# SELECTION OF DAM SITE ALTERNATIVE BY APPLICATION 0F THE PREDICTION METHOD, AND KARST RESEARCH AT "STOR-GLOMFJORD-UTBYGGINGEN" HYDROPROJECT IN ARCTIC NORWAY

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## ABSTRACT

The Stor-Glomfjord-Utbyggingen hydroproject is placed between Bod and Moi Rana localities, just into the artic circle. That project is planned for the drainage regulation of Svartisen ice cap, one of the greatest Scandinavian peninsula ice cap glaciers.

The hydroproject consists of building four different dams. Storglomfjord, the biggest one, has a reservoir capacity of 3.370 cubic hectometers and an expected electrical production of 600 MW, and will be build in an area of well developed karst features.

The dam site areas of Storglomvatn are geologically investigated to detect karst development in the present marble. At Dam site 3 a big cave, the Walbo Cave, was discovered in the dam axis. Smaller conduits and other karstic features are also found at both Dam sites. The karst found, however, is classified as shallow karst. The main drainage direction is N90°-N115° with a 50% probability, approximatively. The conditions of both studied dams are qualitatively identical as, in both cases, leakages can be corrented made because of economical and operativity considerations of chemical analysis made in a 45 points control network.

**Key words:** Karst, endorreic drainage, leakage, dam site selection, hydrochemistry.

## RESUMEN

El proyecto hidroeléctrico Stor-Glomfjord-Utbyggingen, emplazado entre las localidades de Bod y Moi Rana, justo dentro del circulo polar artico, esta previsto para regular el drenaje del casquete glaciar Svartisen, uno de los mayores de Escandinavia.

Consta de cuatro presas, la más grande de las cuales, Storglomfjord, con una capacidad de embalse de 3.370 hectometros cubicos y una producción de energía prevista de 600 MW, debera realizarse en unárea con desarrollo kárstico.

Las zonas de emplazamientos de presas de Storglomvantn han sido analizadas geológicamente para detectar el desarrollo del karst en el mármol presente. En el emplazamiento de la Presa 3, una gran gruta, Walbo Cave, ha sido descubierta en el eje de la presa. Conductos más pequeños y otros rasgos kársticos han sido tambin encontrados en los dos emplazamientos de las presas. El karst encontrado, sin embargo, está clasificado como karst poco profundo. La principal dirección del drenaje es N90°-N105°, con una probabilidad del orden del 50%. Las condiciones de ambas cerradas estudiadas son cualitativamente idénticas pudiendo, en ambos casos, corregir las fugas mediante las operaciones especiales de impermeabilización. La selección del sitio 3 viene dado por consideraciones económicas y de operatividad del embalse. Se completa el trabajo con una relación de análisis hidroquímicos efectuados en una red de control de 45 puntos.

**Palabras clave:** Karst, drenaje subterráneo, fugas, selección de emplazamientos de presas, hidroquímica.

Eraso,A and Lund,C. (1990) Selection of dam site alternative by application of the predicction method, and karst research of the "Stor-Glomfjord-Utbyggingen" hydroproject in Arctic Norway. *Rev. Soc. Geol. España,* 3: 345-355.

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## 1. INTRODUCTION

The investigated area is located at the coastal part of the glacier Svartisen, at the north side of the artic circle (figure 1). This is one of the biggest glaciers in Norway with appx. 300 km² ice cap. The depression forming the lake Storglomvatn will be the largest hydropower reservoir in Norway with 3.370 mill.m³. According to the plans of 1987, regulation heights between 460 m and 585 m will be given by two dams (Loset and Lien, 1986):

— 1st. Holmvatn dam at the river Holmdalselva.
— 2nd. Storglomvatn dam with two alternatives at the river Fykanåga.

The Holmvatn dam will be placed on rocks as granitoids, micaschist and gneiss. The lithology of Storglomvatn dam consist of micaschists and gneisses at the south side, and the same rocks with marble interlayerings at the north side of both alternatives, Dam site 1 in the upper part of the river and Dam site 3, 2km down the river (Loset and Kjaernsli, 1987a).

Karstification takes place in the marble rocks, and when endogenic flow and caves exist, there is a risk of leakage through the marbles from the reservoir during and after the dam operations (Loset and Kjaernsli, 1987b; Lund, 1986 and 1987, Eraso and Lund, 1988).

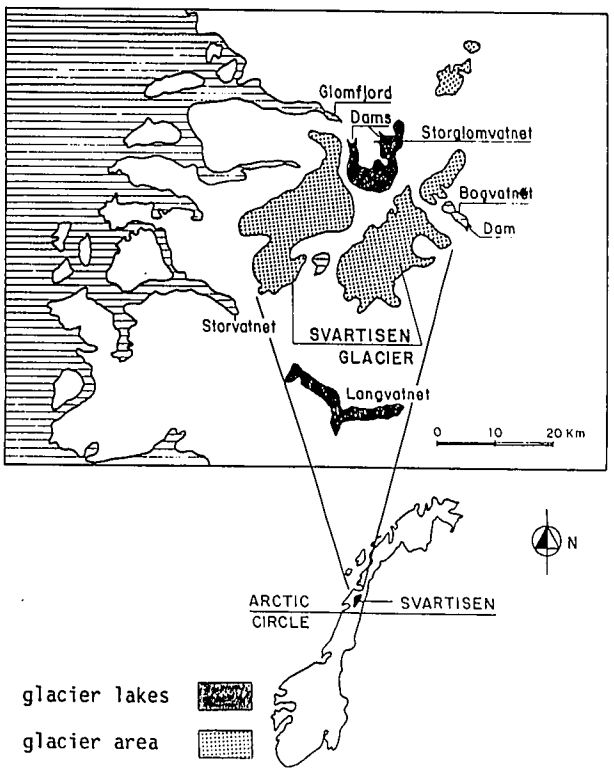


Fig. 1.-Location plan.
Fig. 1.-Plano de localización.

## 2. METHODOLOGY

The karst investigation is developed in three directions:

— 1st: Exploring the caves and endogenic flow that exist in the area (Hansen, 1962).
— 2nd: Applying the Prediction Method of the main directions of drainage in karst (Eraso, 1983, 1986c and 1987).
— 3rd: Water sampling at the inlets (ponors) and springs of the Storglomvatn area (Lund, in prep.).

### 2.1. *The exploration work*

The exploration work is made by several round trips into an area of 22 km², visiting caves, measuring the direcctions of galleries and flow channels and tracing the endogenic flow at the ponors with Rhodamin solution to determine their connection with existing springs. Special attention is given to the north side of both dam alternatives of the Storglomvatn dam.

