SOLUTION MINING RESEARCH INSTITUTE

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MEETING PAPER

Solution Mining Technique
in the Brinefields of Schweizerhalle
and Riburg of the Vereinigte
Schweizerische Rheinsalinen (United
Rhine Salines of Switzerland)

authored by

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1. Introduction

In the region of Basel near the 3-Country-Corner, Switzerland, France and Germany salt has been extracted by leaching since 1837 (Fig. 1).

After 16 unsuccessful drillings the German saline expert, Carl Christian Friedrich Glenck, discovered the salt bed in the Rhine valley to the east of Basel in the year 1836.

One year later the Schweizerhalle Saline commenced salt production. By 1848 3 further production sites were opened; 2 highly modern equipped salines are still in operation today, namely

- Schweizerhalle saline, approx. 7 km to the east of Basel; and

- Riburg saline, approx. 20 km to the east of Basel.

Salt deposits in Switzerland are the property of the Cantons (States). In order to mine the salt deposit a concession from the respective Canton is required. Salt is practically the only mineral mined in considerable quantities in Switzerland. For this reason there are no Mining Authorities in Switzerland to supervise or regiment the mining or leaching operation. The operator himself has an unlimited liability for all possible mining damages and is fully liable for any compensation.

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2. Geologie

The salt deposits of Schweizerhalle and Riburg belong to the middle Muschelkalk of the Middle Triassic age. They are therefore 210 million years old and form part of a horizontal sediment sequence dipping slightly to the south between the crystalline massive of the Black Forest and the Jurassic plateau (Tafeljura).

The centre of the Muschelkalk sea was located in Northern Germany. Flat sea basins extended over Central Germany (salt deposits of Heilbronn) as far as Switzerland. The salt deposits of Lothringen in the East of France are from the same sea basin (Fig. 2).

Although both salt deposits originate from the same period they still have individual differences caused by their genesis and tectonics (Fig. 3) which can be traced back to the depression of the Upper Rhine fault between the Black Forest and the Vosges. The salt deposits are located near the south end of the Upper Rhine fault (Oberrheingraben). They are therefore interstratified by a large number of faults and disturbances, which impede the design and operation of the cavern fields.

The stratigraphic bedding sequence is as follows (in Rhine valley):

Gravel	0	-	30	m
Trigonodus dolomite	15	-	25	m
Main Muschelkalk	40	-	60	m
Dolomite	10	-	15	m

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Anhydrite	30 - 50 m
Salt	0 - 90 m
Anhydrite	5 m
Wellengebirge	40 - 50 m

In the area of the Jurassic plateau of Schweizerhalle, above the Rhine valley, the Trigonodus dolomite is overlain by 100 - 200 m thick Keuper layer.

Schweizerhalle

The salt bed extends from the edge of the Rhine valley fault, approx. 10 km in an easterly direction. The northern boundary is just to the North of the Rhine. The extent in a southerly direction is not known.

The salt bed has a thickness of up to 65 m and is located in the Rhine valley at a depth of 150 m in the Zinggibrunn and Sulz-Eigental cavern fields due to the Keuper cover layer of 250 - 350 m.

From the viewpoint of chemical composition the salt is pure rocksalt (halite) without traces of potash or other salts. The salt bed is, however, markedly interstratified by clay-marl and anhydrite in the form of crystal inclusions, larger fragments, blocks or layers. Sections without impurifications are rare.

Riburg

The salt bed has the form of a lentil and extends from Rheinfelden 7 km in an easterly direction and about

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4 km in a North-South direction. The salt layer has a thickness of up to 90 m and is located at a depth of 140 m.

The salt reservoir is subdivided by a 4 - 8 m thick anhydrite layer into an upper and lower salt bed.

At the base there are a few metres of very pure, clear rocksalt. The remainder is similar in character to that found in Schweizerhalle.

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3. Leaching of both fields from 1837 to date

Since the beginning of salt production in the year 1837 salt has been extracted by leaching. Rocksalt was never excavated by conventional mining. Until a short time ago the wells were drilled in the immediate vicinity of the salines. In Schweizerhalle the brine production was transferred in 1970 from the Rhine valley approx. 2.5 km to the South into the Jurassic plateau and the Zinggibrunn cavern field put into operation. In Riburg the new production field Sulz-Eigental approx. 2.5 km south of the old cavern field will come into operation this year.

In Schweizerhalle just under 6 million tons of salt have been produced by 52 wells from 1837 to date. Currently 20 brine wells are in operation for a yearly salt production of about 200 000 tons.

Since the beginning of production in the year 1847 in Riburg approx. 4.5 million tons of salt have been produced from 36 wells. Today's production lies at approx. 200 000 tons per year with 12 brine wells in operation.

There have been several modifications to the leaching technique in the course of time (Fig. 4). The first wells were located in the region of the Rhine valley groundwater flow. The casings, run as far as the salt roof, were perforated at the groundwater flow level.

This made it possible for the water to have free access to the salt bed. The saturated brine was pumped

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through the inner casing by a piston pump into the air separator tank on the leaching tower (Fig. 5). From there the brine flowed by gravity through pipelines for processing in the saline. Around the turn of the century the piston pumps were replaced by mammoth pumps (airlift pumps), at a later stage by submersible electro-pumps.

Nowadays the wells cased with an 8 5/8" string are sealed by cementation bond to protect against groundwater. The 4 1/2" production tubings extend as far as the base of the salt bed. The water is injected through the annulus under pressure causing the brine to flow back to the surface via the inner casing.

In the case of a large salt thickness (Riburg) the caverns are operated as single wells. Where the salt thickness is smaller (Schweizerhalle) leaching is carried out in cavern groups in a kind of "gallery". One group covers 2 - 4 wells with a spacing of 50 - 80 m. The individual wells in the group are leached in series with the result that despite the relatively high leaching rate in the rearmost well a totally saturated brine is produced. The well sequence is changed on a monthly basis.

After 1 - 3 years the brine caverns coalesce. From this time onwards the leaching operation is changedover as follows:

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Alternately freshwater is injected through the one borehole and brine withdrawn through the other. If the borehole group starts leaking in the course of time due to a roof collapse, then a changeover to "leaching without freshwater intake" is made. In this case, a submersible electro-pump is installed in every borehole and the brine thus pumped out of the cavern. The water inrush due to the cavern leakage is normally large enough to maintain the leaching operation. If not, the 8 5/8" casings are perforated on the level of the presumed groundwater level, so that the groundwater can flow into the cavern via the casings. In this way the Vereinigte Schweizerische Rheinsalinen have constantly succeeded in repeatedly "saving" a well or group of wells which have become untight during the course of operation.

For environmental protection reasons and for better agricultural utilization all installations (wellhead, pump station) are normally arranged underground (see Figs. 6 and 7).

Service-work on the borehole will be undertaken using a truck-mounted workover rig.

The cavern fields are monitored by annual subsidence measurements. The first subsidence measurements were carried out in Schweizerhalle already in 1896.

Echometric cavern sonar surveys have been performed periodically on individual selected caverns for 15 years now by Prakla.

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To ensure the brine supply Rheinsalinen are obliged to explore new cavern fields in the immediate future both in Schweizerhalle as well as in Riburg.

Rheinsalinen have ordered KBB(KAVERNEN BAU- UND BETRIEBS-GMBH), Hannover with a study to develop an optimal leaching technique for both new production fields bearing in mind the specific geographic, topographic, geologic and stratigraphic peculiarities. This study covers the partial sections

rock mechanics,
drilling,
leaching.

The following factors had to be taken into consideration with regard to the new cavern fields:

Riburg

- Narrow strips of land 600 - 700 m wide, located between two highly frequented traffic routes, the Motorway N3 Basel - Zürich and the Canton road No. 3 Basel - Zürich. Neither of these routes must be jeopardized by surface subsidence or collapse.

- Large salt thickness (to 90 m) with a relatively small rock cover (approx. 120 m).

- Greatly weakened overburden due to fractures, faults in the dolomite and Muschelkalk and extensive karstification.

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Schweizerhalle

- topographically difficult, hilly terrain.

- environmental protection zone in local recreation area of the city of Basel:

  -- as small as possible a damage of the environment due to terrain trenches for cavern pads, roads etc.

  -- as small a number of cavern pads as possible, with topographically favourable locations.

