Coastal landslides and swelling clays at Røsnæs, Denmark

By D. B. Prior

Fig. 1. Part of the active landslide area advancing on to the foreshore at Røsnaes.
Fig. 1. Del af det aktive skred. (David Prior fot.).

Prior, D. B., 1973: Coastal landslides and swelling clays at Røsnæs, Denmark. Geografisk Tidsskrift, 72: 45–48. København, september 30, 1973.

The landslide morphology of the Røsnæs area has been examined and materials involved in active landsliding analysed.

Dr. D. B. Prior, Department of Geography, The Queen's University of Belfast, Belfast BT 7, 1 NN, Northern Ireland.

Introduction

Landslides have been described in the Røsnæs area of North-west Sjælland by *Schou* (1949). Three stages of development are envisaged involving young slide forms, secondary slides and mature slide forms. The morphology varies with each stage but the total effect is the development of elongate valleys with smooth sides running normally to the coastline. Rejuvenation can take place at any stage producing fresh slide morphology with active slide planes and soft, moving mud. Schou reports that these landforms are associated with plastic clays which, when softened by water can flow as streams of mud. These plastic clays are derived from Eocene sediments which occur in North-west Sjælland, on the north shores of Fyn and in places on the east coast of Jylland. They are sometimes referred to as the Little Belt clays (*Mertz*, 1928; *Hansen and Tadashi*, 1964) and have been studied in connection with construction of bridges over the Little Belt (e.g. *Jeppesen*, 1948).

In 1972 a short visit was made to the Røsnæs area to examine the landslide morphology and to collect samples for mineralogical analysis. Three types of mass-movement morphology could be identified. In the immediate vicinity of the village of Røsnæs there are several valleys which represent the former locations of landslides. These represent the mature forms described by *Schou* (1949). Also, along the coast, at several localities south-east of the village there are areas of complicated, stepped topography. These possess the steep front slopes and shallow-angle reverse slope morphology of small rotational slide blocks and these occur in groups rather than singly. Some of these areas are clearly stable at present and are well ve-

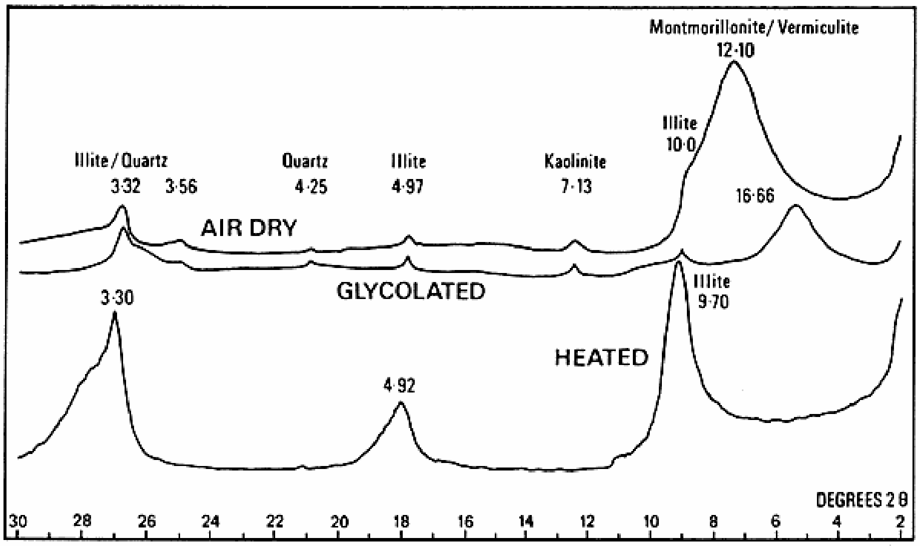

Fig. 2. X-ray diffraction traces of clay from Røsnæs in air dry, glycolated and heated states.
Fig. 2. Røntgen diffraktionsanalyse af ler fra Røsnæs hhv. lufttørret, glykolbehandlet og glødet (550°).

getated while others appear more active. The third type of mass-movement is represented by a small area of actively moving mud which is advancing on to the present foreshore at a point 3 km south-east of Røsnæs. The mud emanates from a basin-shaped depression (130 m in length, 100 m in width) which exposes sections through the fluvio-glacial cover sands which overlie the Eocene beds. The latter are soft grey, and grey/blue fissured shales which occur in situ in the adjacent marine cliffs. The basin-shaped area was clearly active. Large blocks of broken shale were being transported seawards within a matrix of soft, clay-rich, wet mud. In places, blocks of sand and sand rich areas represented transported and incorporated glacial sediments. Fresh, slickensided shear planes could be observed bounding individual flow tracks. Systems of oblique cracks trended obliquely away from the marginal shear planes. The advancing toe lobes were burying foreshore litter such as seaweed and driftwood. Locally the beach sands and gravels could be pushed cracked and overthrust. Samples were collected at this site.