### 2.2. *Prediction of the endogenic drainage*

Prediction of the endogenic drainage is made using the Prediction Method. The method is based on two hypotheses, the first one is qualitative and the second is quantitative.

— The first hypothesis gives a predetermined, three dimensional net of drainage into the karst regions, preprinted or imposed by tectonic conditions suffered by the rock massif. Hence, it determines the underground drainage net, according to its geological history.

— The second gives the most probable drainage directions, organized inside plans which have the main stress $\sigma 1$, and intermediate stress $\sigma 2$, of each one of the ellipsoid given by every tectonical phase. In consequence, they are perpendicular to the minor stress $\sigma 3$, of each ellipsoid, respectively.

In fact, field work investigations were limited to the application of structural geological technique, searching for tectoglyphs in the field areas and reading their parameters at locations wherw they were measurable.

Tectoglyphs are: Stylolite plans, mineral veins and fault plans. Parameters are principally strike, dip and sense of dip. By applying the stereographic projections in WULFF's or SCHIMIDT's net, the ellipsoid of principall stresses will be resolved for each case. To make the field data processing easier, the method is available with three computer programmes: GEORED, GEODRE and GEOPOL.

Finally, this method gives the cuantitative estimation of the directional aspect of anisotropy in the rock massif, and hence its underground drainage in karstic processes.

### 2.3. *Hydrochemical investigations*

The hydrochemical investigation was carried out

| NO | STRIKE | DIP | SENSE | MINERAL | NO | STRIKE | DIP | SENSE | MINERAL |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 80 | 110 | Calcite | 23 | 165 | 80 | 90 | " |
| 2 | 12 | 77 | 110 | " | 24 | 175 | 50 | 89 | " |
| 3 | 5 | 71 | 276 | " | 25 | 20 | 85 | 286 | " |
| 4 | 6 | 70 | 274 | " | 26 | 95 | 81 | 5 | Quartz |
| 5 | 250 | 80 | 330 | " | 27 | 93 | 79 | 4 | " |
| 6 | 272 | 89 | 355 | Quartz | 28 | 96 | 76 | 359 | " |
| 7 | 279 | 86 | 5 | " | 29 | 275 | 80 | 5 | " |
| 8 | 282 | 83 | 10 | " | 30 | 278 | 78 | 7 | " |
| 9 | 106 | 88 | 15 | Calcite | 31 | 273 | 81 | 4 | " |
| 10 | 109 | 86 | 16 | " | 32 | 185 | 75 | 95 | Calcite |
| 11 | 110 | 86 | 15 | " | 33 | 182 | 76 | 94 | " |
| 12 | 100 | 80 | 5 | " | 34 | 165 | 88 | 251 | Quartz |
| 13 | 98 | 82 | 3 | Quartz | 35 | 90 | 10 | 180 | Calcite |
| 14 | 95 | 79 | 1 | " | 36 | 86 | 12 | 179 | " |
| 15 | 85 | 85 | 185 | Calcite | 37 | 87 | 9 | 179 | " |
| 16 | 190 | 80 | 270 | " | 38 | 271 | 50 | 175 | Quartz |
| 17 | 186 | 80 | 272 | " | 39 | 273 | 50 | 178 | " |
| 18 | 77 | 67 | 165 | Quartz | 40 | 274 | 50 | 176 | " |
| 19 | 185 | 80 | 270 | Calcite | 41 | 90 | 86 | 180 | " |
| 20 | 183 | 79 | 269 | " | 42 | 95 | 82 | 182 | " |
| 21 | 350 | 89 | 79 | " | 43 | 92 | 85 | 180 | " |
| 22 | 170 | 88 | 265 | " | 44 | 350 | 73 | 75 | Calcite |

Table 1.-Station of tectoglyphs.
Tabla 1.-Estaciones de tectoglifos.

| | | EXPLORATIONS | | | | | | | | | | PREDICTIONS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CAVES MAPPED IN THE AREA AND ENDOGENIC FLOW MEASUREMENTS | | | | | | | | | | STATIONS OF TECTOGLYPHS | |
| Φ | INTERVAL | YAN-GROTTEN | LINDS-GROTTEN | GUNNAR-GROTTEN | STORM-GROTTEN | KLØFT-GROTTEN | RUFFEN-GROTTEN | LEFT SIDE STOR-GLOMVT. | RIGHT SIDE NAVNLØS-ELVA | Σmts | % | Nr. | % |
| 1 | N0°-N15° | 50 | 30 | 83 | 116 | 60 | 44 | — | 15 | 398 | 23'93 | 10 | 22'72 |
| 2 | N15°-N30° | — | — | — | — | — | — | — | — | — | — | 1 | 2'27 |
| 3 | N30°-N45° | 20 | — | — | — | — | — | — | — | 20 | 1'20 | — | — |
| 4 | N45°-N60° | — | — | — | — | — | — | — | — | — | — | — | — |
| 5 | N60°-N75° | — | — | — | — | — | — | — | — | — | — | 1 | 2'27 |
| 6 | N75°-N90° | — | — | — | 28 | — | — | — | — | 28 | 1'68 | 2 | 4'55 |
| 7 | N90°-N105° | 92 | 15 | 157 | 209 | 18 | 188 | 150 | — | 829 | 49'85 | 21 | 47'73 |
| 8 | N105°-N120° | — | — | 20 | 15 | — | 50 | — | 170 | 255 | 15'33 | 3 | 6'82 |
| 9 | N120°-N135° | — | — | — | — | 7 | 38 | — | 45 | 90 | 5'41 | — | — |
| 10 | N135°-N150° | — | — | — | — | — | — | — | — | — | — | — | — |
| 11 | N150°-N165° | — | — | — | — | 43 | — | — | — | 43 | 2'59 | 2 | 4'55 |
| 12 | N165°-N180° | — | — | — | — | — | — | — | — | — | — | 4 | 9'09 |
| | Σ | 162 | 45 | 260 | 368 | 128 | 320 | 150 | 230 | 1663 | | 44 | |
| | % | 9'74 | 2'70 | 15'63 | 22'13 | 7'70 | 19'24 | 9'02 | 13'83 | | 99'99 | | 100 |

Table 2.-Data of explorations and stations of tectoglyphs.
Tabla 2.- Datos de las exploraciones y de las estaciones de tectoglifos.