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4. Rock mechanical cavern design

The aim of the rock mechanical calculations carried out with the help of a simulation model using the Finite Element Method was to develop a hexagonal cavern grid for stable cylindrical caverns with a maximum diameter and minimum spacing for optimal salt recovery. Over- and underburden of the salt deposit were to be corporated as supporting layers.

Cores extracted form all layers of representative wells in both fields were uniaxially and triaxially tested in the laboratory to determine their strength and the results incorporated into the calculations.

The theoretical simulation model was based on a simplified geological profile (Fig. 8). Here differences were made between

- overburden
- upper sulfate zone
- salt bed
- Wellengebirge

Simulation produced the following admissible dimensions:

		Schweizerhalle	Riburg
Cavern diameter		70 - 75 m	65 m
Cavern height		30 m	50 m
Well spacing		112.5 m	112.5 m
Pillar thickness		37.5 - 42.5 m	47.5 m
Volume	approx.	115 - 130 000 m^3	165 000 m^3

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No further simulation was performed for the alternative of developing the cavern fields in galleries. Under the simplified assumption that the salt recovery remains the same when compared to the single cavern grid, more wells are required with the gallery variant.

Assuming that there is a uniform radial cavern development from the well, the cavern already reaches the limit of the rock mechanically required minimum pillar thickness prior to coalescing with the neighbouring cavern. The well spacing must therefore be reduced in order to achieve an earlier coalescing during leaching.

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5. Drilling problems

The drilling design had to take into consideration the fact that the caverns had to be leached with a blanket medium in order to prevent a fracture of the overburden layers during leaching, possibly connected with surface damages. For this reason there must be a tight bond of the last cemented casing and this is very difficult to achieve in the highly cavernous overburden layers. Thus a cement bond of only approx. 40 m was achieved with the 3 first wells because the cement above flowed into the rock formation. Above the loss zone cementation of the annulus was carried out with the help of a basket. Tightness tests were successful.

In order to obtain a mud circulation with salt-saturated mud during coring and enlarging of the well in the salt bed, a retractable intermediate casing had to be set.

In general it must be said that despite the shallow depth there are difficult drilling problems to be solved in order to obtain a tight cavern well with an end casing diameter of 8 5/8" in Schweizerhalle and 9 5/8" in Riburg.

6. Leaching technique

The aim of the leaching design was

- to produce saturated brine at the highest possible rate and lowest cost

- to achieve a maximum salt recovery per well, i.e. to totally leach the rock-mechanically specified form

The prerequisite for such a definite leaching was the use of a blanket medium; after due consideration of the various possiblities air was selected as medium. The decisive reason for this was that:

- air does not pollute the groundwater in the event of a possible leakage,

- when air is used no contamination of the salt can occur

- no special explosion proofing measures are necessary with air

The disadvantages of a possibly increased degree of corrosion are to be disregarded, as the casings are anyway overdimensioned with this shallow depth and the leaching rate of 45 m^3/h limits the cavern life to a period of 2 - 3 years, especially as no further use of the cavern as storage facility is intended.

The following alternatives for air-blanket injection were investigated:

- Injection into blanket annulus
- Injection continuously into the freshwater flow

and for a speedy first fill with blanket medium at the start of leaching and after echometric sonar surveys a direct injection into the annulus was decided upon. During leaching, however, as shown in Fig. 9, small quantities of air, to be ascertained in leaching practice, are injected into the freshwater flow after boosting. This method has the advantages that

- the air pressure need only be increased to the freshwater pressure (approx. 8 - 10 bar as opposed to 24 bar),

- the air dissolves partly in the freshwater, rises within the cavern upon release from the brine and also covers areas which are not reached by annulus injection.

Blanket level monitoring is initially via Ermeto-pipes (Fig. 10), fixed externally to the protection string at 20 cm intervals and later by means of calculation using the differential pressure method. The blanket interface can be precisely determined using Ermeto-pipes and the differential pressure method calibrated for determination of the blanket depth.

Pressure determination is recorded by a sensitive pressure gauge.

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In order to be able to produce saturated brine at a relatively early stage, even if at a smaller rate, the indirect method is employed already at the start of leaching.

The following is intended as leaching concept (Fig. 11)

- leaching of a sump cavern to a diameter of about 50 m with a sump cavern height of approx. 10 m,

- raising of the blanket interface in stages within the main phase up to the stope,

- leaching of this stope possibly in the final phase without using a blanket medium.

The sump cavern serves to accommodate the solids, which are released from the salt structure in the main phase resp. occur by stoping-in the insoluble clay and anhydrite intermediate layers. During the sump phase the leaching rate can be slowly increased.

In the main phase the leaching rate can be increased further, up to maximum, due to the availability of a larger dissolution surface.

In the final phase the stope can be totally leached. No blanket medium is used. It must however be assumed that the overlying layer thereby becomes fractured and possibly surface subsidence occurs. For this reason the leaching of this final phase is only intended in Schweizerhalle, whereas in Riburg the stope is kept in tact due to the proximity

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of the motorway and the Canton road. As can be seen from Fig. 8 the salt deposit in Riburg is divided into two sections by an anhydrite layer. For reasons of stability the total leaching of this upper section is not planned.

A cavern gallery leaching concept is shown in Fig. 12. The only difference between this concept and that of the single cavern is that after coalescing of the caverns at the end of the sump phase the wells are alternately used for fresh-water injection resp. brine withdrawal.

A final decision as regards a single cavern or a gallery concept is only possible after further rock mechanical calculations have been undertaken.

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7. Pilot leaching project Riburg

To verify the proposed leaching concept a pilot project has been running in Riburg since the beginning of September 1982, which is intended to develop the individual stages of the leaching concept to production stage.

Fig. 13 shows the flow diagram for the three pilot caverns. As no saturated brine occurs in the sump leaching phase, the brine must be subsequently saturated in an already existent cavern. This is a method generally practised in brine production.

To verify the most favourable air-blanket-injection a possibility was created to inject air at various points and measure air volumes. In this start-up phase the calculation of blanket interface depth by differential pressure method is to be examined with regard to its application.

The three pilot caverns are currently in the sump leaching phase, as planned. No problems of any greater significance have arisen as yet.

8. Fracing between two wells

As already mentioned, the brine production field Schweizerhalle is found in an environmentally protected zone in the local recreational area of the City of Basel. Apart from this it is a district of topographically difficult, hilly terrain and therefore can only be developed with a very great outlay as far as roads and sites are concerned. Ideas of reducing the number of wells without giving up salt reserves very soon led to the connection of greater spaced wells by means of fracing and the developing of a gallery along the frac.

Although it is true that a great deal of practical experience has been obtained worldwide on the problem of salt fracing - in particular from the stratified salt in the USA - it is not necessarily possible to apply this to the conditions in Schweizerhalle. For this reason a pilot frac should first be made between two wells with a spacing of about 150 m, in order to acquire experience necessary for the development of the entire field. In particular VSR hope to be able to increase the spacing between the wells even further. Fig. 15 shows the underground borehole equipment. After examining various frac methods it was decided to undertake the frac below a rock packer at the base of the salt.

After a successful hydraulic link has been made between the two wells, a uniform leaching should be achieved between the wells by means of the injection of air as blanket medium (Fig. 15). In this way areas which are totally leached more quickly are covered by the air and the leaching thereby interrupted. After other areas have been subsequently leached, the blanket is released again and accumulates in the roof zone of both wells from where it can be discharged.

This project is in the planning stage. Drilling, fracing and start of leaching is scheduled for 1983.

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9. Summary

The object of this paper was to show that even for the development of relatively small brine production fields at a shallow depth detailed consideration of rock mechanical as well as drilling and leaching engineering factors are imperatively necessary.

After giving an outline of the geological situation of the salt deposits in Switzerland a description was given as to the method of brine production since 1837.

The changeover of leaching method to a process using air as blanket to develop rock mechanically stable caverns was described.

A pilot operation for single caverns has been successfully started up. A pilot frac between two wells is planned for 1983.

