DIRECT CURRENT THROUGH SALINE ROCK.

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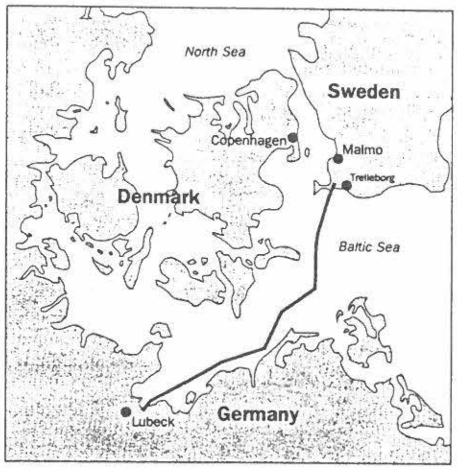

ABSTRACT

The geological conditions for an effective electrical grounding at large depths are often favourable because of a lower earth resistivity resulting from a higher salt content.
A new type of ground electrode installed in a 550 m deep bore hole is under test in the Baltic Cable HVDC transmission system in Scania in the south of Sweden.
The deep hole electrode has the advantage of low grounding resistance, low ground surface voltages and thereby a reduced risk for corrosion of buried metal structures in the surroundings.

In the last few years a lot more knowledge has been acquired regarding salt groundwater, especially in connection with radwaste investigations in Finland and Sweden. Within the Research and Development Programme at the Geological Survey of Sweden numerous tests have been carried out in order to find out whether it is possible to measure the depth to salt groundwater both in sedimentary and crystalline bedrock using electrical, as well as electromagnetical, soundings. The results are promising. The picture is becoming rather clear that deep groundwater is saline everywhere, but the interface between fresh and salt groundwater, which is often rather sharp, is situated at different depths in different areas.

The experience from investigations around various HVDC projects, and direct studies of the adjacent potentials have confirmed these observations. The Baltic Cable deep hole grounding is an illuminating case.

1. INTRODUCTION

Effective ground electrodes in HVDC transmission systems are of primary concern to suppliers and utilities for many reasons. A low electrode resistance reduces the power loss and the DC potentials at the surface of the earth. Low electric earth surface potentials and potential gradients diminish the risk of interference, e.g. increased corrosion on burried metallic structures due to DC earth current. Existing HVDC ground electrodes are located in remote areas often at a distance of several tens of kilometers from the converter station itself due to the risk of interference.
Significant advantages can be achieved, when electrodes of low resistance are located in low resistivity earth layers. This results in low DC electric potentials and potential gradients at the surface of the earth;

* the electrode can be located closer to the converter station
* shorter electrode line
* reduced power loss
* reduced interference in the vicinity of the electrode
* further opportunities to use monopolar HVDC transmission.

The main objective of this project has been to design and test a new type of HVDC ground anode installed in a bore hole of 550 m depth at the site of the Baltic Cable HVDC converter station in the far south of Sweden, where favourable conditions for a deep grounding point was found.
The project is a joint venture between ABB Power Systems, Vattenfall Transmission, Baltic Cable and Statnett SF. Consultants have been SGU and Vattenfall Hydro Power. STRI (Swedish transmission Research Institute) is managing the project.
The test electrode was installed in the borehole in June 1994 and was taken into operation for the first time at the end of January 1995.
The electrode is in fact located within the HVDC station area and connected in parallel to the ordinary sea electrode located about 23 km from the HVDC station.