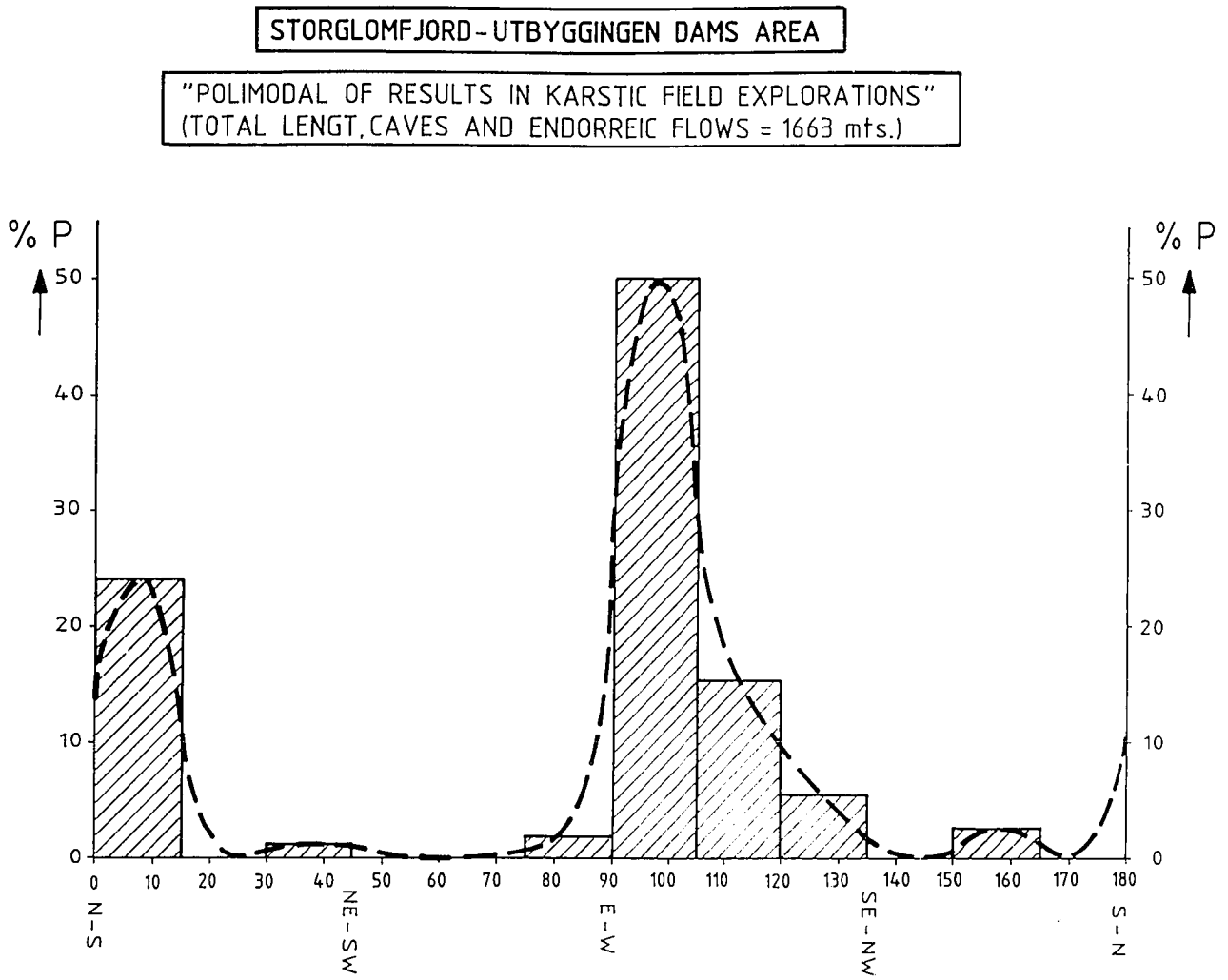


Fig. 2.-The result of explorations.
Fig. 2.-Resultados de las exploraciones.

STORGLOMFJORD-UTBYGGINGEN DAMS AREA

KOLMOGOROV'S TEST BETWEEN BOTH KARSTIC POLIMODALS:

1.- PREDICTION GIVES BY ERASO'S METHOD
2.- RESULTS OF THE FIELD EXPLORATIONS (CAVES AND ENDORREIC FLOWS).

| | INTERVALS Ø | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PREDICTED VALUES % | 22'72 | 2'27 | — | — | 2'27 | 4'55 | 47'73 | 6'82 | — | — | 4'55 | 9'09 |
| | COMMUL. VALUES $\Sigma_1$ | 22'72 | 24'99 | 24'99 | 24'99 | 27'26 | 31'81 | 79'54 | 86'36 | 86'36 | 86'36 | 90'91 | 100 |
| 2 | EXPLORED VALUES % | 23'93 | — | 1'20 | — | — | 1'68 | 49'85 | 15'33 | 5'41 | — | 2'59 | — |
| | COMMUL. VALUES $\Sigma_2$ | 23'93 | 23'93 | 25'13 | 25'13 | 25'13 | 26'81 | 76'66 | 91'99 | 97'40 | 97'40 | 99'99 | 99'99 |
| | $\lvert\Sigma_1 - \Sigma_2\rvert$ | 1'21 | 1'06 | 0'14 | 0'14 | 2'13 | 5'00 | 2'88 | 5'63 | 11'04 | 11'04 | 9'08 | 0'01 |
| | MAXIMUM ERROR $\varepsilon$ % | 0'35 | 0'31 | 0'04 | 0'04 | 0'61 | 1'44 | 0'83 | 1'63 | 3'19 | 3'19 | 2'62 | — |

$$\text{DEGREE OF ACCURACY} = 100 - \varepsilon\,\%;\ \text{Ø} = 12;\ \varepsilon\,\% = \frac{\lvert\Sigma_1 - \Sigma_2\rvert}{\sqrt{\text{Ø}}}$$

$$100 - 3'19 = 96'81$$

$$\text{DEGREE OF ACCURACY} = 96'81$$

Table 3.-Kolmogorov's test between both karstic polimodals.
Tabla 3.-Test de Kolmogorov entre ambas polimodales kársticas.

