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**MAPPING AND EVALUATION OF
GROUNDWATER IN THE WAJID
SANDSTONE OF THE
SA'DAH REGION**

**Final Report
September 1993**

DHV CONSULTANTS bv
in association with
TEAM CONSULTING ENGINEERS CO. LTD
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PREFACE

This report was prepared by Mr. Chinda Piromsuttipong, hydrogeologist, from the staff of Team Consulting Engineers.

Although the report deals principally with the Wajid Sandstone, preliminary work was also carried out on the Kohlan sandstone around Hajjah. This work led to the conclusion that its potential as an aquifer is so low that more detailed studies were not justified.

Desk studies leading to the production of the first draft of the geological map, were carried out between June and September 1991; fieldwork over a six week period in November and December 1991; and the final mapping and reporting in February and March 1992.

The draft report was issued in March 1992 for review and comment. The results of this study were used in the groundwater resources study for the Sa'dah Target Area, which formed a basis for the Water Management Plan of that area.

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1 INTRODUCTION

As stated in the inception report, the mapping of the Wajid Sandstone in the Sa'dah governate and the Kohlan Sandstone in the Hajjah governate was done as part of the data collection for a Water Management Plan for the Northern Region Agricultural Development Project. The main objective of the study was to determine the extent of these sandstones and to estimate the volume of exploitable groundwater of the formations.

2 KOHLAN SANDSTONE AROUND HAJJAH INVESTIGATION AND FINDINGS

A geological map of Yemen, 1:500,000 scale, prepared by M.J. Grolier and M.C. Overstreet in 1983, shows the extent of the Kohlan sandstone in the Hajjah governate.

Results of preliminary studies of aerial photographs and satellite images, together with field reconnaissance, show that the Kohlan Sandstone outcrops in only a small area, especially on the slope of escarpments topped by the Amran Limestone and underlain by the Akbra Shale.

The geological map, sheet Al Hodaydah at 1:250,000 scale prepared by W. Kruck in 1984, gives valuable additional data, confirms the restricted outcrop area of the Kohlan Sandstone and shows the thickness of the formation to be about 70-90 m.

As a result of these findings further detailed mapping of the Kohlan Sandstone was not considered to be justified.

Wajid Sandstone Mapping; Sa'dah

3 WAJID SANDSTONE IN THE SA'DAH GOVERNATE

3.1. LOCATION AND TOPOGRAPHY

The study area is located in the northern region of the Republic of Yemen, Sa'dah governate, between 16° 33' to 17° 35' North and 42° 13' to 44° 15' East. It lies in the catchment area of Wadi Najran. Based on the geographical units system originally developed by the Swiss Airphoto Interpretation Team in 1978, the area is situated in the northern highland geographical unit where elevation is over 1,500 m amsl.

To the west the area is bounded by the mountain ranges of the Precambrian Basement Complex. In the north and the east it joins the Kingdom of Saudi Arabia. To the south the boundary is delimited by the mountainous terrain of the Amran Limestone, Kohlan Sandstone and Akbra Shale.

About 70% of the area is mountainous terrain, while the rest consists of intermontane basins formed by graben and horst structures, for example, Sa'dah, Baqim, Mahathir, and Abdin Plains.

3.2 HYDROGEOLOGICAL MAPPING : TECHNICAL ACTIVITIES

3.2.1 Collection and Review of Existing Information/Data

The available information and data that were collected and reviewed are listed below:

- (1) Topographic maps with a scale of 1:50,000, 1:250,000 and 1:500,000
- (2) Geological map of the Yemen Arab Republic (Sana'a), 1:500,000 scale, prepared by M.J. Grolier and M.C. Overstreet, reprinted in 1983
- (3) Geological maps of the Yemen Arab Republic, 1:250,000 scale:
 - sheet of Sa'dah prepared by N.W. Roland, in 1979
 - sheet of Al Hazm prepared by W. Kruck, in 1980
- (4) Report on Geology of the Yemen Arab Republic, written by Mohamed Ibrahim El-Anbaawy, in 1985
- (5) Satellite images, including MSS and TM images, 1:250,000 scale
- (6) Aerial photographs of Yemen, taken in 1973 and 1980, approximately 1:60,000 scale
- (7) Report on Water Resources of the Sa'dah Area, Report WRAY-3, YOMINCO & TNO-DGV, 1985.

3.2.2 Airphoto Interpretation/Initial Map Preparation

On the basis of these geological maps boundaries, especially those of the Upper and Lower Wajid Sandstone, and structures were interpreted on the aerial photographs. These results were then transferred to the topographic maps at 1:50,000 scale, from which the draft map of the Wajid sandstone was prepared at 1:100,000 scale.

3.2.3 Field Geological Investigation/Final Map Preparation

Field geological investigations were then performed to confirm geologic boundaries, structures, rock types and, in particular the orientation of the Wajid Sandstone. Information and data obtained from the field were used to complete the map.

3.2.4 Groundwater Level Measuring

Some existing wells assumed to be located in the Wajid Sandstone aquifer were visited and simultaneously well location, altitude and groundwater levels were recorded. Locations of these wells are shown in Figs. 1, 2, 3 and 4 (see also section 3.5.4).