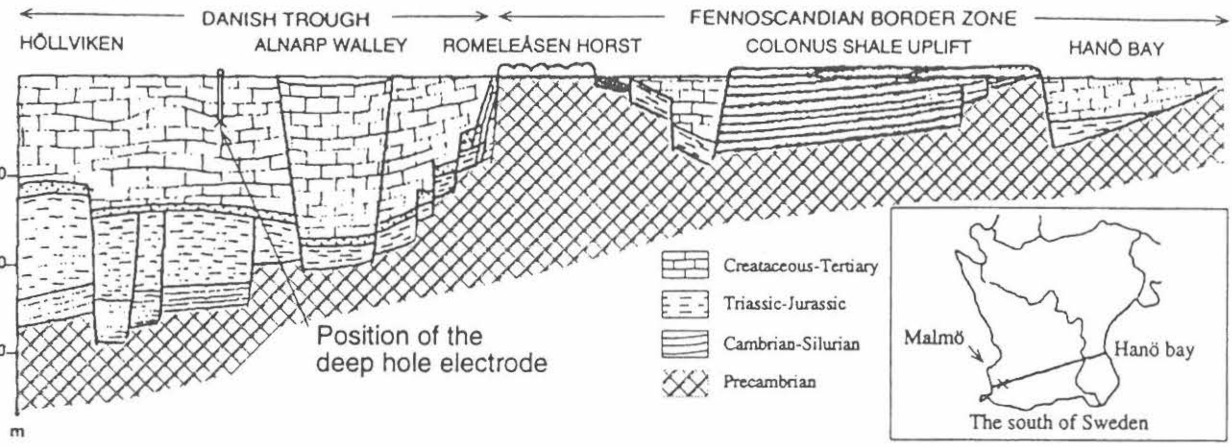

Fig. 2 Cross section through the fossile-bearing bedrock of Skåne

2. GEOLOGICAL CONDITIONS IN SKÅNE

Fig. 2 shows a section through the fossile-bearing bedrock in Skåne, the southernmost province of Sweden (1). This delineates a several kilometer deep sedimentary bedrock characterized by relatively young and thus porous rocks covering the crystalline basement. This type of bedrock occurs commonly in large areas of the world and represents the dominating situation in Europe, for example.
Porous sedimentary bedrocks are well suited to electrical grounding because of their content of electrolyte, i.e., salty water. The resistivity of the electrolyte present in the close vicinity of the grounding point, i.e., out to some hundred meters, is the primary determining factor for the resistance of the grounding point. As the diagram in Fig. 3 shows, this resistivity is determined by salt content and temperature and in this particular case (appr. 1 % NaCl and 10 °C) it can be just below 1 Ωm.
Regarding actual earth deposits it can be said that their resistivity depends on the content of electrolyte and its salinity. On land down to about 100 m (depending on the groundwater level above sea level) the electrolyte consists of fresh water, which means that sand and gravel have a resistivity between 100 and 500 Ωm. whereas clay can be between 10 and 100 Ωm. In exeptional cases, salty electrolytes are present resulting from seawater penetration or from relict saltwater deposits.
Below an often rather thin earth layer usually less than 10 m in depth one meets the initial bedrock consisting of limestone. Its resistivity is also determined by the porosity and the salinity of the electrolyte. The resistivity can be calculated by means of Archies law if the porosity and resistivity of the electrolyte are known, see Fig. 4. If the electrolyte consists of freshwater, the resistivity is of the order of 50 - 100 Ωm.