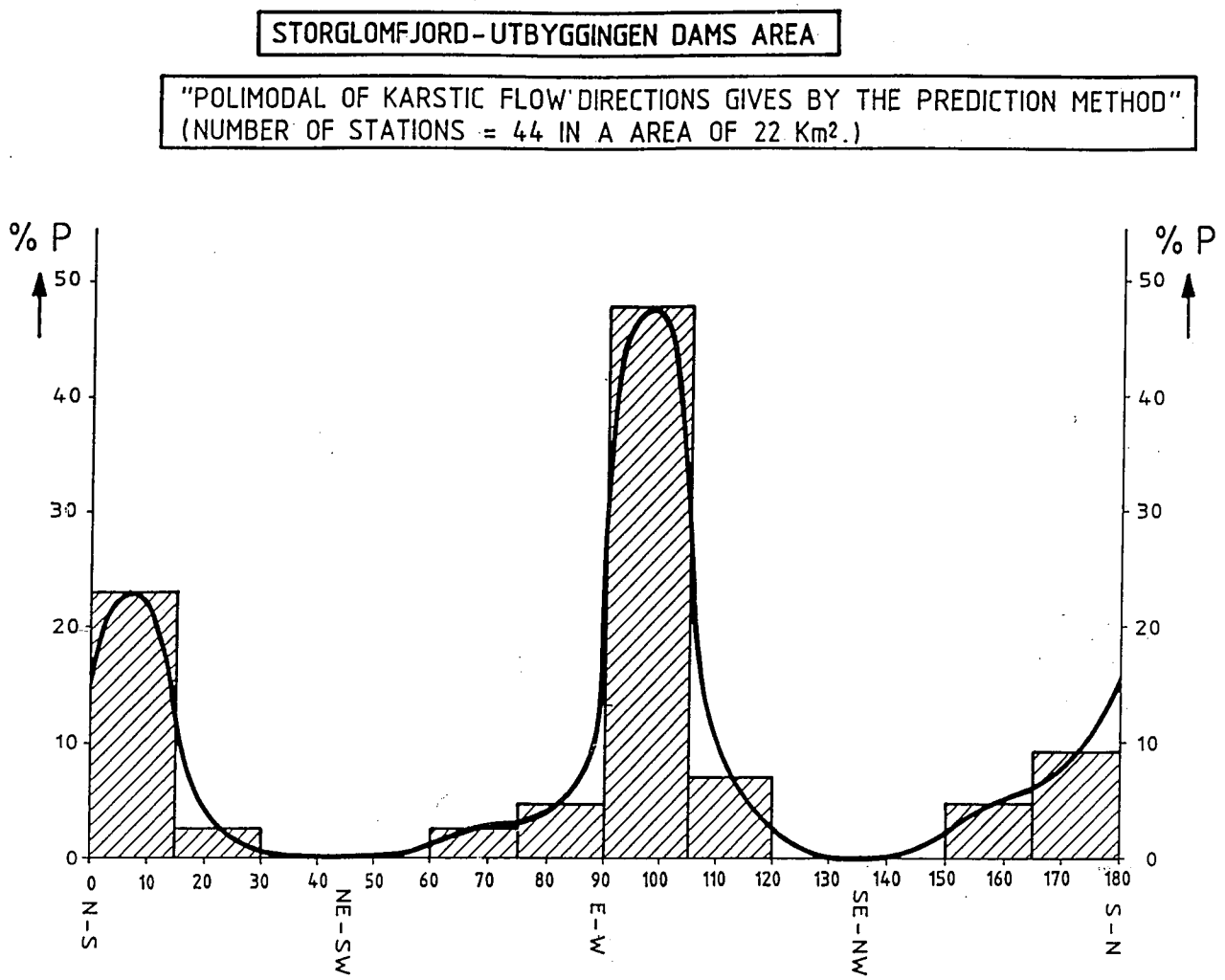


Fig. 3.-Directions of underground flow in the area.
Fig. 3.-Direcciones del drenaje subterráneo en el área.

| | $SiO_2$ | $TiO_2$ | $P_2O_5$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | $CaCo_3$ | MgO | $MgCO_3$ | S | $Na_2O$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 44,2<br>2,10 | 0,4 | 0,05 | 9,80 | 5,00 | 19,40 | 34,6 | 1,73 | 3,6 | 0,16 | 0,50 | |
| ($CO_2$) | | | | | | (15,2) | | (1,9) | | | | |

Total loss of ignition at 1000°C 17,2%
$CaCO_3/MgCO_3$ $CO_2$ loss at 1000°C 17,1%

Table 4.-Mineral contents of the rock sample in percentages.
Tabla 4.- Contenido en minerales de la muestra de roca en porcentajes.

in 1987. Rock, sediment and water samples were collected in the dam site areas on the karstic north side of the river Fykanaga.

40 water samples in total, 35 (july) + 5 (sept.), one sediment sample and piece of rock of the representative local marble were collected. The results of the analyses give the trend of dissolved materials or the corrosion potential, and hence the possibilities of karstification. The amount of samples, however, is too scarce to give a complete hydrogeological picture.