FIGURES

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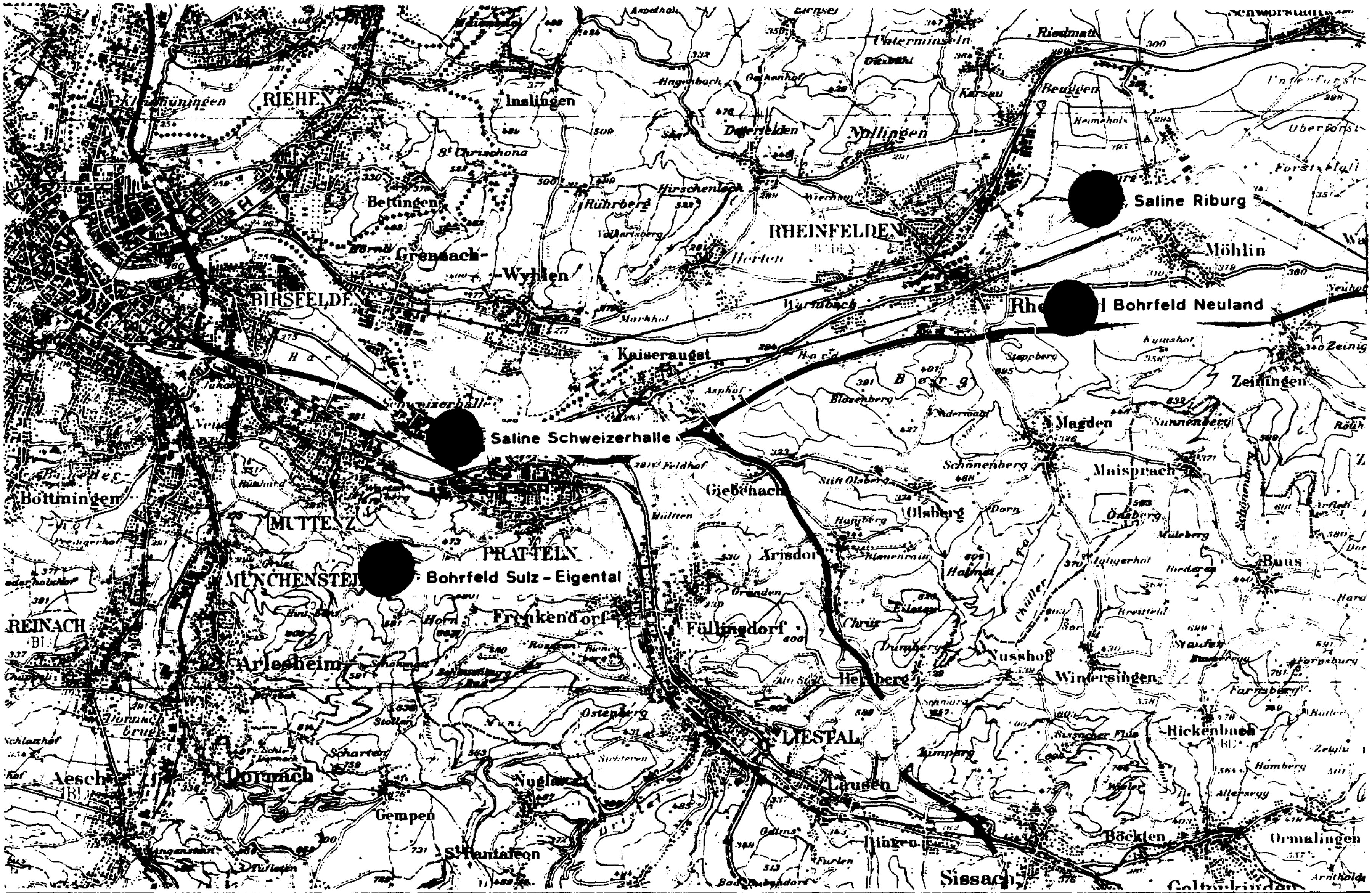

VSR / KBB	AREA MAP OF THE TWO SITES SCHWEIZERHALLE AND RIBURG	Fig. 1

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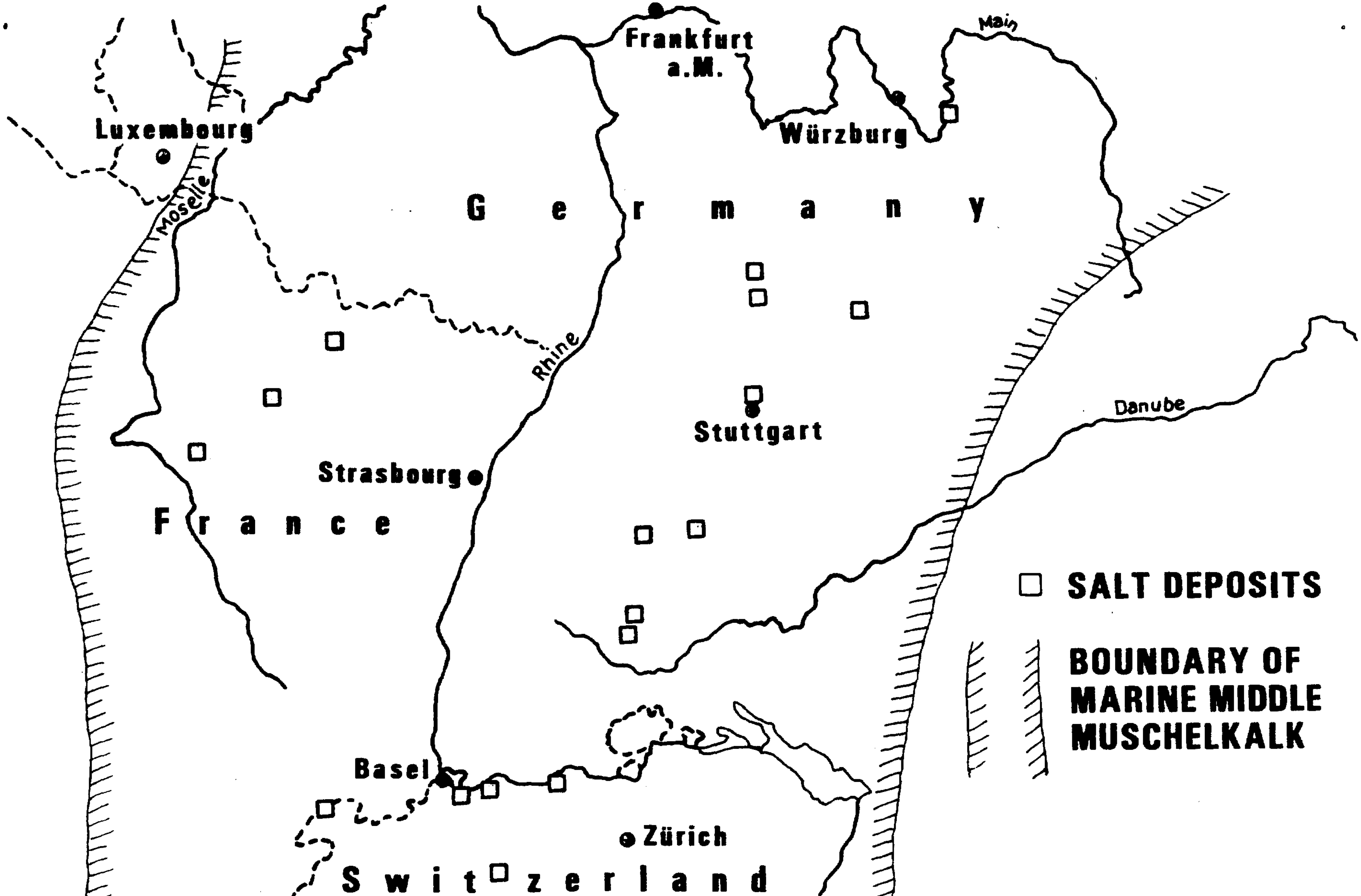
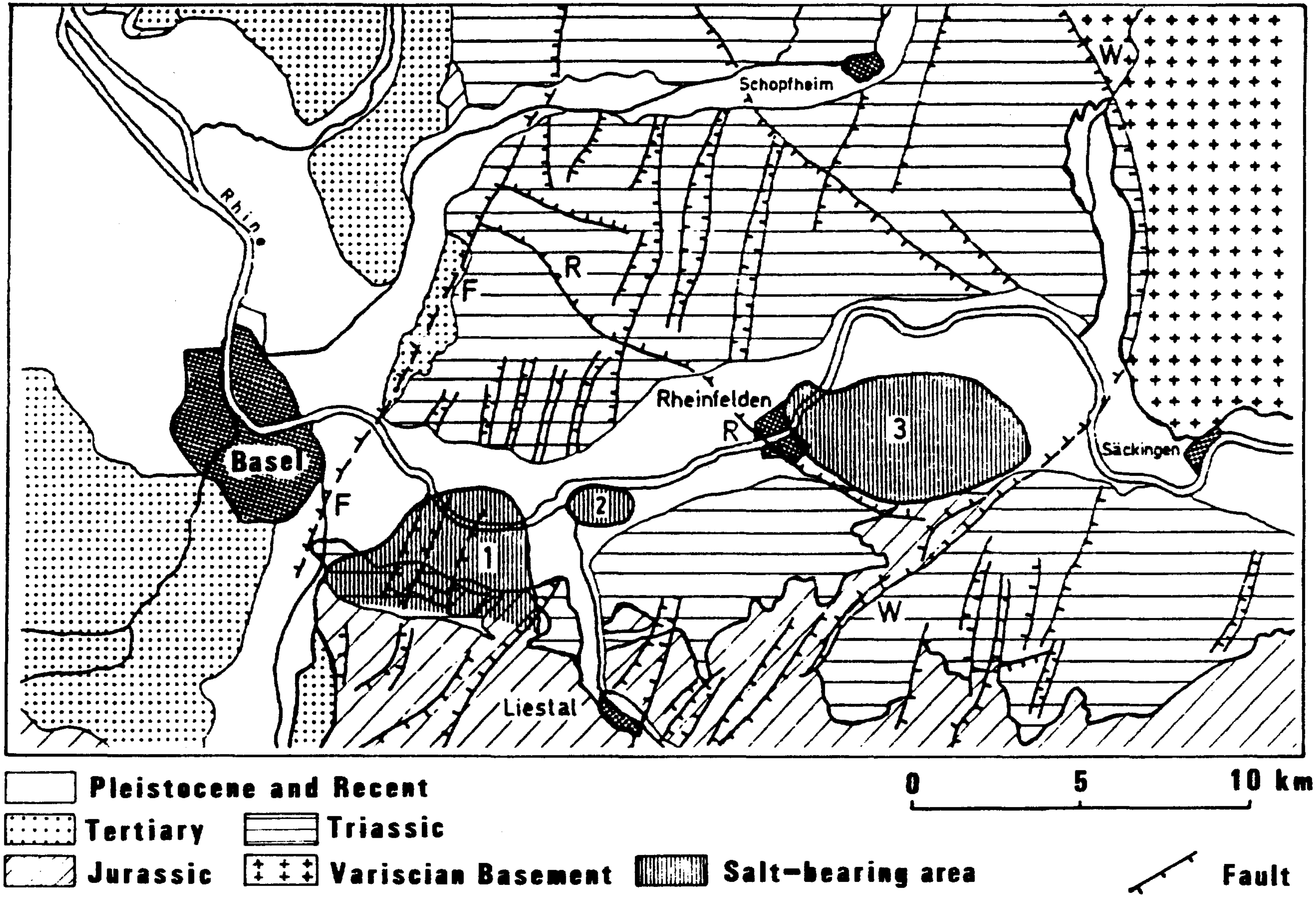