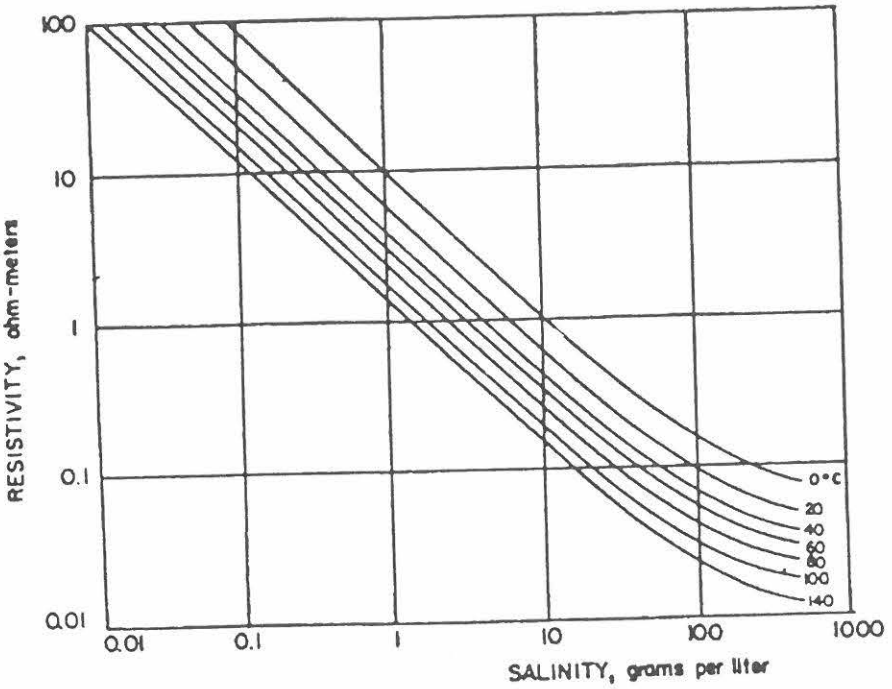

Fig. 3 Resistivity of solutions of sodium chloride as a function of concentration and temperature.

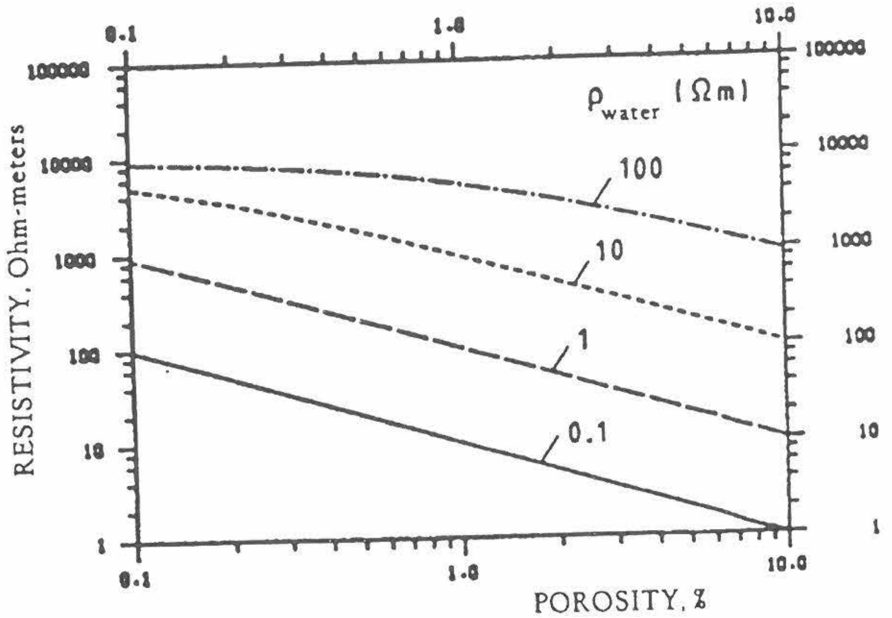

Fig. 4 Resistivity of the bedrock as function of porosity and the resistivity of the electrolyte.

At larger depths the salinity and the porosity can rise to very high values. In the lowest part of the limestone (Cenoman), there exist remarkably high salt contents (10 - 15 %) and also high porosities, which can be over 30 %. Since the temperature increases with depth by some 20 °C per kilometer, the resistivity will decrease for that reason too.
In connection with such projects as prospecting for oil, SGU and OPAB have drilled a large number of deep bore holes in the far south of Sweden. Bore hole loggings show that resistivity at somewhat deeper levels in the limestone is of the order of 5 - 10 Ωm but taken in the Cenoman horizon at deeper level (1200 m in Höllviken) the value is 0.1 - 1 Ωm. Some of the deepest holes continue down through the sedimentary bedrocks and into the crystalline basement, which of course has a considerably lower porosity, perhaps only of the order of 0.1 %, but has a salt saturated electrolyte and therefore a resistivity as low as 300 - 500 Ωm.

At a very early stage it was proposed by SGU that one of these existing bore holes, that is not in use at present, should be utilized for grounding, or at least for tests of deep grounding in parallel with those tests that were conducted in cooperation between SGU and Vattenfall Västsverige. In some introductory tests the grounding resistance of the steel casing of some of the deeper holes were measured according to the Bolzman methode, resulting in resistances of 0.1 - 0.2 Ω. However, the resistance of the long steel casing itself was included in these measurements and it was obvious that the major part of the current was leaving the casing at minor depths. It should therefore be possible to consider a shorter bore hole, but yet have a sufficiently low grounding resistance.

