Geogene and anthropogene salinization-phenomenons in the groundwater of Bremen (northern Germany)

Dieter Ortlam [1] & Michael Sauer [2]

[1] Department of Bremen of the geological survey of Lower Saxony, Werderstr. 101, D-28199 Bremen
[2] Roggenkamp 26, D-28259 Bremen

Motivation for this presentation is the first time square covered groundwater-mapping in Germany. From 1989 until 1992 the procedure of the „Rollendes Peilrohr" was realized in the city of Bremen. It allows a quick, environmentally careful and low-priced research of groundwater especially contaminated by geogene salt sources and waste deposits. The elaborated background results of the groundwater chemism are published in the atlas „Geochemische Grundwasser-Kartierung Bremen" (ORTLAM & SAUER 1993) and are an important contribution for an efficient risk valuation of waste deposits.

Location and geology

Bremen is settled along the river Weser 80 km south of the coast of the North Sea, where Bremerhaven is situated (Fig. 1). The two towns are parts of the fossil valley of Weser and Aller, which stretched to the Bremen basin. This basin (=region with freshwater depression) is surrounded by the geest of northern Bremen, the geest of Zeven, Achim and of Delmenhorst-Syke (=regions with freshwater recharge, Fig.1).

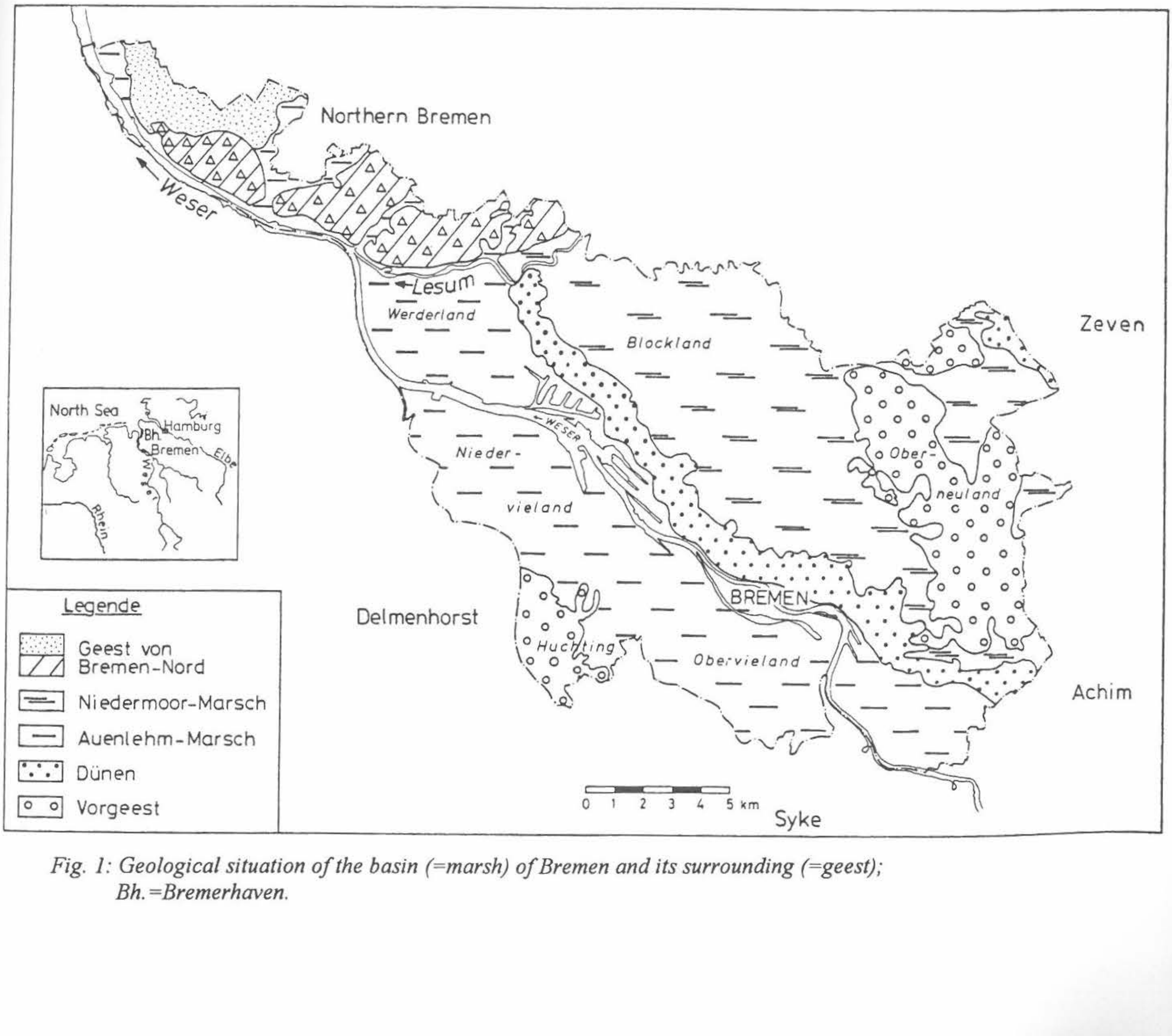

Fig. 1: Geological situation of the basin (=marsh) of Bremen and its surrounding (=geest); Bh.=Bremerhaven.

The geest of northern Bremen is generally covered by Saalian tills (up to 18m thickness), underlayed by the Lauenburger Schichten (=Elsterian glaciation). The sandy facies (sands of Ritterhude) represents the upper aquifer. A silty clay (clay-facies of the Lauenburger Schichten) or the silty layers of the higher miocene (tmi) are the basis of the upper aquifer (ORTLAM & SCHNIER 1980, ORTLAM et al. 1981, ORTLAM 1983b, 1989, ORTLAM & SAUER 1995b).

In the marsh of Bremen generally we have an upper aquifer consisting of glaziofluviatile sands of Saalian and Weichselian glaciation with a thickness between 5m to 50m, medium 15m. He is covered by holocene sediments of the river-marsh (loam of the valley) and peat with a thickness of 1m to 4m (maximum: 12m; ORTLAM & SAUER 1995b, 1995c). The city of Bremen is situated on a dune (Fig. 1) with a thickness up to 16m (ORTLAM & SAUER 1995b). The basis of the upper aquifer consists of the Lauenburger Schichten (Elsterian glaciation) in silty or sandy facies (ORTLAM et al. 1981, ORTLAM 1983b, 1989,).