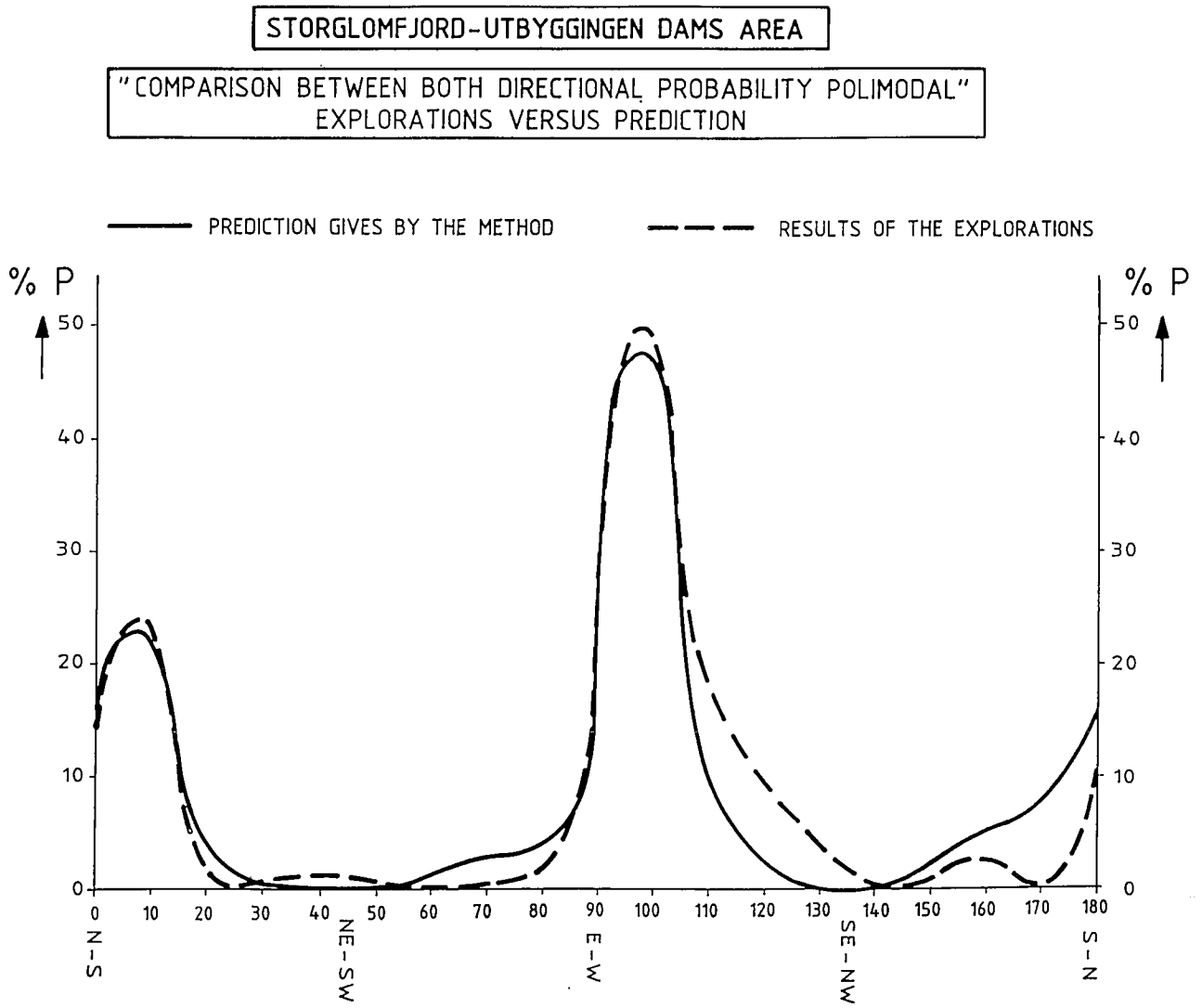


Fig. 4.-Comparation between both directional probability polimodals —exploration and prediction—. The main direction of N90° N105° with 47,73% probability and the associate direction of NO° N15.° with 22,72% probability.
Fig. 4.-Comparación entre ambas polimodales de probabilidad direccional -exploración y predicción-. La dirección principal de N0°-N105° con 47,73% de probabilidad y la dirección asociada de N0°-15° con 22,72% de probabilidad.

Water tracing is carried out by using Rhodamin. The aim of using this method was to investigate the depht (and shape) of the karst channels at the actual dam site.

## 3. RESULTS

An area of 22 km² is investigated, concerning principally marble band and layers found in the described area:

- The peninsula placed in Storglomvatn between the rivers Holmdalselva and Fykanaga.
- The right and left side of the Holmvatn.
- SW part of Kjerringa.
- E part of Synkenhogda.
- S part of the Navnlosvatn.
- Both sides of both alternatives, Dam site 1 and Dam site 3.
- Both sides of river Navnloselva.

### *3.1. Prediction measurement of caves and endogenic flow*

The results are given by:

- 44 stations of tectoglyphs (i.e. mineral veins) with the relations of table 1.
- 1.633 m measured into cave galleries and endogenic flow. The list of the caves is:

| | |
|---|---|
| * Yangrotten | 162 m |
| * Lindsgrotten | 45 m |

| Test no. | Date | $K_{20}$ µS/cm | pH | $Ca^{2+}$ ppm | $Mg^{2+}$ ppm | $Na^{+}$ ppm | $K^{+}$ ppm | $HCO_3^{-}$ ppm | $CL^{-}$ ppm | $SO_4^{2-}$ ppm | Tot.filt. res.. | $CO_2$ mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 230787 | 86,5 | 7,8 | 17,6 | 0,4 | 1,9 | 0,2 | 56,1 | 3,2 | 0,5 | | |
| 2 | 230787 | 36,1 | 7,3 | 6,3 | 0,2 | 1,0 | 0,2 | 22,0 | 1,9 | 0,5 | | |
| 3 | 230787 | 50,8 | 7,5 | 9,6 | 0,3 | 1,2 | 0,2 | 31,7 | 2,1 | 0,9 | | |
| 4 | 230787 | 57,9 | 7,6 | 11,2 | 0,3 | 1,3 | 0,1 | 35,4 | 2,4 | 0,9 | | |
| 5 | 230787 | 85,7 | 7,8 | 17,8 | 0,4 | 1,7 | 0,1 | 54,9 | 2,4 | 1,3 | | |
| 6 | 230787 | 44,0 | 7,6 | 8,2 | 0,2 | 1,0 | 0,1 | 26,8 | 2,0 | 0,5 | | |
| 7 | 230787 | 28,6 | 7,4 | 5,5 | 0,1 | 0,6 | <0,1 | 17,1 | 1,6 | 0,5 | | |
| 8 | 230787 | 100,8 | 7,8 | 20,5 | 0,5 | 2,5 | 0,3 | 64,7 | 4,2 | 1,3 | | |
| 9 | 230787 | 33,1 | 7,5 | 5,6 | 0,2 | 1,0 | 0,2 | 18,3 | 2,0 | 0,9 | | |
| 10 | 230787 | 45,1 | 7,6 | 8,7 | 0,2 | 1,1 | 0,2 | 28,1 | 2,4 | 0,9 | | |
| 11 | 230787 | 84,2 | 7,9 | 16,9 | 0,4 | 1,8 | 0,2 | 54,9 | 3,5 | 0,9 | | |
| 12 | 230787 | 41,4 | 7,6 | 6,3 | 0,4 | 1,7 | 0,4 | 22,0 | 2,6 | 2,1 | | |
| 13 | 230787 | 18,2 | 7,4 | 3,3 | 0,2 | 0,8 | 0,7 | 9,8 | 23,7 | 1,3 | | |
| 14 | 230787 | 14,9 | 6,8 | 1,8 | 0,2 | 1,0 | 0,2 | 7,3 | 1,7 | 1,3 | | |
| 15 | 230787 | 25,6 | 6,8 | 2,8 | 0,3 | 1,8 | 0,3 | 9,8 | 4,2 | 1,7 | | |
| 16 | 230787 | 12,5 | 6,9 | 1,6 | 0,1 | 0,9 | 0,1 | 6,1 | 1,8 | 0,9 | | |
| 17 | 230787 | 9,3 | 5,4 | 0,6 | 0,1 | 0,9 | 0,1 | 2,4 | 2,2 | 0,9 | | |
| 18 | 230787 | 7,4 | 6,3 | 0,8 | 0,1 | 0,7 | 0,1 | 3,7 | 1,7 | 0,5 | | |
| 19 | 230787 | 16,1 | 6,8 | 1,6 | 0,5 | 1,1 | 0,2 | 8,5 | 2,0 | 0,5 | | |
| 20 | 230787 | 26,3 | 7,1 | 3,3 | 0,5 | 1,6 | 0,3 | 14,6 | 2,0 | 0,9 | | |
| 21 | 230787 | 25,6 | 7,1 | 3,1 | 0,5 | 1,5 | 0,2 | 12,2 | 2,6 | 1,3 | | |
| 22 | 230787 | 46,6 | 7,4 | 8,7 | 0,2 | 1,1 | 0,2 | 28,1 | 2,6 | 0,9 | | |
| 23 | 230787 | 48,9 | 7,5 | 9,1 | 0,2 | 1,1 | 0,1 | 29,3 | 2,4 | 0,9 | | |
| 24 | 230787 | 86,5 | 7,9 | 17,2 | 0,4 | 1,7 | 0,2 | 53,7 | 3,4 | 1,3 | | |
| 25 | 230787 | 67,7 | 7,8 | 11,3 | 0,4 | 2,3 | 0,2 | 36,6 | 6,5 | 1,3 | | |
| 26 | 230787 | 47,4 | 7,6 | 8,0 | 0,3 | 1,5 | 0,2 | 28,1 | 2,9 | 1,3 | | |
| 27 | 230787 | 45,9 | 7,5 | 7,8 | 0,3 | 1,5 | 0,2 | 25,6 | 3,5 | 1,3 | | |
| 28 | 230787 | 60,2 | 7,6 | 11,2 | 0,3 | 1,4 | 0,2 | 36,6 | 3,2 | 1,3 | | |
| 29 | 230787 | 71,4 | 7,5 | 13,4 | 0,3 | 1,7 | 0,2 | 41,5 | 3,3 | 0,9 | | |
| 30 | 230787 | 63,9 | 7,8 | 12,3 | 0,3 | 1,3 | 0,1 | 39,0 | 3,0 | 0,5 | | |
| 31 | 230787 | 24,1 | 7,3 | 3,1 | 0,4 | 1,1 | 0,3 | 13,4 | 11,2 | 1,3 | | |
| 32 | 230787 | 47,0 | 7,6 | 8,1 | 0,5 | 1,2 | 0,3 | 29,3 | 1,9 | 0,9 | | |
| 33 | 230787 | 42,1 | 7,6 | 5,9 | 1,0 | 1,3 | 0,6 | 25,6 | 2,3 | 1,7 | | |
| 34 | 230787 | 58,7 | 7,5 | 9,3 | 1,0 | 1,5 | 0,6 | 34,2 | 7,0 | 1,7 | | |
| 35 | 230787 | 58,7 | 7,6 | 9,7 | 1,0 | 1,3 | 0,5 | 34,2 | 2,5 | 1,3 | | |
| 40 | 220987 | 142,0 | 8,0 | 29,4 | 0,7 | 1,7 | 0,4 | 97,6 | 4,0 | 2,3 | 135,0 | 2,0 |
| 41 | 220987 | 126,7 | 8,0 | 24,8 | 0,6 | 1,7 | 0,5 | 83,0 | 4,1 | 1,9 | 115,0 | 1,6 |
| 42 | 220987 | 100,8 | 8,0 | 23,6 | 0,6 | 1,1 | 0,3 | 74,4 | 3,1 | 1,5 | 105,0 | 1,5 |
| 43 | 220987 | 79,7 | 7,8 | 13,7 | 0,5 | 1,3 | 0,4 | 45,1 | 4,9 | 1,0 | 65,0 | 1,5 |
| 44 | 220987 | 134,4 | 7,8 | 24,8 | 0,6 | 1,5 | 0,4 | 85,4 | 5,0 | 1,9 | 120,0 | 2,6 |
| 45 | 220987 | 145,0 | 8,3 | 32,4 | 0,7 | 1,3 | 0,3 | 93,9 | 3,8 | 2,3 | 135,0 | 1,0 |

Table 5.-Results of the water analyses.
Tabla 5.-Resultados de los análisis del agua.

* Gunnargrotten 260 m
* Stormgrotten 368 m
* Kloftgrotten 128 m
* Ruffengrotten 320 m
* Walbögrotten 30 m
(slightly measured only)

The interval is marked for directions or strikes. Table 2 contains a lot of galleries and flow (in metres), and number of tectoglyphes.

The intervals are defined every 15° (12 times in 180°) and in each one the orientation is referred to the magnetic north.

Figure 2 is a polimodal of results in karstic field explorations, and shows the two directions of underground flow in the area:

— The main direction of N90°-N105° whit 49.85% probability and
— The associate direction of N0°-N15° with 23.93% probability.