VSR

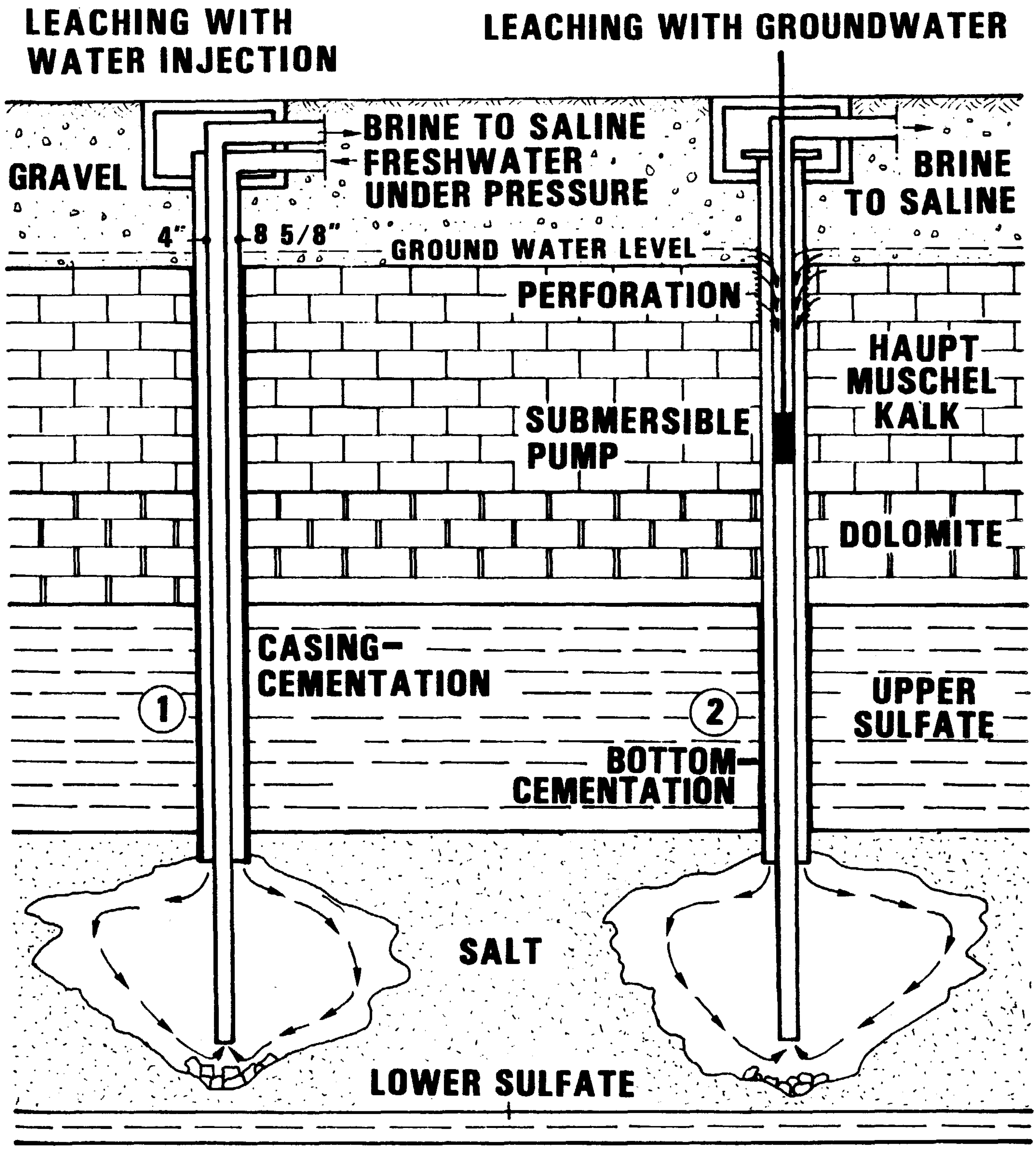
KBB

MAP OF SOUTH GERMANY, FRANCE AND SWITZERLAND SHOWING SALT DEPOSITS, ACCORDING TO DR. HAUBER

Fig.2



VSR	SALT DEPOSITS OF VEREINIGTE SCHWEIZER. RHEINSALINEN (VSR) NEAR BASEL, ACCORDING TO DR. HAUBER	Fig. 3
KBB		