Methods of pre-treatment and analysis

The samples were analysed for grain size, exchangeable cations, Atterberg limits and clay mineralogy. The exchangeable cations were measured using an atomic absorbtion spectrophotometer. Atterberg limits were determined following procedures described by *Lambe* (1967). Clay mineralogical examinations were conducted using a Philips X-ray diffractometer yielding CuKα radiation. For X-ray analysis a few grains of material, dispersed in water, were treated with ammonium acetate and hydrogen peroxide to remove carbonates and organic material. Each sample was washed and centrifuged several times and then well dispersed. After settling for 33 minutes at 25° C the $\angle$ 5μ fraction was separated with a pipette according to Stoke's law. Slides were made of the resulting solution and allowed to dry in air, giving orientated samples. Each slide was submitted to X-ray diffraction in three different states, namely air dry, when treated with ethylene glycol and after heating at 550° C for 20 minutes. Additional pre-treatment of the samples included the preparation of homoionic suspensions of magnesium, potassium and sodium respectively. Each sample was washed in 1 N salt solution containing the desired cation (i.e. $MgCl_2$, KCl, NaCl) then rinsed and centrifuged before slides were made.

Results and discussion

The materials involved in active landsliding near Røsnæs are extremely rich in clay sized particles. The total clay fraction ($\angle$ 4μ) accounts for 69–75 % of the material, with the principal component being $\angle$ 2μ (65–71 %). The sand and silt content is variable but the silt component is always larger with an average of 18.7 % for the 63–4μ range compared to an average of 9.0 % for the ⟩63μ fraction. The Atterberg limits measure the susceptibility of clay soils to physical changes in the presence of water, in terms of plastic limit, liquid limit and plasticity index. The plastic limits of the Røsnæs clay average 31 % as compared to liquid limits of 70 %. The activity of these materials, defined as the ratio of plasticity index to percentage clay fraction ($\angle$ 2μ) is about 1.7 and thus the clays can be described as 'active' (*Skempton*, 1953). However, these values ignore one extremely high value for liquid limit of 273.5 % from analysis of a piece of soft, fissured shale. The clays are alkaline in reaction (pH 8.6) and contain calcium, magnesium, sodium and potassium cations in order of decreasing abundance. The average values are relatively low, calcium 7.97, magnesium 6.34, sodium 1.50 and potassium 1.32 me/100 gms.

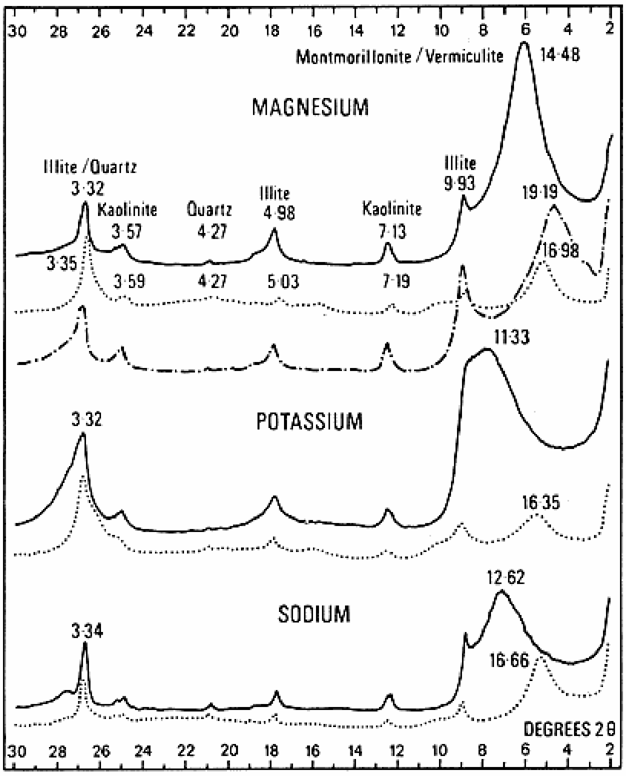

Fig. 3. X-ray diffraction traces of clay from Røsnæs with homoionic pre-treatments. Air dry, glycolated and water treatments are provided for magnesium saturated clay; but only air dry and glycolated states for potassium and sodium.