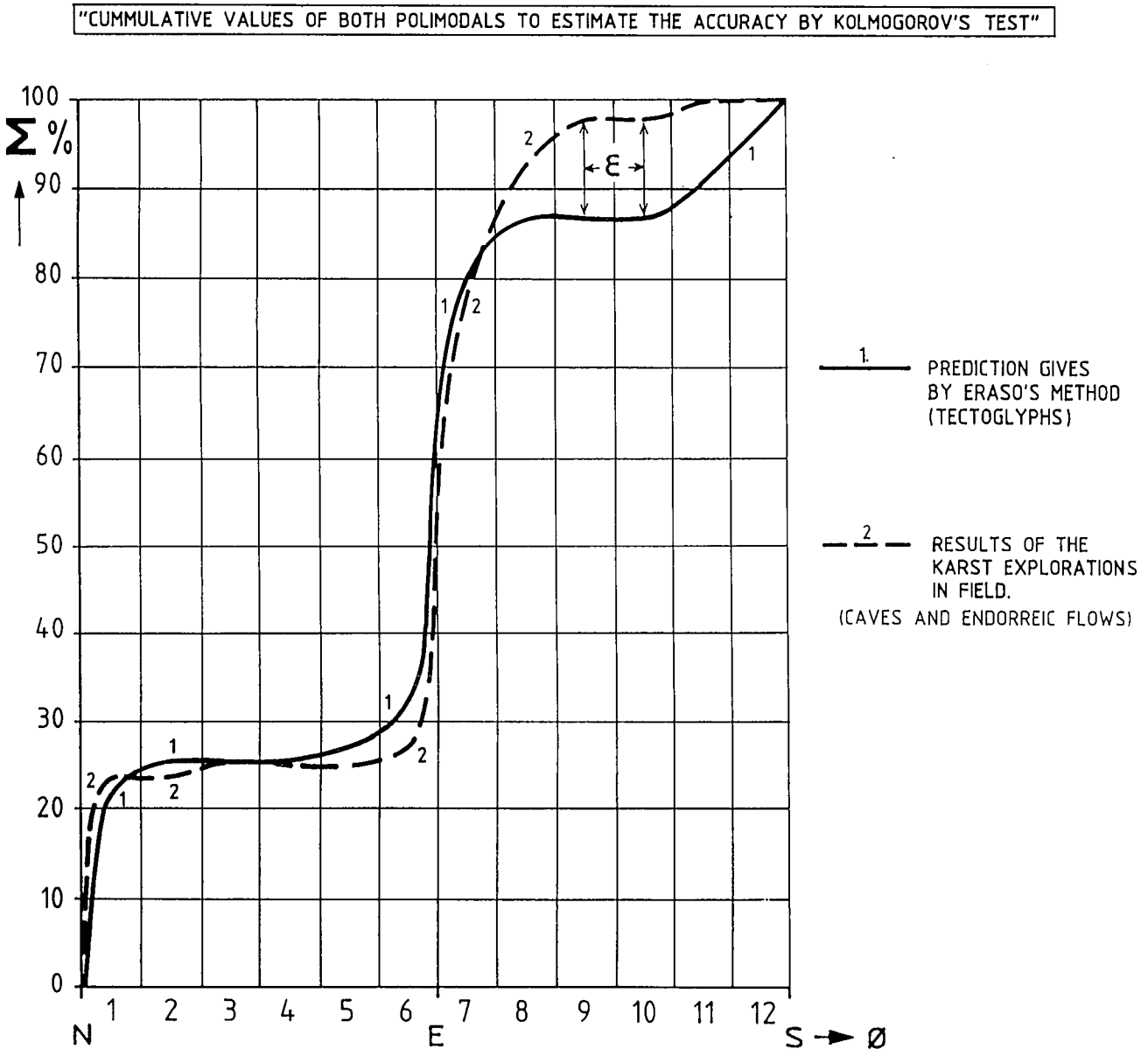


Fig. 5.-Cummulative values of both polimodals to estimate the accuracy by Kolmogorov's test.
Fig. 5.-Valor acumulativo de ambas polimodales para estimar el grado de precisión por el test de Kolmogorov.

Figure 3 is a polimodal of karstic flow direction gives by the prediction method, and also shows a similar position end amount of both modes of subterrain flow:

— The main direction of N90°-N105° with 47.73% probability and
— The associate direction of N0°-N15° with 22.72% probability.

Figure 4 is a comparison between both directional probability polimodal. With the values of table 3 the polimodals are constructed. The results are given in figure 5.

A very important indication of the field investigation results is that the karst seems to be *really Shallow Karst* with very little penetration.

In fact the depth of karst channels seems to be at a maximun of between 20 to 30 m, and its size at a maximum of 1.3-1.8 m. This is based exclusively on observations from caving and existing cave maps.

One stated exception of the last affirmation is the Yangrotten. This cave is an old ponor (sump, inlet) in which the main gallery has 4-5 m width for more than 50 m length, and its depth is nearly 40 m, all in marble.

This ponor, placed 1.5 km to the NW of Dam site 3, collects the drainage coming from the eastern slope of Synkenhogda, where the height is about 800 m. Similar natural conditions aren't found north of the Dam site 3. Similar karst development is therefore not expec-

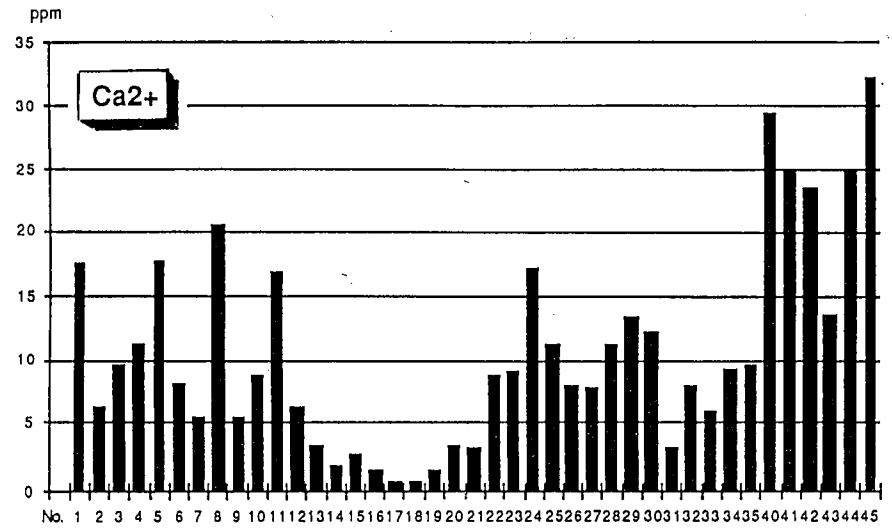


Fig. 6.-$Ca^{2+}$ content of the analysed water series.
Fig. 6.-Contenido en $Ca^{2+}$ de la serie de aguas analizadas.

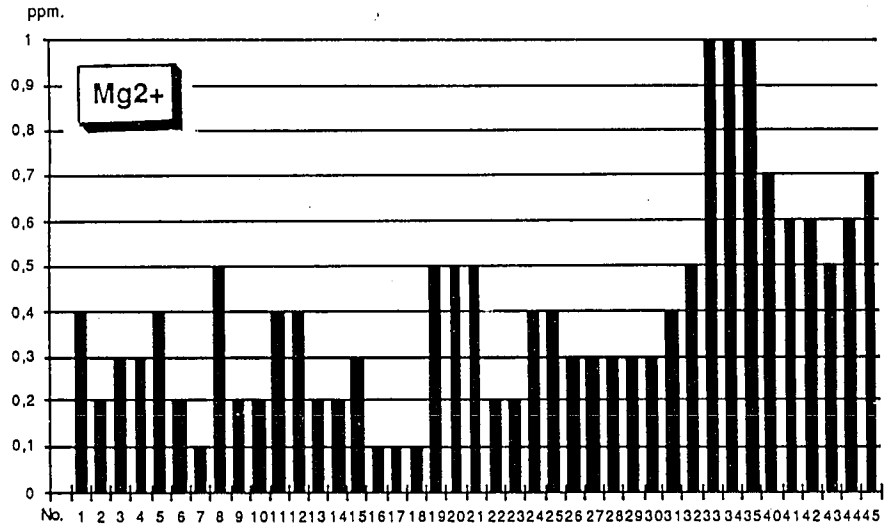


Fig. 7.-$Mg^{2+}$ content of the analyses water series.
Fig. 7.-Contenido en $Mg^{2+}$ de la serie de aguas analizadas.