Salinization-phenomenons in the groundwater of Bremen

The geochemical maps of groundwater show the geogene charakter of groundwater-chemistry which is defined by different geological cover of the upper aquifer, the structures of saltdomes, the deep pleistocene channels and the areas of saltwater with saltspots. Beyond that the chemistry of groundwater changes anthropogenically by water-infiltration of the river Weser, leakage of the sewage system and waste deposits (ORTLAM & SAUER 1995b). The following salinization-phenomenons are important for the different groundwater-chemistry in Bremen.

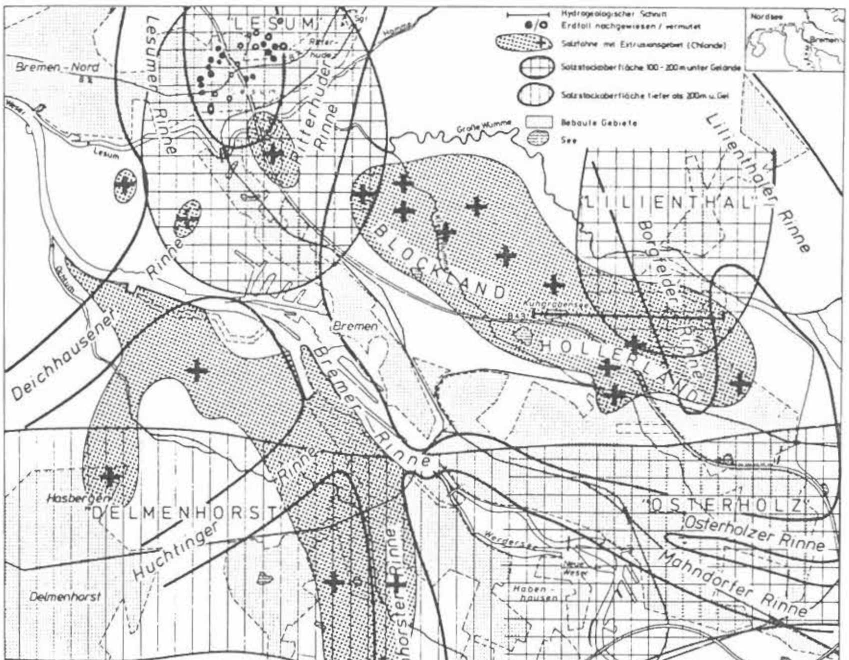

Fig. 2: Pleistocene channels, saltstructures and areas of saltwater with salt spots (✚, modified after ORTLAM 1989).

1. Principle of salt/mineral spots

The swelling of high mineralized deep groundwater into the upper aquifer is responsible for large salinizations in the Bremen basin. This is caused by three structures of Permian salt in Bremen: the saltdome of „Lesum", the saltdome of „Lilienthal" and the saltwall of „Delmenhorst-Osterholz" (Fig. 2; ORTLAM 1989). Zechsteinian salt swelled up from a depth of 4500m to 130m up to 400m under the surface (ORTLAM 1989). Pleistocene channels have eroded the tertiary layers up to 350m depth like a wide-branch-system in the underground of Bremen (Fig. 2; ORTLAM & SAUER 1995b). The pleistocene channels cut salinar structures, too. For example the channel of „Borgfeld" (Fig. 3; ORTLAM 1984) eroded the saltdome of „Lilienthal" and the channel of „Lesum", the saltdome of „Lesum"(ORTLAM 1989).

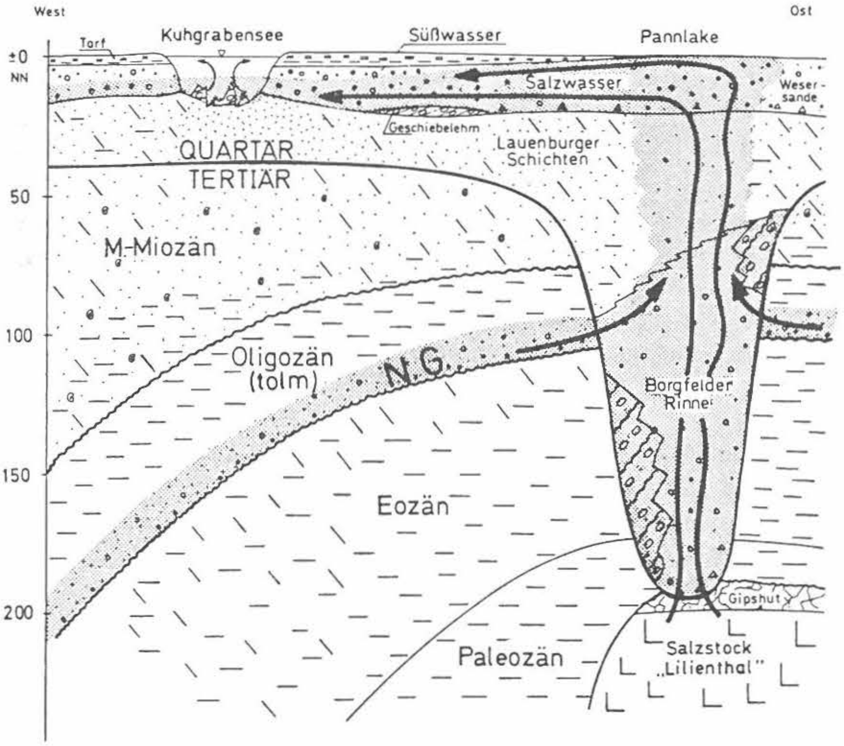

Fig. 3: Hydrogeological section through the Hollerland of Bremen (modified after ORTLAM 1989); position of the hydrogeological section see Fig. 2 and Fig. 6; N.G.=Neuengammer Gassand (Oligocene, tolm).

The salinars were solved and therefore this deep-groundwater of the channels is highly mineralized. On account of the solution of salt on the top of the different salinars in northern Germany the groundwater normally contents high concentration of chlorides and further lower concentrations of sulphates and magnesium. This demonstrates the possibility to solute the different salt-materials in the groundwater: the saltdome of „Lilienthal" as **donator of chlorides**. In the area of the saltdome of „Lesum" especially sulphates are solved out of the caprock (up to a maximum concentration of 1700 mg/l, Fig. 4). The chlorides are kept back by residual-clay along the salt-mirror. Therefore the saltdome of „Lesum" represents a **donator of sulphates** with important aspects on the density of the clayic salt-mirror (=enclosure of waste materials in saltdomes). In the geest of northern Bremen many (30) sinkholes are situated on the top of the saltdome „Lesum" on account of the solution of the caprock (Fig. 2 and 4; ORTLAM & SCHNIER 1981). A large gypsum cavern was found in the caprock „Lesum" (diameter >50m). This large druse was formed by recristallisation of gypsum as Marienglas in pre-oligocene time by down-streaming groundwater (Fig. 4; ORTLAM 1989, ORTLAM & SAUER 1995b). The Neuengammer Gassand (tolm) is filled up with fossil saltwater now in contact with the channel of „Lesum" (Fig. 4; ORTLAM 1989, ORTLAM & SAUER 1995a).