In order to gain information about variations in resistivity in the upper part down to a depth of 250 m, where old bore hole loggings started, electrical soundings were carried out with current electrodes gradually separated up to a maximum half distance of 320 m. Results show that fresh water has displaced salt water down to 60 m depth, where the resistivity decreases from 200 Ωm to appr. 20 Ωm and gradually decreases further to 5 - 10 Ωm. See Fig. 5. It can be concluded that a deep hole grounding means that a low resistivity bedrock which is not affected by fresh water can be used as the location for a ground electrod.

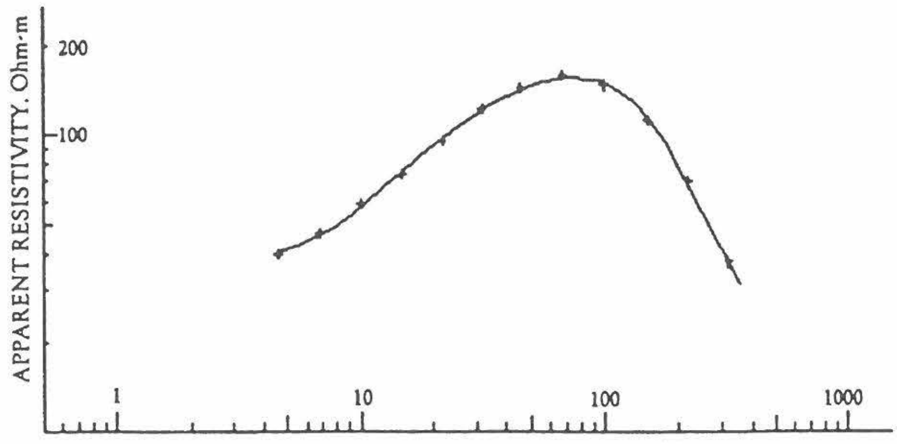

Fig. 5 Resistivity as function of depth from electrical sounding in Håslöv.
(AB/2= half distance between current electrodes)

Layer	Resist. [Ωm]	Thickn. [m]	Depth [m]
1	36.59	5.5	5.5
2	247.82	55.1	60.6
3	17.84		