VSR	**DIFFERENT METHODS OF BRINE PRODUCTION**	**Fig.4**
KBB		

VSR / KBB	OLD FASHIONED LEACHING TOWERS	Fig.5

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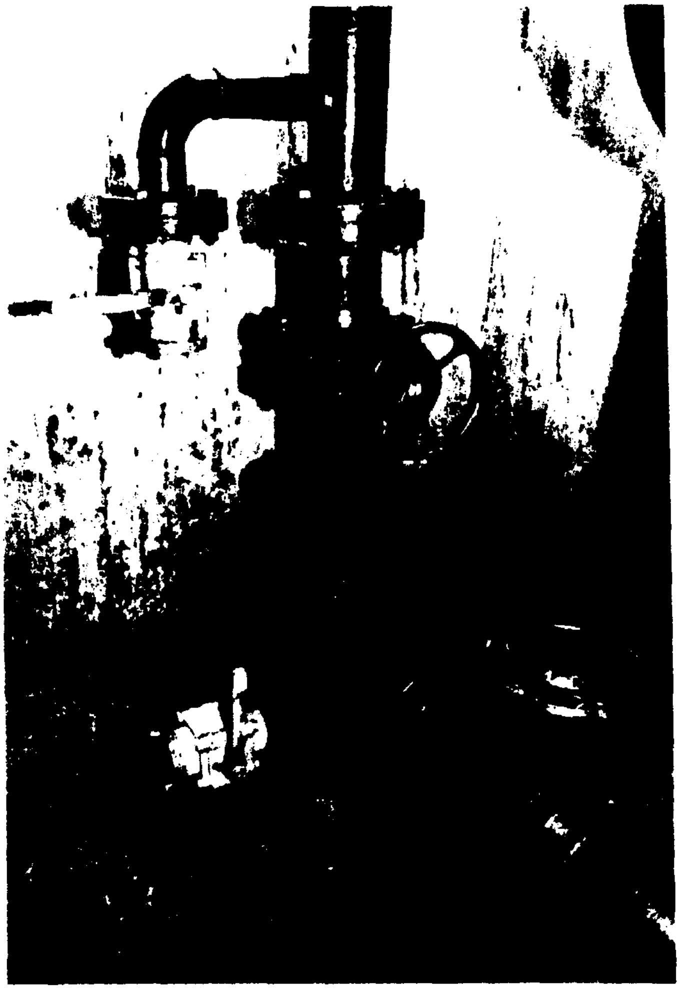
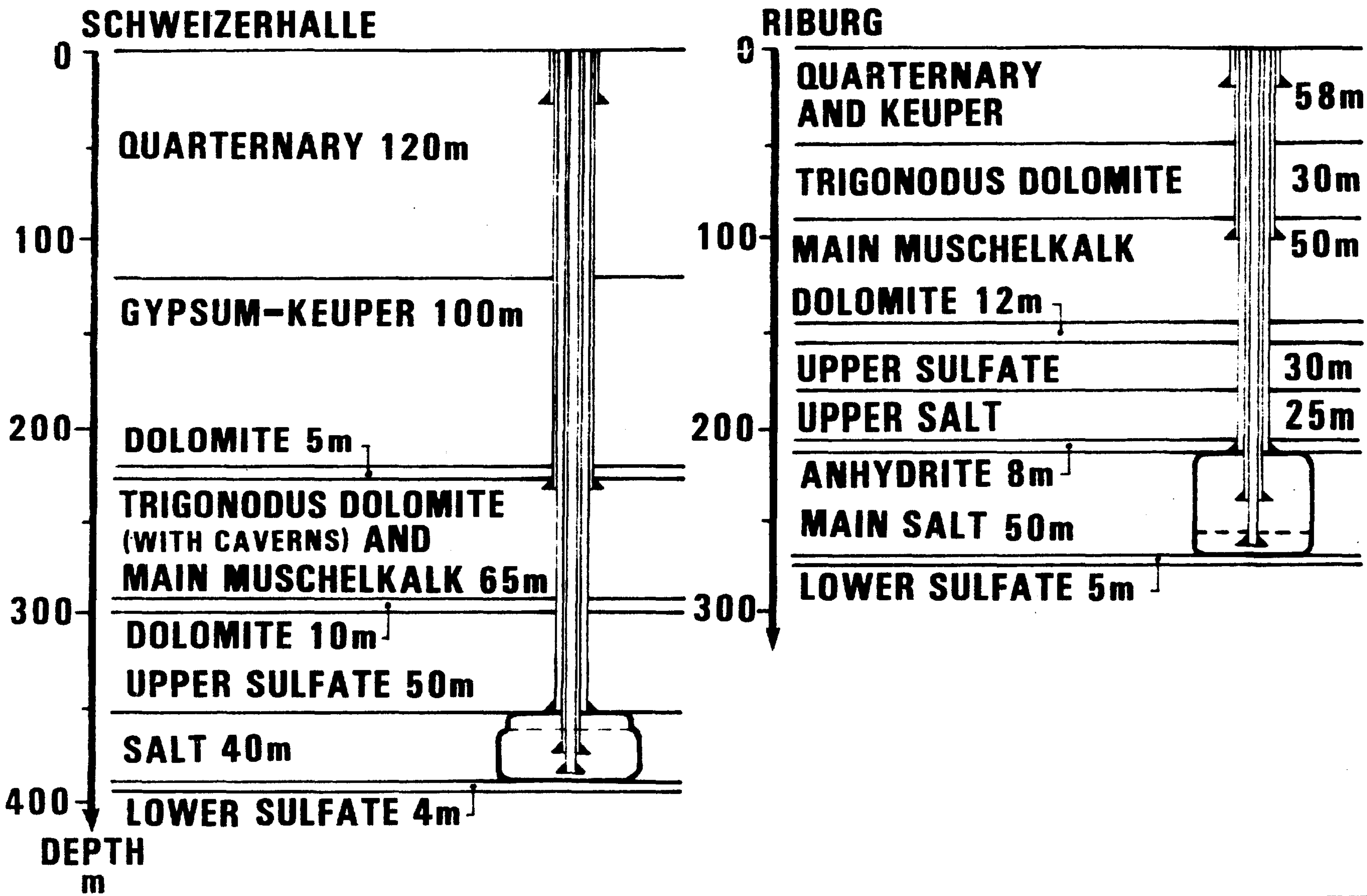
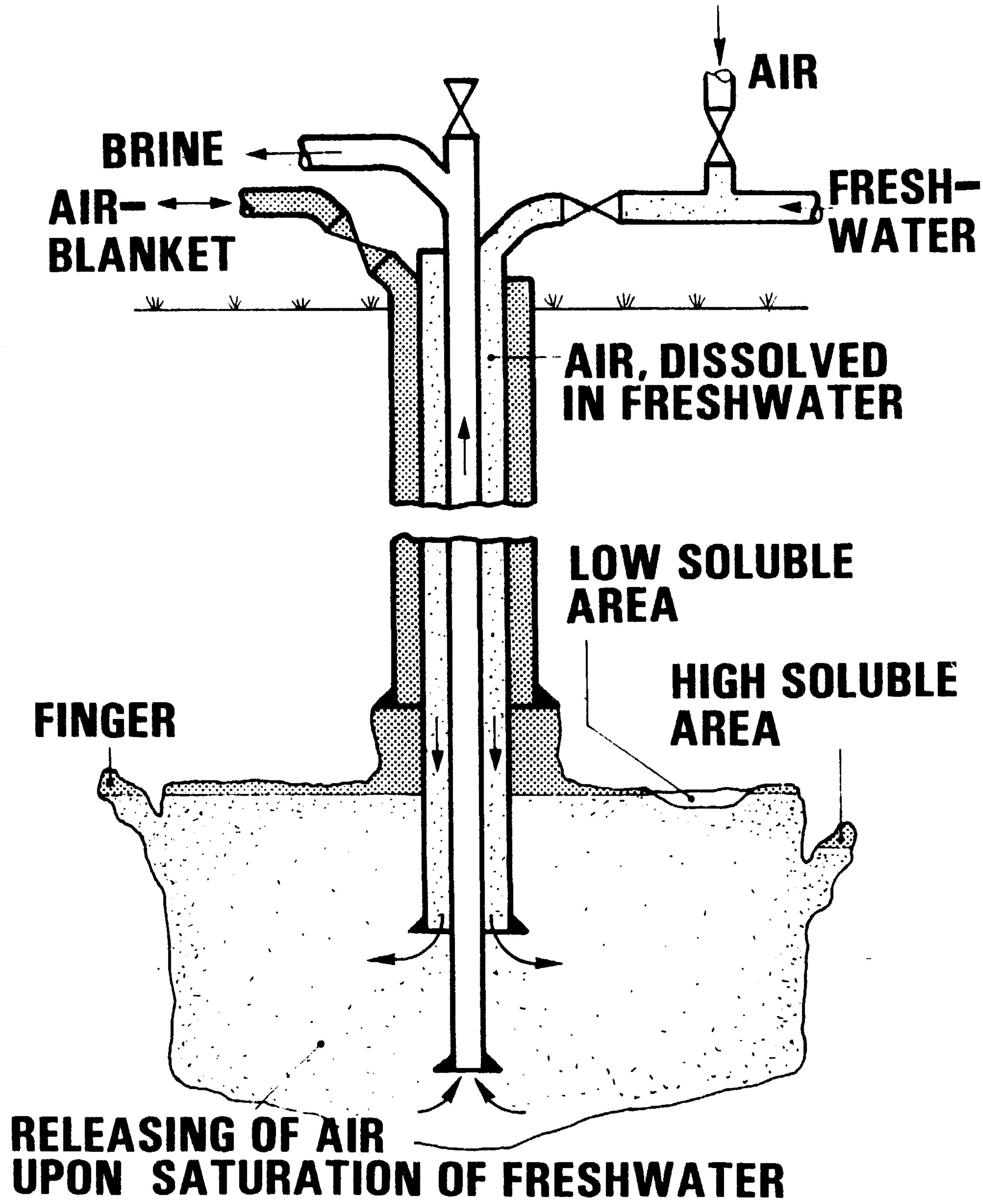