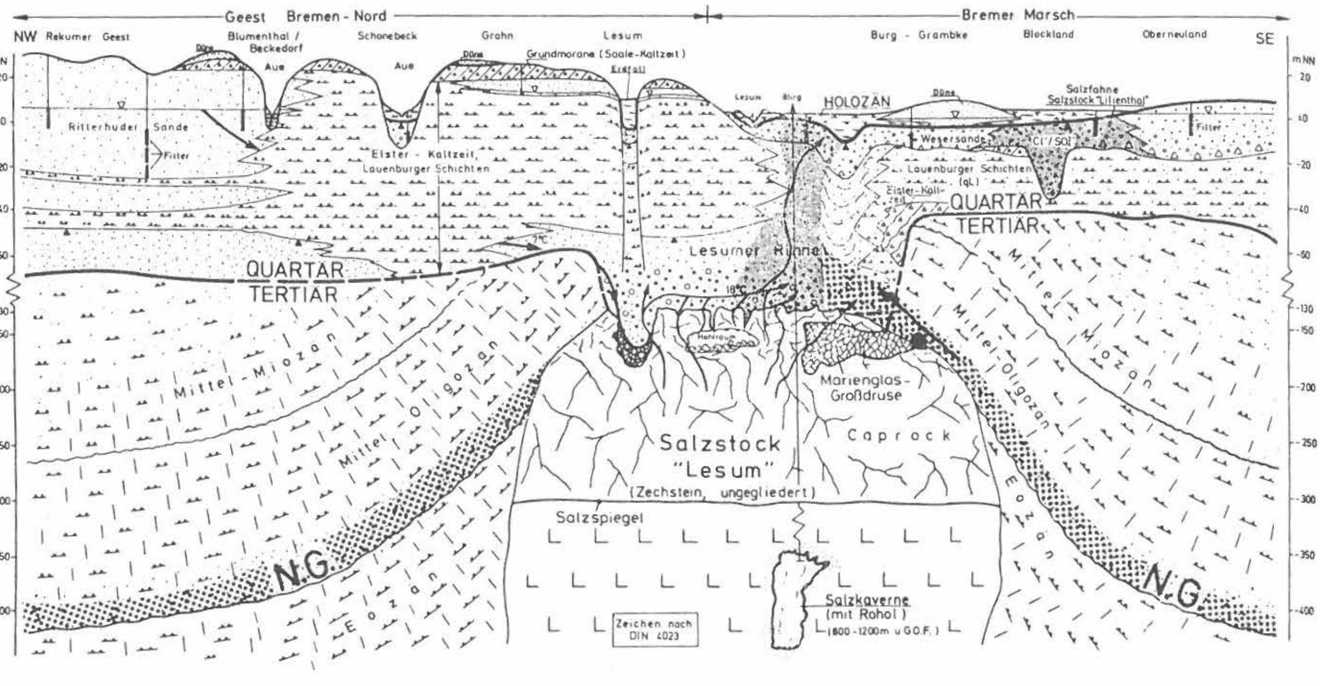

Fig. 4: Half-schematical hydrogeological section through the town of Bremen (modified after ORTLAM 1989) with the position of the druse of Marienglas (●); N.G.=Neuengammer Gassand (Oligocene, tolm).

The mineralized deep groundwater has hydraulic contact with the upper aquifer by a „window-situation" of the step-formed sandy facies in the Lauenburger Schichten (Fig. 3 and 4; ORTLAM 1989). The freshwater depression of the Bremen basin drives the high mineralized saltwater like a motor to swell up into the upper aquifer (DRABBE-GHIJBEN-HERZBERG-effect = DGH-effect after ORTLAM 1989, ORTLAM & SAUER 1993; named by DRABBE & GHIJBEN 1889, HERZBERG 1901). The border line between fresh- and saltwater is in slope function of the movement of the groundwater level in the upper aquifer (Fig. 5).

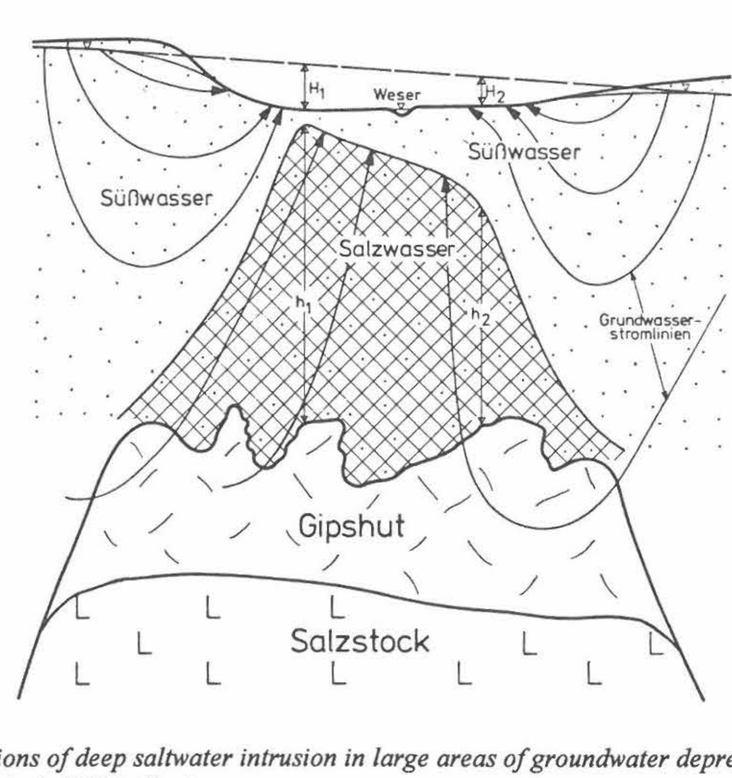

Fig. 5: The conditions of deep saltwater intrusion in large areas of groundwater depression in the Bremen basin (=DGH-effect).