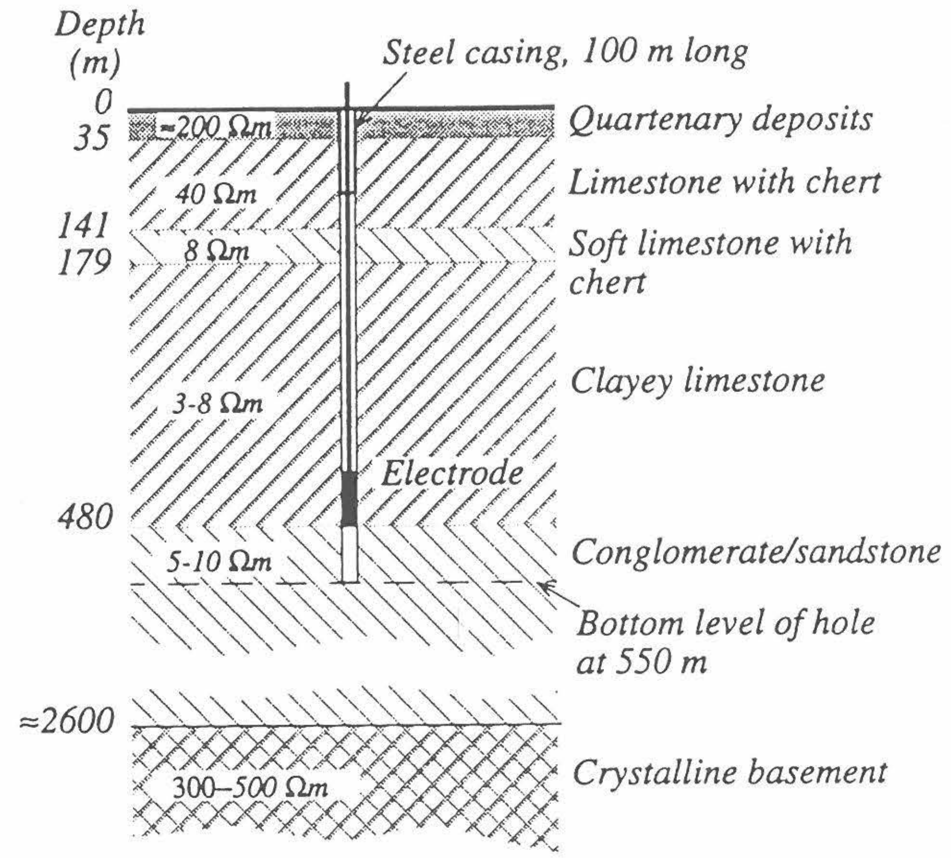

Fig. 6 Resistivities, earth layers and location of the electrode in the bore hole.

3. ELECTRODE DESIGN

The bore hole is 550 m deep, and drilled by means of a 96 mm bore except for the first 100 m where a steel casing of 139 mm diameter is inserted in order to stabilize the bore hole. The bore hole is naturally filled with water with salt content of about 1.5 % at the bottom.
The principal dimensions of the cylindrical electrode are 45 m in length and 70 mm in diameter. The electrode consists of 34 modules connected in series. The active electrode material is a titanium mesh with a special oxide coating of precious metals. High chemical resistance is required in insulating and other materials due to acidic environment generated by the electrode in service, as clorine and oxygen result from the anod process.
The electrode resistance depends mainly on the earth resistivity close to the electrode. The resistivivity is measured to be around 3 Ωm at the location of the electrode. Equation (1) aplicable to homogenous earth gives a first estimate of the resistance of 0.08 Ω.

$$R = \frac{\rho}{2\pi l} \cdot \ln\left(\frac{l}{a} \cdot \sqrt{\frac{4h+3l}{4h+l}}\right) \qquad a<<l,\ h>>a \qquad (1)$$

where ρ is the earth resistivity, l the electrode length, a the electrode radius and h the distance from the surface of the earth to the top of the electrode [2]. If l is small compared to h as in this case the square root expression is close to one.

Measurement of the electrode resistance where the sea electrode was used as counter electrode shows an electrode resistance of 0.086 Ω. The resistance of the deep hole electrode and the sea electrode together was 0.12 Ω. If cable resistances are included, the total resistance of the deep hole electrode (0.11 Ω) is considerably lower than the resistance of the sea electrode (0.38 Ω) due to long sea electrode cables (two in parallel, 23 km each)

4. POTENTIAL DISTRIBUTION

Compared to electrodes at the surface, the deep hole electrode gives lower potentials on the earth surface in an area relatively close to the electrode (in this particular case up to some km). The size of the area is mainly depending on the depth to the electrode. See Fig. 7 which for simplicity's sake concerns a case with homogeneous earth.