VSR	SUBSURFACE WELLHEAD IN A CONCRETE-CELLAR	Fig.6
KBB		

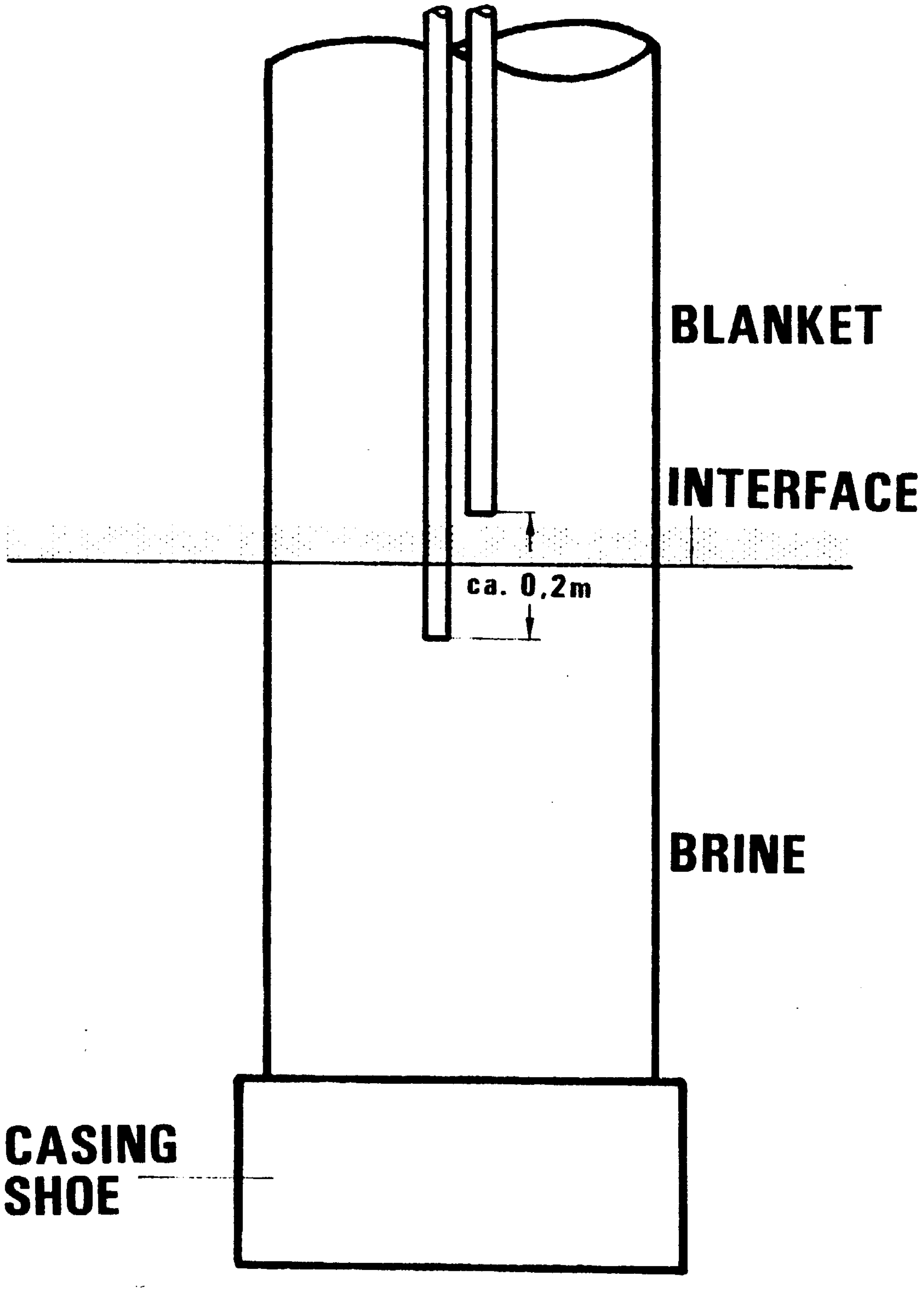
VSR	SURFACE OVER A SUBSURFACE WELLHEAD	Fig.7
KBB		