During the „Geochemische Grundwasser-Kartierung Bremen" (ORTLAM & SAUER 1993, 1995b, 1995c) we took the groundwater in a homogeneous depth of approximately 7m below the surface. On account of the DGH-effect we found areas with freshwater nearby areas with saltwater in slope function of the different freshwater-charge. The upstreaming zones coming from the salinars are narrow. Therefore we call them „mineral-spots" or „salt-spots" (Fig. 6; ORTLAM & SAUER 1993, 1995b). If the freshwater-charge is very low (<1m) the deep saltwater is swelling up to the surface. For that reason we find high mineralized ditch water and plants of halophytes in several regions of the Bremen basin (Fig. 2; ORTLAM 1982, 1984, 1989).

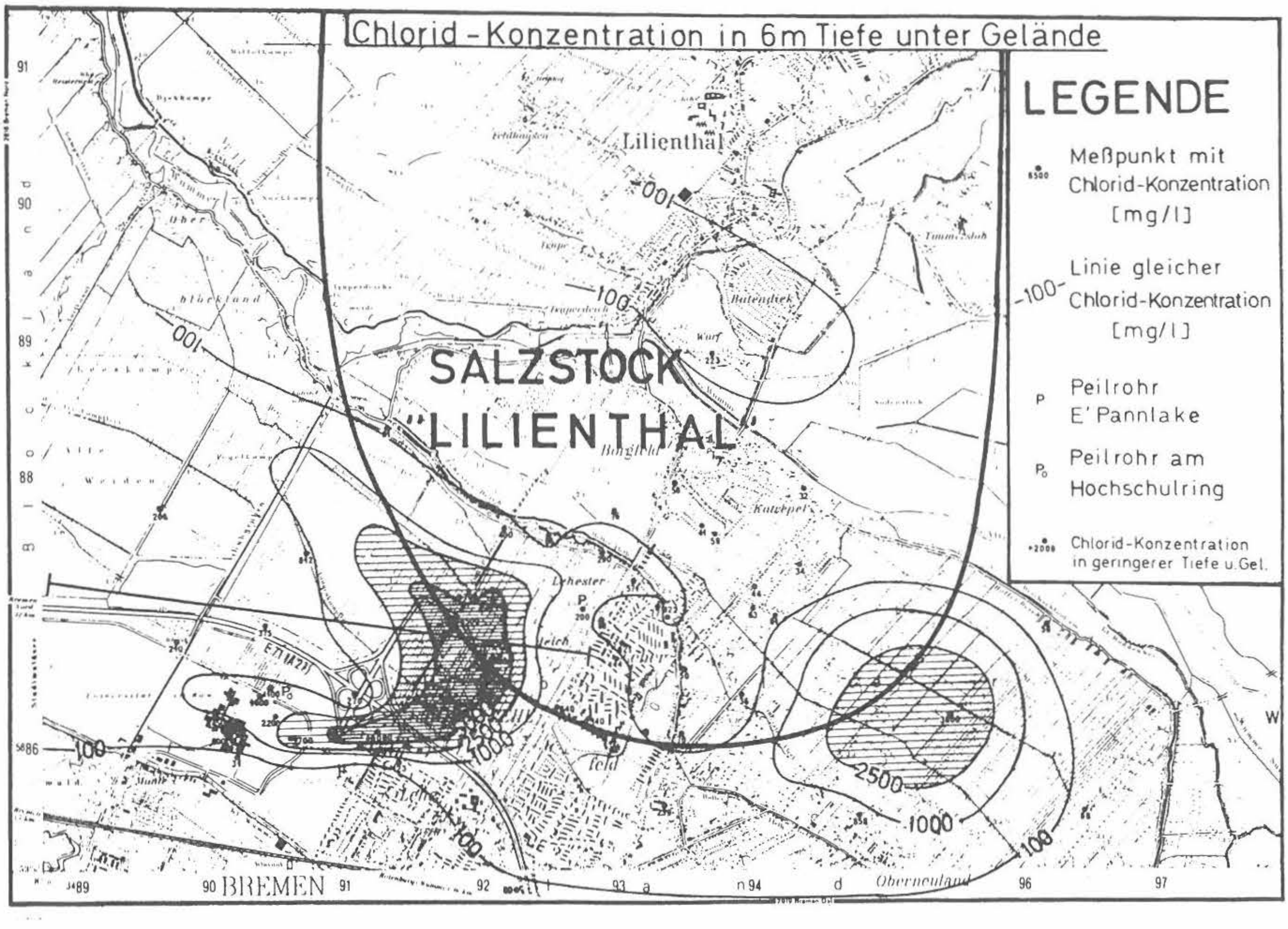

Fig. 6: Concentration of chlorides in the higher part of the upper aquifer (=Wesersande) in the Hollerland of Bremen and the position of the hydrogeological section (Fig. 3).

In the Pannlake area of Bremen-Hollerland an experiment was started in the year 1982 to investigate the fresh-/saltwater-zone and its variability (Fig.6; ORTLAM 1982, 1984). Therefore the depth gauge P was total filtered (Fig. 7a). Between march and october 1982 we measured in a depth between 1m to 18m under surface freshwater with a conductivity of less than 500 µS/cm. Below of 18m the conductivity jumped up very quick about 2000 µS/cm. The fresh-/saltwater-zone is situated in 18m and consists of a very narrow border line about 10 cm. During the year 1982 the border line between fresh- and saltwater variated in slope function of the movement of the groundwater level (Fig. 7b) on account of the several rainfalls: the border line between fresh- and saltwater moved reverse proportionally to the groundwater level. The quotient of the dive equilibrium (after ARCHIMEDES) of fresh-/saltwater amounts at this locality 1:15 (ORTLAM 1982) in comparism to the quotient of the North Sea 1:37.