Fig. 3. Røntgen diffraktionsanalyse af homojonisk forbehandlet ler fra Røsnæs. Magnesiummættet ler hhv. lufttørret, glykolbehandlet og opslemmet i vand. For kalium- og natriummættet ler er kun anvendt lufttørring og glykolbehandling.

The X-ray diffraction traces from 2–30°2Θ are presented in Figs. 1 and 2. The air dry preparations gave a pronounced peak at 12Å together with one at 7.13Å and others at smaller Ångstrom spacings. Glycolation expanded the 12Å peak to 16.7Å and revealed a peak at 10.0Å. Heat treatment destroyed both the 12 and 7Å peaks entirely but enhanced that at 9.7. Others at 4.9 and 3.3Å also remained after heating. From these analyses certain firm interpretations can be made. The 10 and 4.9Å spacings indicate the presence of illite. The 3.3Å peak supports this but further suggests that quartz may be present. The latter is confirmed by the small 4.2Å peak on both the air dry and glycolated traces. The interpretation of the 12–16Å and 7.13Å spacings is more contentious. The latter indicates either chlorite or kaolinite or a combination, since the chlorite second order-peak and the 001 kaolinite spacing coincide at this position. In this respect the heat treatment is helpful since chlorite, if present, should be relatively unaffected by dehydration while it is well known that kaolin crystallinity can be destroyed by heating to 550° C. The complete destruction of the peaks thus clearly indicates the absence of chlorite and the presence of kaolinite. The 12Å spacing, expanding to 16Å with glycol shows the presence of a swelling clay mineral. This could be either vermiculite or montmorillonite. The distinction between these two is notoriously difficult to make on the basis of X-ray diffraction traces since both groups consist of expanding triphormic lattices (*Walker*, 1961). Since the behaviour of these minerals can depend on the exchangeable cations present it was considered desirable to prepare homoionic samples as an aid to further identification (Fig. 2).

Magnesium saturated clay gave a 14.47Å spacing which expanded to 16.98Å after glycolation. This is consistent with either montmorillonite or vermiculite. Treatments with potassium are sometimes used as a diagnostic test for vermiculite and thus the presence of an 11.32Å peak expanding to 16.35Å slightly favours the interpretation of vermiculite. The sodium saturated samples are inconclusive but also demonstrate the swelling capabilities of these materials. The conclusive identification, however, rests on the amount of swelling exhibited by the clays immersed in water. It is commonly held that montmorillonite, especially when magnesium saturated will expand to 18Å or more whereas magnesium vermiculite rarely expands beyond 14.8Å (*Walker*, 1961). Figure 2 shows that the magnesium saturated clays expanded to 19.19Å, convincingly demonstrating the presence of montmorillonite.

The mineral assemblage present in the landslide clays at Røsnæs can thus be summarised as montmorillonite, illite and kaolinite with some quartz. Quantitative measurements from diffraction traces are frequently inaccurate, however, it would appear that montmorillonite is the dominant constituent. The association between landslides and clay-rich sediments composed of predominantly swelling montmorillonite is not coincidental. Such clays are susceptible to changes in physical properties when subjected to hydration and dehydration. This is reflected in the high liquid limit values recorded for these materials. Such changes are enhanced by the presence of exchangeable cations such as magnesium and sodium.

Various recent investigations have noted the association between landslides and swelling clay minerals (Table 1). The Røsnæs area of Denmark thus provides another excellent example of the presence of swelling montmorillonite clays contributing to the instability of slopes. There are, of course, other additional factors. The mantle of fluvioglacial sands and gravels undoubtedly aids the supply of water to the underlying clays. Also, continuing sporadic coastal erosion in the Røsnæs peninsula undercuts and oversteepens the coastal slopes. The landslides in this area are the result of a combination of circumstances, not least, the presence of water absorbent, swelling, montmorillonite clay minerals.

Table 1. Some examples of the association of landslides and swelling clays.

Author	Location	Rock Type	Clay Mineralogy
Yatsu, E. (1967)	British Columbia	till	montmorillonite, illite, chlorite
	Sweden	quick clays	montmorillonite, illite, chlorite
	Norway	quick clays	montmorillonite, illite, chlorite
Anderson, D. W. et al. (1969)	Alaska	shales	bentonite
Prior, D. B. and Ho, C. (1970)	Caribbean	weathered lavas	montmorillonite
		Tertiary shales	kaolinite, montmorillonite, chlorite, illite
	Northern Ireland	Liassic shales	montmorillonite, illite, kaolinite
Quigley, R. M. et al. (1972)	Toronto	varved clays	pseudo-montmorillonite interlayered with vermiculite and illite
Kerr, P. F. and Drew, I. M. (1972)	California	Miocene and Pliocene shales	montmorillonite and illite

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