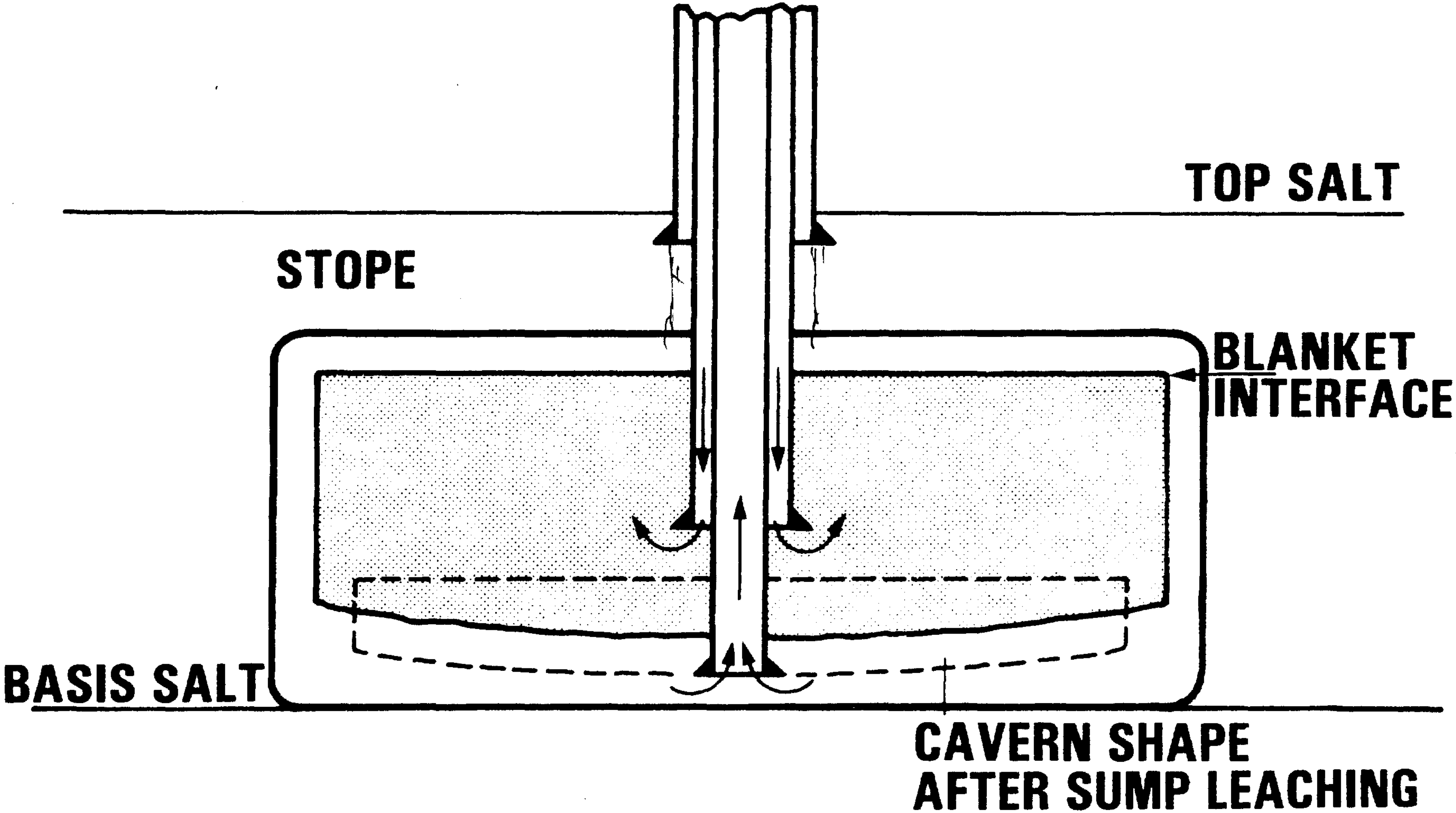
VSR KBB	STANDARD GEOLOGICAL PROFILE IN SCHWEIZERHALLE AND RIBURG	Fig.8



VSR / KBB	DEVELOPMENT OF BLANKET-INTERFACE BY AIR-INJECTION INTO THE FRESHWATER	Fig.9



VSR / KBB	BLANKET-INTERFACE-CONTROL BY ERMETO-PIPES	Fig. 10



VSR	LEACHING CONCEPT FOR SINGLE WELL CAVERNS	Fig. 11
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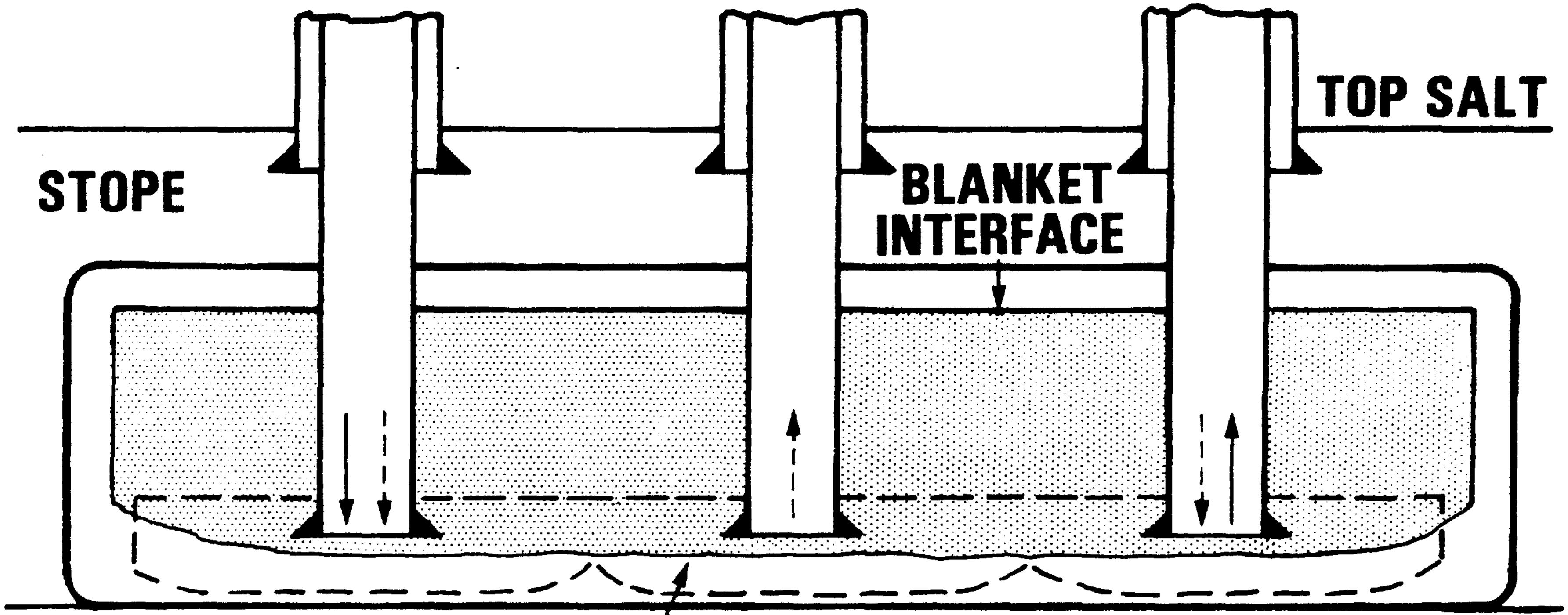