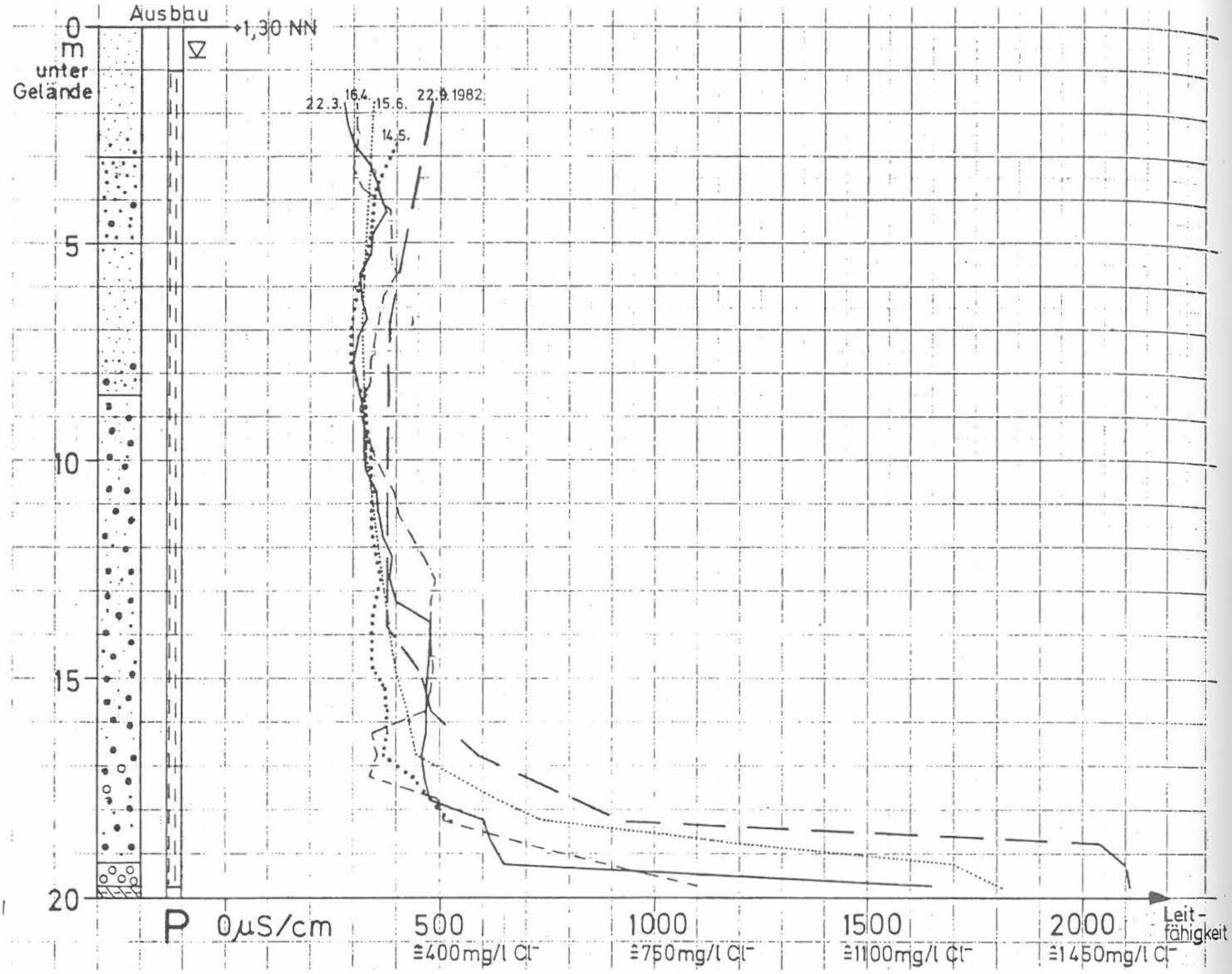

Fig. 7a: Variations of the border line between fresh- and saltwater in the depth gauge P (position see Fig. 6) under meteorological influences during the year 1982, Bremen-Hollerland.

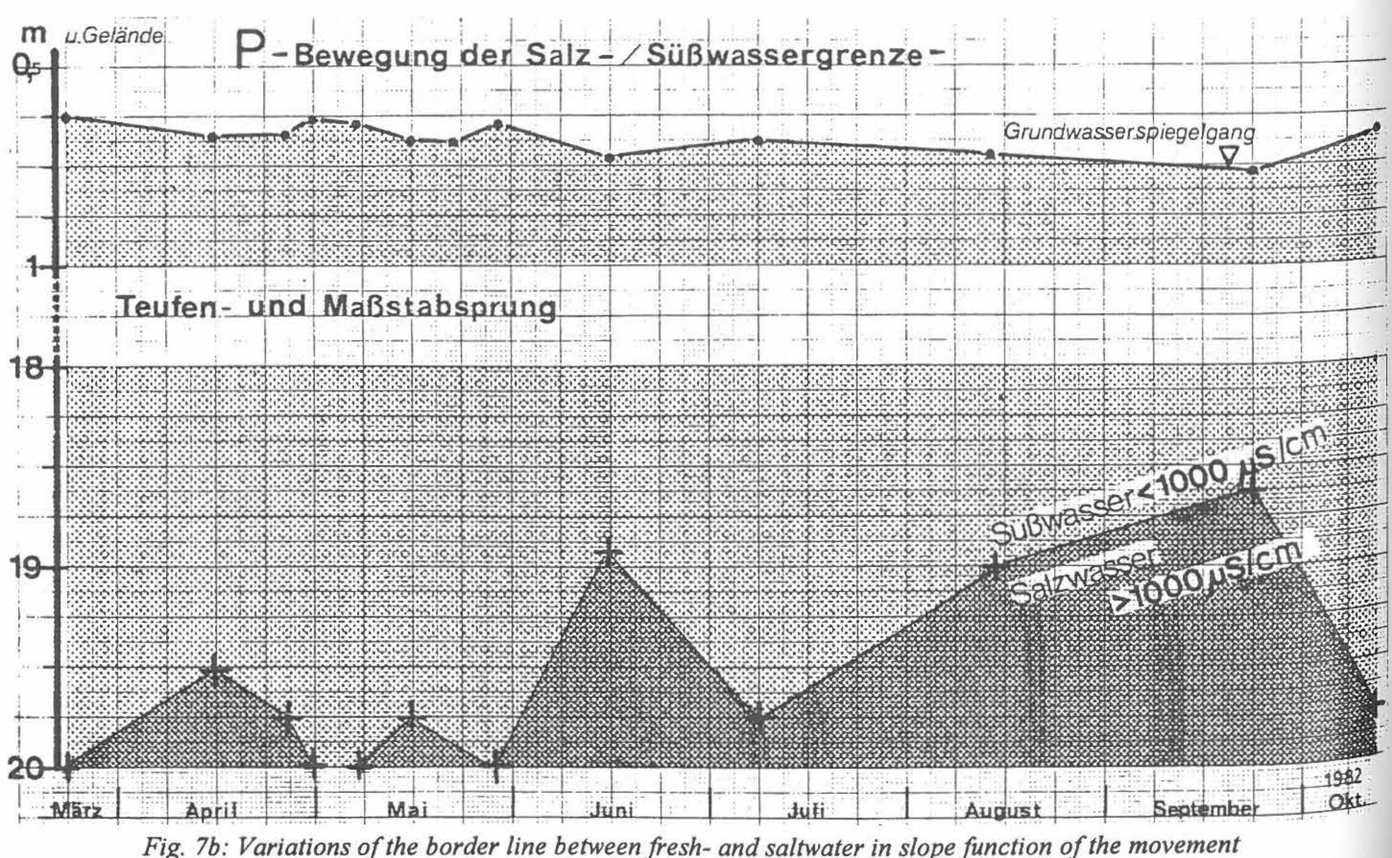

Fig. 7b: Variations of the border line between fresh- and saltwater in slope function of the movement of the groundwater level (=charge of freshwater) during the year 1982, Bremen-Hollerland.

