modern concepts of nature conservation and rehabilitation on the other hand now lead to restoration of the originally dynamic drift sand ecosystems. However, it is inevitable that reactivation projects that primarily promote sand drifting processes may come into conflict with classic habitat strategies that aim to achieve maximum biodiversity and natural vegetation succession. Consequently, in all field studies, choices have to be made which intended results should take priority. Finally, in all previously mentioned reactivation projects, it has become abundantly clear that efficient management practices must be based on a solid understanding—and monitoring—of the interaction between actual climatic conditions, relief characteristics, availability and properties of sediments, and the character and rate of vegetation development.

A European Perspective

In conclusion, inland dune landscapes where aeolian processes of sediment transport and deposition can be observed and investigated are very rare in northwestern Europe, in fact, much more rare than in coastal dune landscapes. Moreover, the dynamism in these landscapes, i.e., the geodiversity of these areas, forms the basis for an exceptional biodiversity. Areas where an ecological gradient exists from bare sand surfaces to partly stabilized surfaces with pioneer plant species to the first stages of forest succession next to each other are equally rare in northwestern Europe. However, geoconservation of these important “natural” landscapes needs careful planning and management that requires a profound knowledge of the interaction of the many geomorphological, ecological, and land use processes. The findings of Riksen (2006) and Ketner-Oostra (2006) can be of great value for the

rehabilitation and monitoring of former drift sand areas with their interesting geodiversity and biodiversity all over the “sand belt” in the northern European Lowlands.

Sound geoconservation is a complicated process. It demands an effective strategy, a solid legal framework, and a clear and transparent procedure from basic geological/geomorphological data to protected, managed, and monitored geosites. Fortunately, the specific role geodiversity plays in nature and landscape planning in general and its relation to biodiversity and cultural history in particular are becoming more and more recognized. Rehabilitation of drift sand landscapes in the Netherlands is a development which will hopefully be followed in other countries in northwestern Europe.

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- The establishment in 1988 of the European Association for the Conservation of the Geological Heritage (ProGEO) has been of great importance in promoting the importance of geoconservation in Europe (Gonggrijp 2005; Erikstad 2008). My colleague and friend Gerard Gonggrijp was one of the “founding fathers” of ProGEO and an early advocate for geoconservation in the Netherlands since the 1960s (Gonggrijp 1994; Gonggrijp and Boekschoten 1981). Therefore, this contribution is dedicated to him.