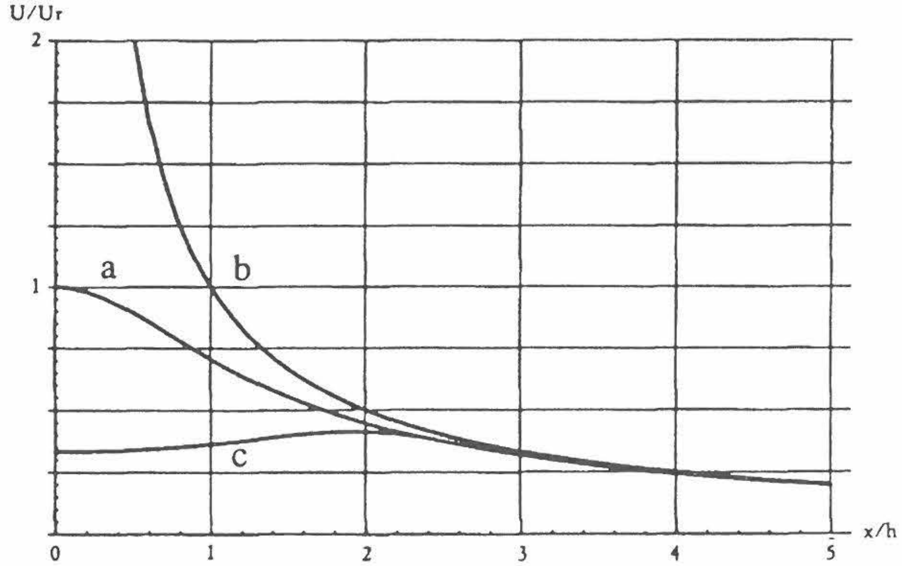

Fig. 7 Potential distributions at the surface of a homogeneous earth. x=horizontal distance, U_r=maximum voltage in case a.

a. Electrode at depth h
b. Electrode at the surface
c. Four sub-electrodes at depth h, separated a distance of 4h (placed in the corners of a square)

A relatively thin top layer (a fresh water layer) of larger resistivity will, however, not significantly increase the potentials at the surface around the deep hole electrode. If instead the electrode is placed in that surface layer, then the potentials within a distance of about 2d, where d is the depth of the surface layer, are very sensitive to the surface layer resistivity and the potentials are increased markably as the resistivity goes up (2).

The potential distribution was measured using the successive voltage drop methode, which simply consists of measuring voltages between successive pairs of points on the earth surface. The potential to a reference level can then be obtained by summation of the measured voltages. Measurements were carried out up to a distance of 3.6 km along available roads out from the electrode site. Fig. 8 shows the result of the measurements referred to an electrode current of 350 A. The potential at 3.6 km is

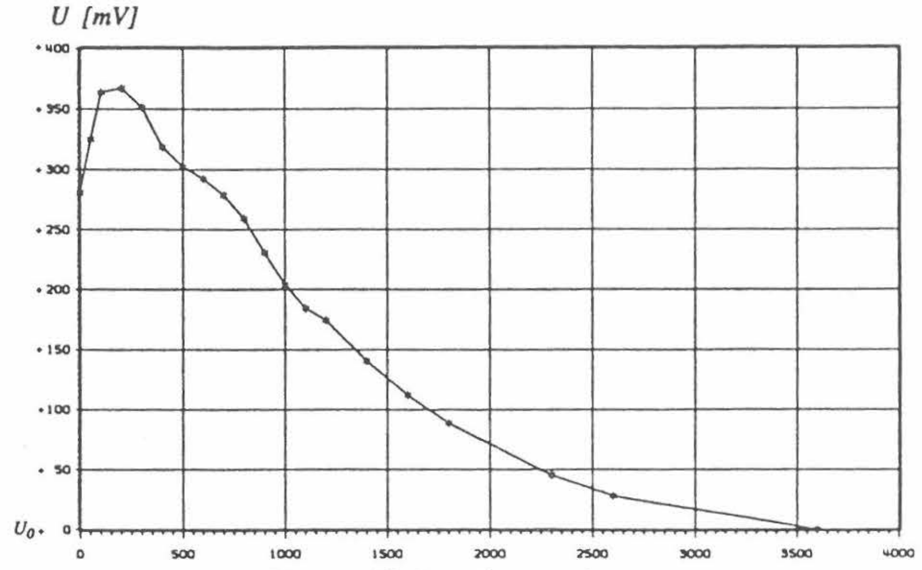

Fig. 8 Measured potential distribution referred to 350 A. U_0=reference voltage at 3.6 km.

estimated from electric field calculations to be 0.13 V. The maximum potential rise at the earth surface is thus 0.37 + 0.13 = 0.5 V.

A full scale electrode would comprise more than one bore hole. To keep the maximum potential rise down despite a higher total current, the spacing should in this case be in the order of some kilometers to avoid coinciding areas of higher voltage levels from each sub-electrode. The electrode depth could also be increased.

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(2) Kimbark, E., 1971: Direct Current Transmission, Vol. 1 Wiley, New York.