At another depth gauge P_0 the conductivity of groundwater started on 6m under surface with 700 µS/cm and jumped up to high conductivities nearby 2500 µS/cm (first border line) in 7m under surface and increased to 3500 µS/cm in 18m under surface (Fig. 8; ORTLAM 1982). By pumping of groundwater (19.2. - 5.3.1982) nearby (2m) the depth gauge P_0 a second border line with different concentrations of saltwater raised up from an unknown depth to 10m under surface. After this artificial conditions of the freshwater-charge by lowering and raising the groundwater level the second border line felt down during two month (march/april 1982) at a depth of > 16m under surface (=end of the depth gauge; Fig. 8). The quotient of the dive equilibrium of fresh-/saltwater amounts at this locality 1:12 (ORTLAM 1982).

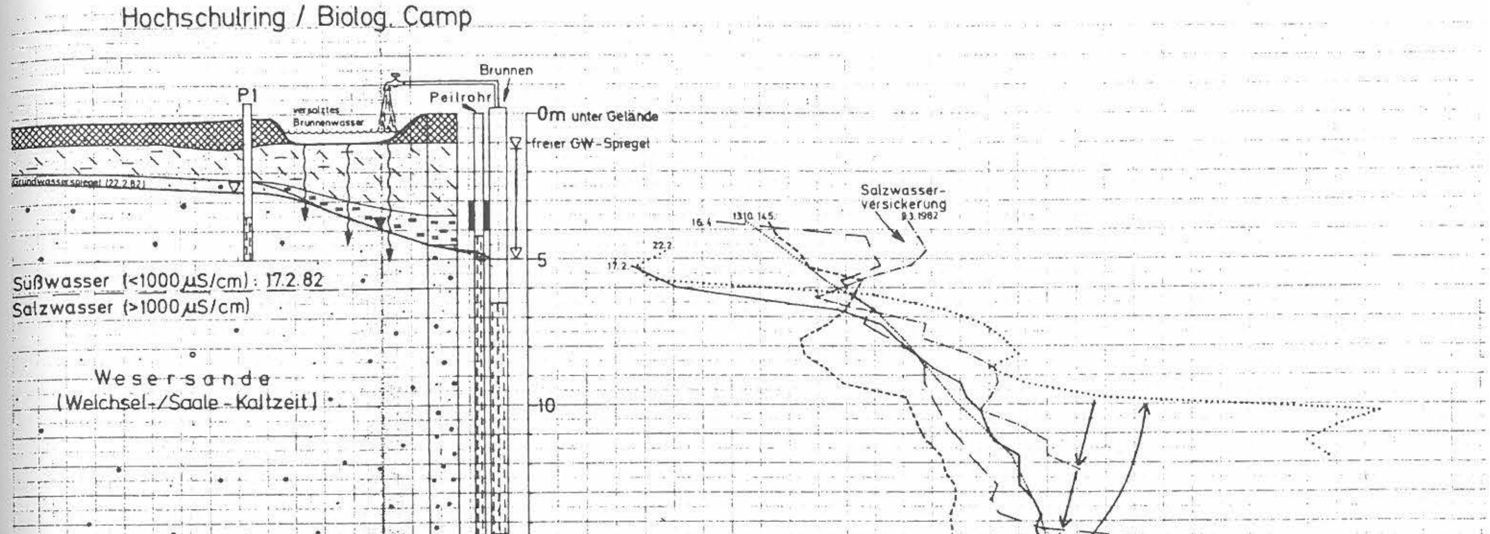

Fig. 8: Variations of the border line between fresh- and saltwater in the depth gauge P_0 (position see Fig. 6) under artificial conditions (=lowering of the groundwater level by pumping) during the year 1982, Bremen-University.

On account of the DGH-effect the saltwater was pumped up nearby in a polder with natural underground (sandy loam and peat). This saltwater infiltrated into the upper aquifer during 15 days the holocene layers (3,5m thick). Therefore one is able to measure a permeability of the local underground layers $K_f=3x10^{-6}$ m/s by pollution tracer.

2. Salinization by infiltration of the water of the river Weser

Between the groundwater of the upper aquifer and the surface water of the river Weser exists a hydraulic contact. The saltwater of the river Weser infiltrates the upper aquifer around the locked ports in Bremen and above the barrage of Bremen-Hemelingen (see the paper ORTLAM in this book).

3. Salinization by waste deposits

We can observe several contaminations of the groundwater by waste deposits in the geest and in the marsh of Bremen. If we have a low geogene background of the groundwater-chemistry we can recognize the contaminations by regional untypical concentrations of one or more groundwater-parameters in the downstreaming areas of waste deposits (ORTLAM & SAUER 1993, 1995b, 1995c). For example in Fig. 9 we see an anomaly of magnesium in the upper aquifer which is situated nearby a waste deposit of pit-coal ashes in Bremen-Rekum.