3.2.5 Determination of Saturated Wajid Sandstone Volume

Data derived from field investigations were analysed, and maps showing the base of the Wajid Sandstone base and groundwater levels were plotted. Then the thickness of the saturated Wajid Sandstone was calculated and shown as an isopach map, from which the volume of saturated rock was computed. (see also section 3.5.5)

3.3. GEOLOGY

The geology of the Sa'dah area was initially studied by Geukens in 1966; then in 1979 a more detailed geological investigation was carried out by the German Geological Advisory Group in cooperation with YOMINCO. Finally, the geological maps of Sa'dah governate, including sheets of Sa'dah and Al Hazm, with a scale of 1:250,000, were produced by Roland, N.W. in 1979 and Kruck, W. in 1980, respectively.

The principal stratigraphic units and their lithological and hydrogeological characteristics, according to Van der Gun (1985), are summarized in Table 1.

3.3.1 Stratigraphy

The study area is covered by a large area of the Precambrian to Paleozoic Basement Complexes, Paleozoic to Mesozoic sedimentary rocks, Tertiary to Quaternary volcanic rocks and Quaternary sediments, as shown in Fig.5.

The oldest rocks are of the Precambrian to Paleozoic Basement Complexes. These formations mainly consist of granite gneiss in the western part, schist and orthoclase granite in the eastern part, and mafic to intermediate rocks in the northern part of the area.

The oldest sedimentary rock is the Wajid Sandstone of Cambrian to Permian age, unconformably overlying the Precambrian basement rocks. The name "Wajid Sandstone" is derived from the type section of sandstone, about 950 m thick, found in the south of Saudi Arabia. In the Republic of Yemen, the Wajid Sandstone is exposed only in the Sa'dah governate. According to Roland (1979), the maximum thickness of the Wajid Sandstone in Yemen is approximately 300 m. It constitutes deltaic deposition and can be classified into two rock formations, namely Upper and Lower Wajid Sandstones. The Upper Wajid Sandstone of Carboniferous to Permian age comprises cross-bedded, friable, light-coloured quartz sandstone and intercalations of clay, silt and mud balls. It underlies conformably either the Akbra Shale formation as encountered at Jabal Bahi Uwayr, south-south-west of Sa'dah, or the Kohlan Sandstone formation as found at Jabal Barash, southeast of Sa'dah. The Lower Wajid Sandstone consists of yellow to brown coloured, fairly cross-bedded, medium to coarse grained quartz sandstone, interbedded with quartzitic iron stone. At the base, a thin layer of the basal conglomerate overlies unconformably the basement rocks.

The series of younger sedimentary rocks is the Kohlan Group of Permian to early Jurassic age. The Kohlan Group comprises Permian glacio-marine sediments of the Akbra Shale Formation, and Triassic to early Jurassic red bed sediments of the Kohlan Formation. It usually outcrops on the slope of escarpments that are topped by Jurassic Amran Limestone as are found at Jabal al Mishraf, Jabal Sama and Jabal Khunfuur, near Majz village northeast of Sa'dah, as well as at Jabal Ahsan and Jabal al Abla south of Sa'dah. The Akbra Shale formation is composed of glacio-marine laminated shales containing erratic striated boulders of basement rocks. The Kohlan Formation contains argillaceous siltstone and cross-bedded sandstone with some shale and conglomerate together with calcareous sandstone and limestone in the upper part.

During a major marine transgression in the middle to late Jurassic the Amran Group was deposited, which lies conformably on the Kohlan Group. It comprises dense calcareous rocks alternating with marls and shale and outcrops in the south and the northwest of Sa'dah.

During the formation of the Red Sea, from the end of the Cretaceous age through the Tertiary age, intensive tectonic faulting together with volcanic activities occurred in Yemen. At that time the Yemen Volcanic (Trap Series) formed. The series includes basalt flows, andesite and rhyolite mixed with volcanic tuff, ignimbrites and agglomerate. These rocks were found at Jabal Mara in the west, and Jabal Izzam and Jabal Mandabah in the north of Baqim.

During the Quaternary inland volcanism was reactivated. The Quaternary volcanics are in the form of cones associated with volcanic bombs, lapilli tuff and volcanic ashes as well as lava flows and sheets of basaltic materials. In the study area the Quaternary volcanics outcrop at Jabal Barash southeast of Sa'dah Town.

Quaternary unconsolidated sediments are predominantly composed of alluvial gravels, sands, silts and clays that accumulated in the narrow wadis of the mountainous area and in the wash plains such as Sa'dah, Mahathir, Abdin and Baqim Plains. Colluvium is also found along the base of mountains. In the Sa'dah Plain and in the western

part of the Abdin Plain, the thickness of Quaternary unconsolidated sediments varies from 10 m to 40 m.