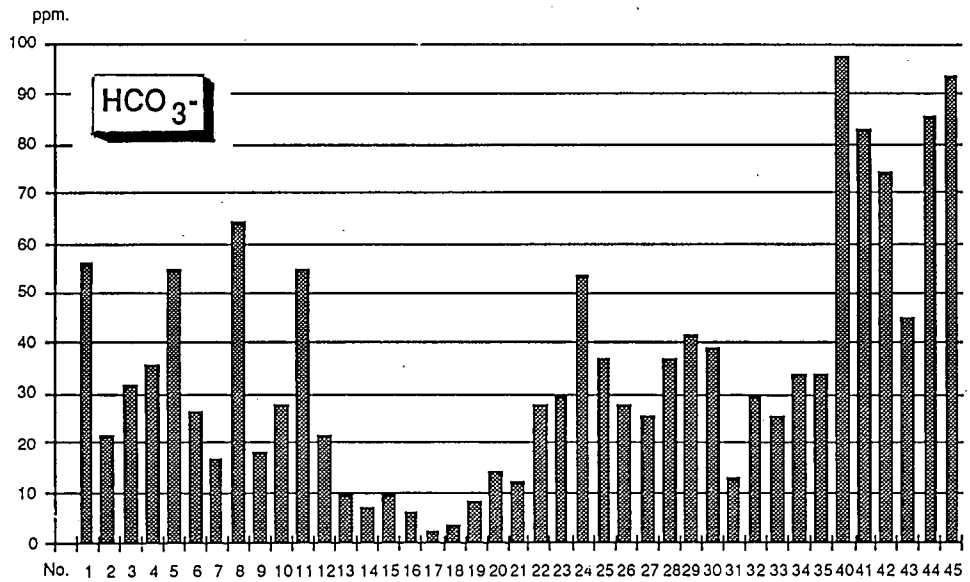


Fig. 8.-$HCO_3$ content of the analyses water series.
Fig. 8.-Contenido en $HCO_3$ de la serie de aguas analizadas.

ted in the dam site areas.

Filling material in caves and conduits are very important to detect before grouting jobs, as they modify the operations to prevent leakage. Bad grouting works might also give different leakage afterwards.

Finally, with all described information given by karst field investigations, the Prediction Method gives a possibility of making accurate verdict as a basis for civil engineering works, and thus selection of the most adequate dam site.

### 3.2. Hydrochemical analyses

The chemical analyses are carried out by the laboratory of Norsk Jerverk A/S, Mo i Rana. The water samples are analysed by the AAS method Atom Absorbtion Spectrometer). (Table 4 and 5).

Investigation of water connections and travelling time through channel systems was difficult, due to aridity. Lack of precipitation during the field work period created conditions of water shortage, both in brooklets and groundwater streams.

In several places, it was possible to watch the subsurface waterflow through karst windows. The travelling time was allways very short, a mean of 10-15 min.pr.100 m.

The appearance of tracer was allways at the eastern hillside of river Navnloselva, running west of the starting point. The dye never outcropped more than 50 m bellow the surface. (vertical measured).

## 4. COMMENT TO THE CHEMICAL CHARTS

All descriptions and detailled explanations of the hydrochemical conditions can be found in Lund (1986) which takes in account governing denudation rates. Nevertheless, some specific features must be remarked.

The content of dissolved minerals shows great variability. The content of $Ca^{2+}$, $Mg^{2+}$ and $HCO_3^-$, however, show higher values in samples taken from springs and brooklets in the dam areas (figures 6, 7 and 8). Samples nos. 30-35 and nos. 40-45 are all taken in the Dam Site 3 area. Nos. 30-35 are sampled in July when the water flow was high. In Sepetember (nos.40-45) the water flow was lower, and then the residue time increased. As seen from the histogrammes, the mineral content is higher in these samples. This indicates a high solution rate in the Dam Site area, which corresponds nicely with the observations of the most developed karstic features of those found in the dam areas.

## 5. CONCLUSIONS

*1st.* The karst drainage in the area is developed in two directions only: The main in N90°-N105° and the associate in N0°-N15°. The most adequate orientation of the grouting curtain is given by the bisectric between both directions.

*2nd.* The karst is shallow, probably not reaching underground dephts bellow 40m in this area. The need for a grouting curtain should be down to 50-70 m from excavation limit in the dam axis.

*3rd.* The open karst is actually shallow karst, probably developed after the retreat of the glaciers. The evidence of paleokarst developed before the glaciation or interstadial is limited. The filling material found is not of paleokarstic character.

*4th.* There aren't qualitative differences in the karst of the two dam site alternatives. Both alternatives are available for dam construction after grouting operations at the north side.

*5th.* In the Holmvatn area the karst also seems to be of a shallow type. The drainage direction is the same as in Storglomvatn dam area. There does'n seem to be any risk of leakage towards Bjornholet spring. This statement is based on the hypothesis that we are dealing with only one continuous marble band. Leakage in that direction is only possible when the conditions of deep karst exist.

*6th.* The degree of accuracy given by the Prediction Method in this area of artic norway is 96,81%. Similar results are found at other latitudes and karstic rocks (Eraso 1983, 1985, 1986a, 1986b and 1986c).

*7th.* The watertracing results state the previous conclusion of only shallow karst in the dam site areas. The short travelling time, 10-15 min/100 m, in spite of very little waterflow, indicates very shallow penetration and straight, uncomplicated shapes of the karst channels, following the topography 10-30 m underground estimated by the height difference between the starting point and the spots of outcropping dye.

*8th.* The mineral content of the marble, according to the analysed rock sample, show a marble of medium corrosion resistance in mean. The cavity prosess creating the diferent karst features takes part where the $CaCO_3$ and other minerals with small weathering resistance is most present and fissured and cracks assambles the run off and groundwater.

The $CaCO_3$ content is high, but not as much as the content of $SiO_2$ or other minerals (table 4). Earlier denudation measurements have given values as 27-39 mm/1000 y. as result. Converted to field observations and findings, the age of the Storglomvatn karst is most likely postglacial.

*9th.* The results of the water analyses (table 5), give both the dissolved marble and remaining corrosion potential.

The corrosion potential is high. The residue time of the karst water is too short to dissolve as much $CaCO_3$ as the aggresive water gives possibilities for, hence, the stored water might keep on corroding karst channels and also the dam concrete. The time aspect here, however, could be too large to create any threat for the dam constructions. Natural karst development and leakage could be a problem if serious cautions are not carried out when grouting. However, such development is known from other dam site locations in the Svartisen area, where serious leakage is discovered 10-15 years after construction of the dams.

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