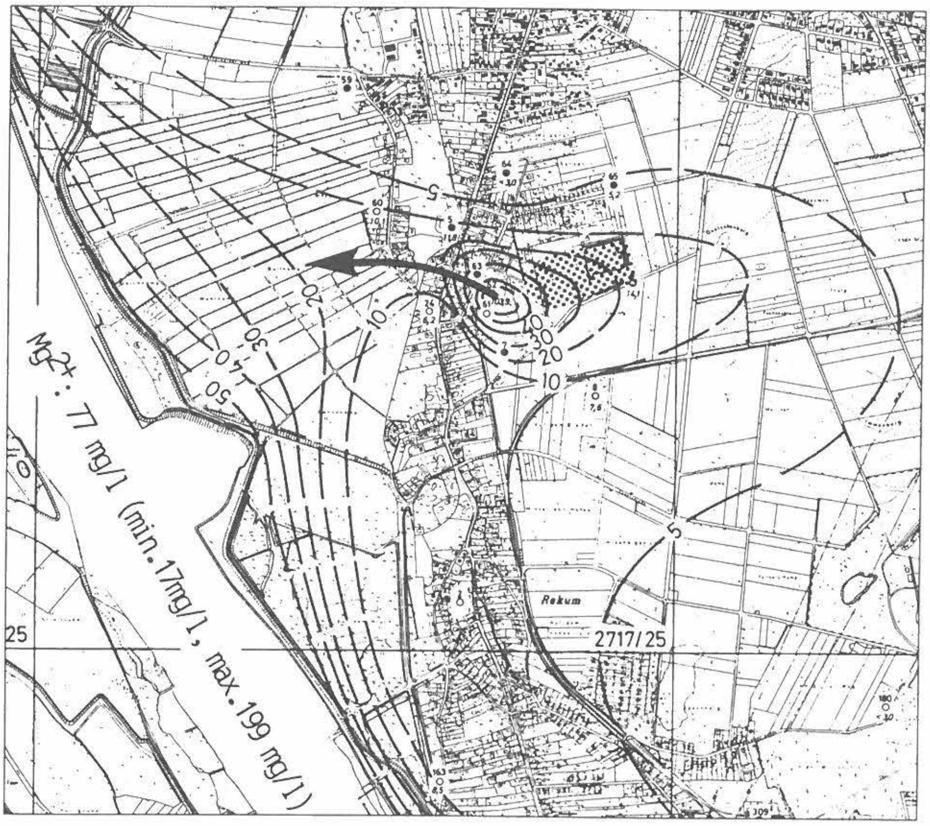

Fig. 9: Anomaly of magnesium in the upper aquifer on account of a waste deposit of pit-coal ashes (screen), Bremen-Rekum.

4. Salinization by the leakage of the sewage system

In parts of the city of Bremen we observe high nitrate-concentrations in the groundwater of the upper aquifer as result of the (war) damage and leakage of the sewage system (KLENKE & ORTLAM 1988). Only along the large dune of Bremen the seawage system is situated above the groundwater level. Therefore the nitrification processes need many oxigene in the percolation zone and many iron in pyrite/markasite around the grains of the upper aquifer. On account of this chemical and bacteriological processes many anomalies of sulphates, iron, protons and nitrates were produced (Fig. 10; KLENKE & ORTLAM 1988, ORTLAM 1989, ORTLAM & SAUER 1993, 1995b).

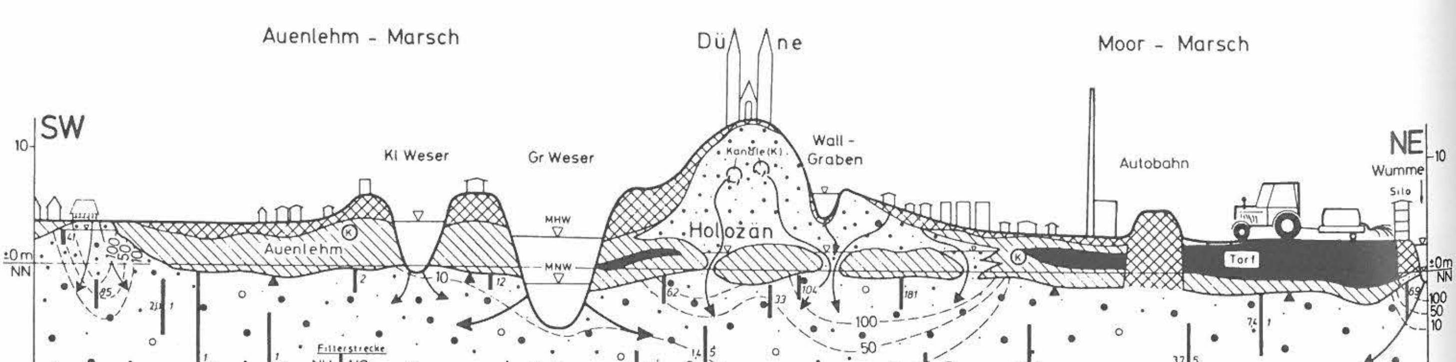

Fig. 10: Schematical hydrogeological section through the center of Bremen showing the input of nitrogene into the upper aquifer: fertilizing and leakage of the sewage system.

5. Intrusion of Seawater

At the coast of the southern North Sea in Bremerhaven we observe different intrusion zones of seawater in the upper aquifer on account of the different hydraulic pressure coming from the higher freshwater level in the geest areas (Fig. 1). The border line of fresh- and seawater is variable during the hydrological year about a distance of > 100m. On account of the higher specific weight of the saltwater and the different permeability in the upper aquifer the border line dips under the freshwater and toothes with the freshwater. At some localities the geest areas have contact with the coastline. Therefore one is able to observe some freshwater springs at the southern coast of the North Sea (p.e. Bremerhaven, Cuxhaven, Esens).