VSR	LEACHING CONCEPT FOR CAVERN GALLERY	Fig.12
KBB		

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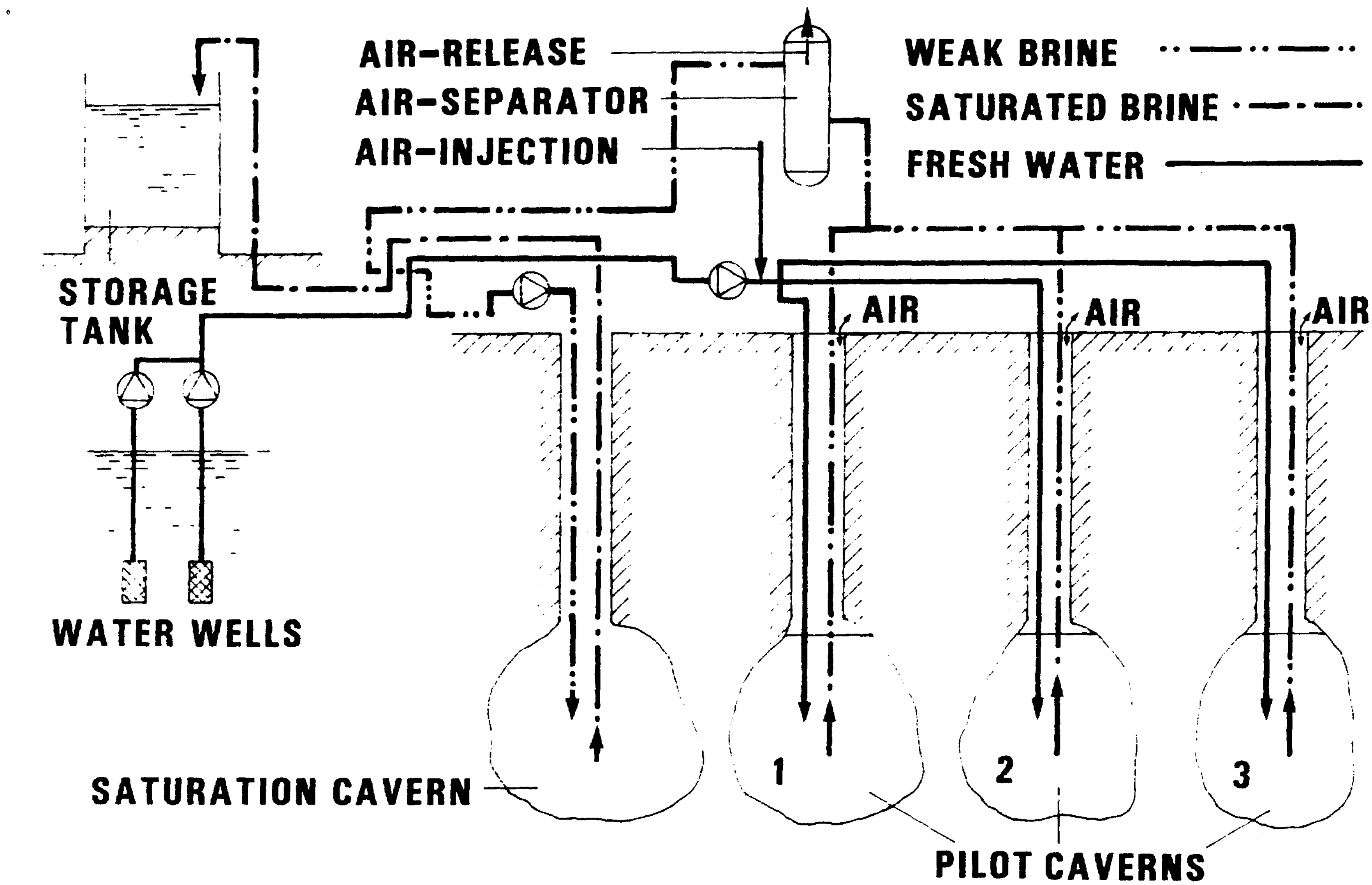
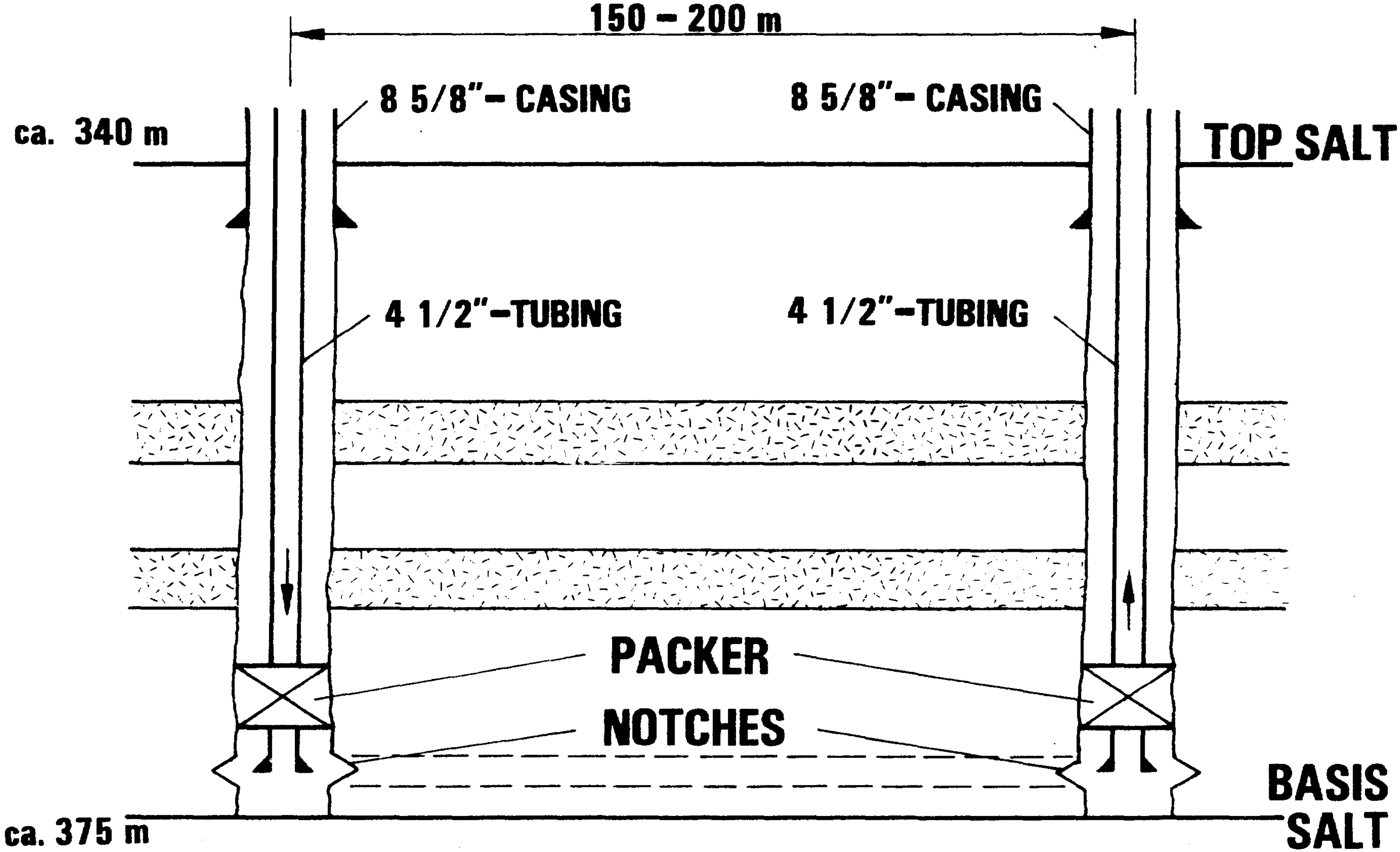


VSR

KBB

PRINCIPAL PROCESS FLOW DIAGRAM FOR PILOT LEACHING

Fig. 13



VSR	FRAC BETWEEN TWO WELLS	Fig. 14
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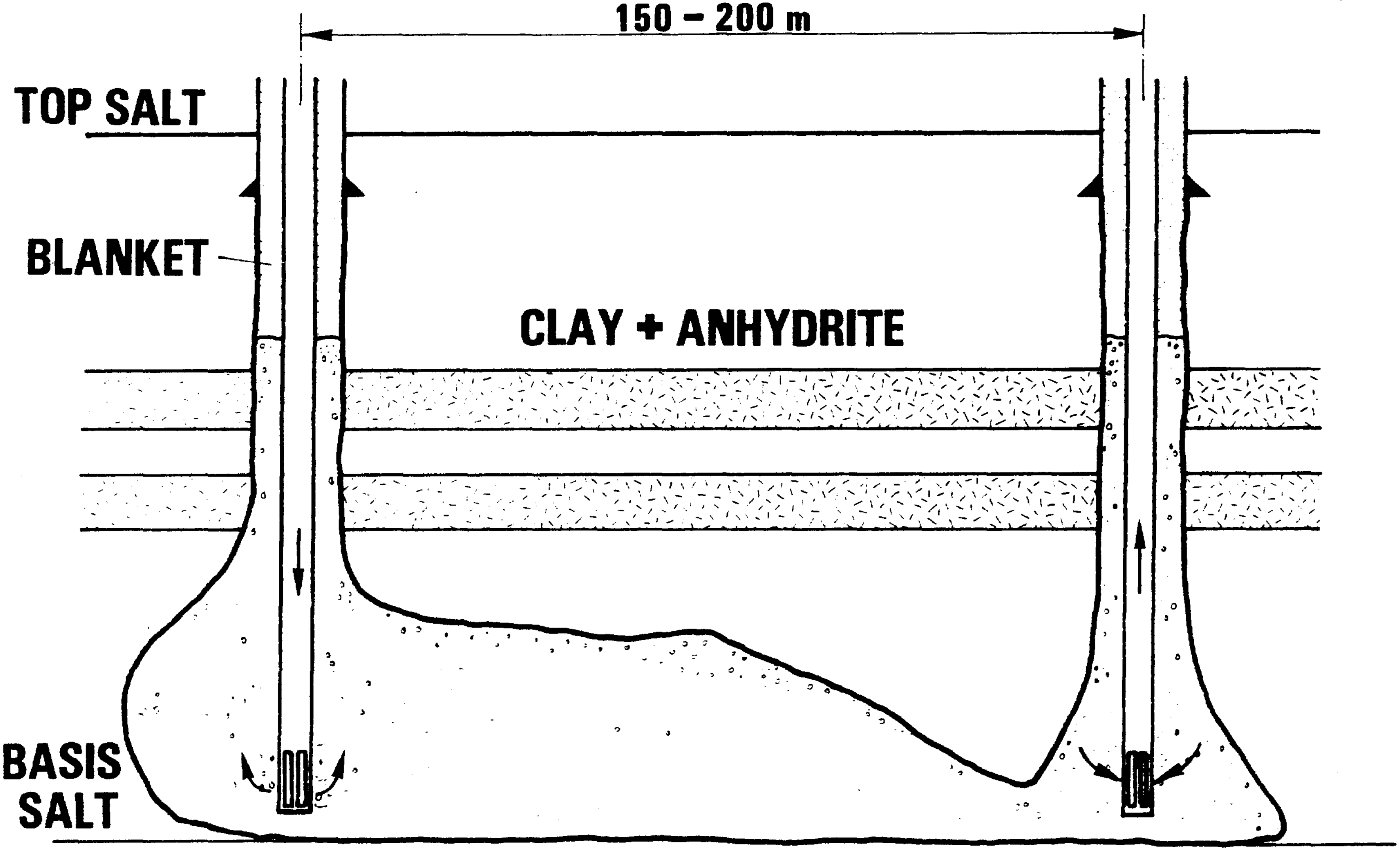

VSR	CAVERN DEVELOPMENT AFTER FRACING	Fig. 15
KBB		