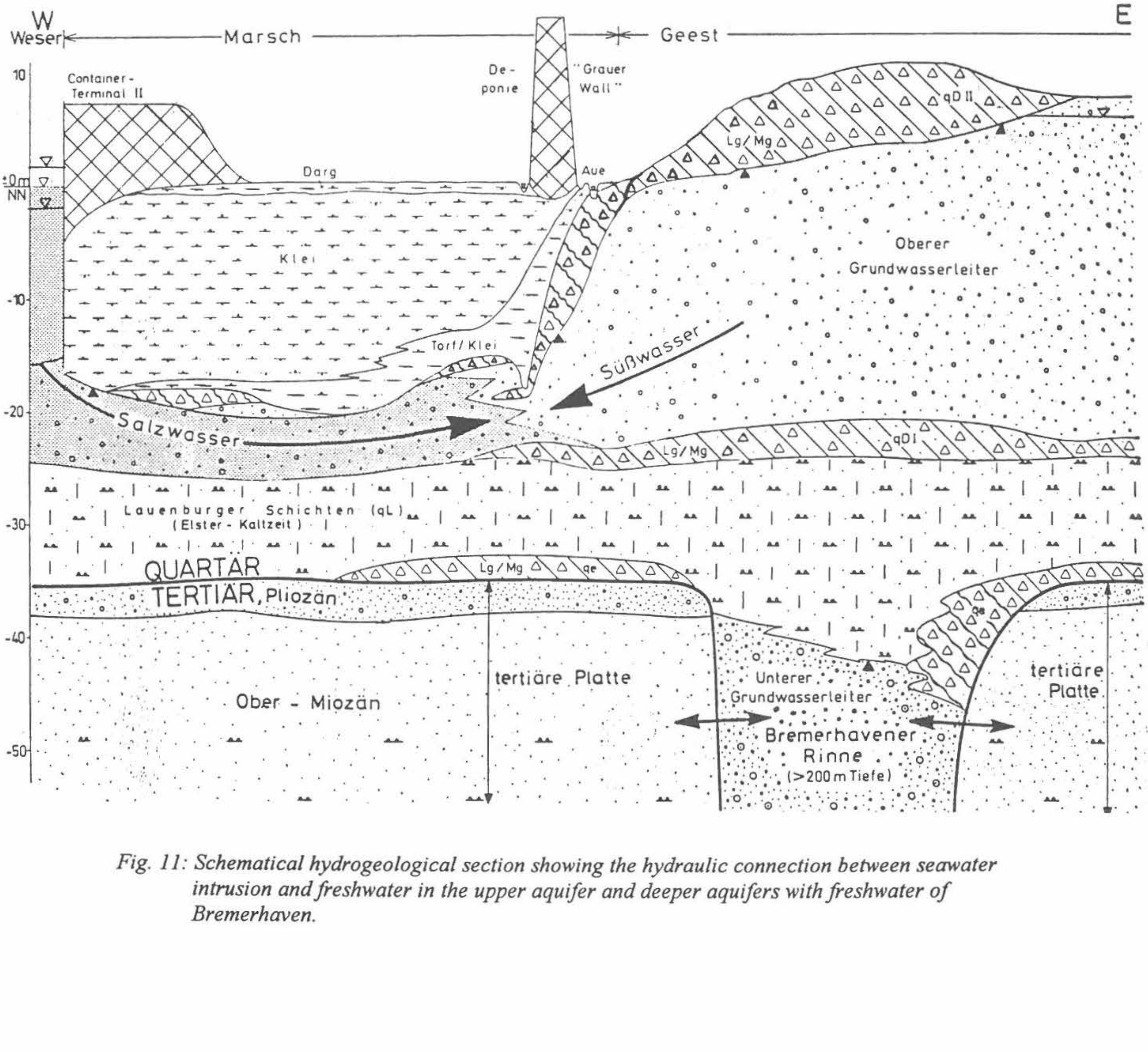

Fig. 11: Schematical hydrogeological section showing the hydraulic connection between seawater intrusion and freshwater in the upper aquifer and deeper aquifers with freshwater of Bremerhaven.

REFERENCES

DRABBE, J. & GHIJBEN, W.B. (1889): Nota in Verband met de voorgenomen putboring nabij Amsterdam. - Kon. Inst. Ing. Tijd-schr., **1888/89**: 8-22, 11 Abb.; Amsterdam.

HERZBERG, A. (1901): Die Wasserversorgung einiger Nordseebäder. - Gasbeleuchtung u. Wasserversorg., **44**: 815-819 u. 842-844, 1 Abb.; München.

KLENKE, Th. & ORTLAM, D. (1988): Beobachtungen zur Nitratverteilung im oberen Grundwasserleiter der Stadt Bremen. - Z. dt. geol. Ges., **139**: 485-492, 3 Abb., 1 Tab.; Hannover.

ORTLAM, D. (1982): Durchführung hydrogeologisch-hydrochemischer Untersuchungen für den Bereich Horn-Lehe-West (Bremen). - In: Senator für das Bauwesen (Bremen), Landschaftsökologische Untersuchungen im Bereich Horn-LeheWest, 10 S., 12 Abb.; Bremen.

ORTLAM, D. (1983a): Einsatz und Möglichkeiten von Pollution-Tracer-Verfahren am Beispiel der Weser. - N. Jb. Geol. Paläont. Abh., **165** (2): 303-325, 12 Abb.; Stuttgart.

ORTLAM, D. (1983b): Neue Ergebnisse zur Baugrundkarte Bremen. - Ber. 4. Nat. Tag. Ing.-Geol.: 273-280, 7 Abb.; Goslar.

ORTLAM, D. (1984): Die geohydrologischen Verhältnisse im Hollerland (Bremen). - Abh. Naturw. Verein Bremen, **40**: 155-164, 7 Abb.; Bremen.

ORTLAM, D. (1989): Geologie, Schwermetalle und Salzwasserfronten im Untergrund von Bremen und ihre Auswirkungen. - N. Jb. Geol. Paläont. Mh., **1989** (8):489-512, 11 Abb., 3 Tab.; Stuttgart.

ORTLAM, D. & SAUER, M. (1993): Geochemische Grundwasser-Kartierung Bremen. Darstellung der Grundwasserbeschaffenheit und deren Beeinflussung durch Altlasten in der Stadtgemeinde Bremen. - Atlas mit Erläuterungen. - 28 S., 9 Abb., 60 Kt., 1 Anl.; Hrsg.: Bremer Entsorgungsbetriebe; Bremen (Druckhaus Lehe-Nord).

ORTLAM, D. & SAUER, M. (1995a): Das „Rollende Peilrohr“ - ein neues umweltschonendes, schnelles und kostengünstiges Grundwasserentnahmeverfahren zur Untersuchung von Altlasten in Lockergesteinen. - Jber. Mitt. oberrhein. geol. Ver., N.F. **77**: 287-305, 11 Abb.; Stuttgart.

ORTLAM, D. & SAUER, M. (1995b): Das Grundwasser in Bremen - seine geogene Prägung und seine Beeinflussung durch Altlasten. - N. Jb. Geol. Paläont. Mh., **1995**, H. 6: 336-354, 9 Abb., 1 Tab.; Stuttgart (Schweizerbart).

ORTLAM, D. & SAUER, M. (1995c): Rollendes Peilrohr und geochemische Grundwasser-Kartierung in Bremen. - gwf-Wasser/Abfall, **09/1995**: 478-481, 6 Abb.; München (Oldenbourg).

ORTLAM, D. & SCHNIER, H. (1980): Erläuterungen zur Baugrundkarte Bremen. - 41 S., 12 Abb., 3 Tab.; Bremen (Schmalfeld).

ORTLAM, D. & SCHNIER, H. (1981): Erdfälle und Salzwasseraufstieg in Bremen - Typbeispiel für Süßwasserdepressionsgebiete. - N. Jb. Geol. Paläont. Mh., **1981** (4): 236-256, 9 Abb.; Stuttgart.

ORTLAM, D., SCHNIER, H., SEYLER, E. & WEMPE, H. (1981): Baugrundkarte Bremen, Teile A-D (1:10000 und 1:25000). - Bremen.