3.2 Geological Structure

At the end of the Cretaceous and at the beginning of the Tertiary ages regional uplift and block faulting occurred in association with the opening of the Red Sea. This caused the formation of structural-geological features in the area, the most important of these are horsts and grabens. The dominant faults, fractures and lineaments are oriented NNW-SSE and N-S. Bedding plane orientation of the sedimentary rocks overlying the basement rocks is nearly horizontal.

4 AQUIFERS

Aquifers in the Sa'dah area can be divided into four units, namely

- (1) Wajid Sandstone aquifer unit, probably also the Kohlan Sandstone in the Sa'dah and the Abdin Plains,
- (2) Amran Limestone aquifer unit,
- (3) Wadi sediment aquifer unit,
- (4) Precambrian basement rock aquifer unit.

4.1 Wajid Sandstone Aquifer Unit

The most important aquifer unit in the area is the Wajid Sandstone underlying unconsolidated sediments in the Sa'dah, Mahathir, Abdin and Baqim Plains as well as in the areas outside these plains. Details of the Wajid Sandstone aquifer unit are given in section 3.5.

4.2 Amran Limestone Aquifer Unit

The Amran Limestone aquifer unit is situated mostly in the south and to some extent in the northwest of the Sa'dah Plain. It consists of dense limestones intercalated with marl and shale. Groundwater storage and flow depend on the characteristics of cracks and fissures. In general, it is considered as a poor aquifer of which the yield is less than 5 l/s (Van Der Gun, 1983). The maximum thickness is approximately 300-320 m. Compared to the underlying Wajid Sandstone the Amran Limestone may be considered as a confining layer or aquitard.

4.3 Wadi Sediment Aquifer Unit

The wadi sediment aquifer unit is composed of Quaternary unconsolidated sediments, and is found along the wadis. It is usually narrow and of limited horizontal extent compared to the Wajid Sandstone and the Amran Limestone aquifers, but has good hydraulic properties. In the Sa'dah Plain and the west of Abdin Plain its thickness ranges from 10 to 40 m and currently it is mostly unsaturated. However, this aquifer

is still an important shallow groundwater resource here and in the Mahathir Plain.

3.4.4 Precambrian Basement Rock Aquifer Unit

The Precambrian basement rock aquifer unit is considered a poor aquifer. Small amounts of groundwater can be obtained only from weathered and fractured zones at shallow depth.

3.5. WAJID SANDSTONE AQUIFER

3.5.1 Extent

A map showing the extent of the Wajid Sandstone in the Sa'dah area is presented in Fig.5. As a potential aquifer it can be divided into four major regions, as follows:

Sa'dah Plain

The Sa'dah Plain covers the upstream part of the catchment area (1,147 km²) of Wadi Marvan, a tributary of Wadi Najran. The plain is surrounded by the mountainous terrain of the Amran Limestone in the south, the Precambrian basement rocks in the west, the Precambrian basement rocks and the Wajid Sandstone in the east and the northeast, and the Wajid Sandstone in the northwest. On the plain the Wajid Sandstone, both upper and lower parts and probably including the overlying Kohlan Sandstone, is overlain by Quaternary unconsolidated sediments the thickness of which ranges from 10 m to 40 m.

According to Van Overmeeren (1985a and 1985b) and Elewaut (1985) the thickness of the Lower Wajid sandstone to the underlying basement rocks varies from 100-150 m locally in the northern part up to 600-650 m in the central and eastern parts. The horsts and grabens are considered as the most important geological structures controlling the depth of the Wajid Sandstone. Fig.6 shows the depth to basement rocks in the Sa'dah plain.

Region North of the Sa'dah Plain

This region extends from the northern edge of the Sa'dah Plain to the Saudi Arabian border in the north of Yemen. In the west it is bounded by faults, basement rocks, and Quaternary volcanic rocks, while in the east the Wajid Sandstone lies on the basement rocks. The area comprises the mountainous terrain of the Wajid Sandstone and the intermontane basins underlain by the Wajid Sandstone, such as the Baqim Plain.

Region East of the Sa'dah Plain

This region covers the Abdin Plain to the southeast, which runs parallel to the limestone mountain range, and to the northeast includes the plains around As Sahlayn, Zarir, and Al Ushash villages as well as the hilly terrain between. The Abdin Plain is bordered by a fault in the northeast and Amran Limestone/Kohlan Sandstone mountains in the southwest. It is covered by Quaternary unconsolidated sands and gravels, usually 10-40 m thick in the western part near the Sa'dah Plain, but only by very thin layers of Quaternary sands in the eastern part near Jabal Barash. Locally, exposure of the Wajid Sandstone was observed. In the wadi near Dammaj village at

the central part of the Abdin Plain, the Kohlan Sandstone and the Akbra Shale outcrop. Other plains in this area are also covered by thin layers of Quaternary unconsolidated sediments.

Region South of the Sa'dah Plain (Mahathir Plain)

The potential areas for the Wajid Sandstone aquifer in this area are the Mahathir Plain and a small area of Wadi Alaf.

The Mahathir Plain is confined by two NW-SE faults at the northeast and southwest boundaries. The Wajid Sandstone is exposed and overlies Precambrian dark-coloured schist, at the northwest of the plain and dips to the southeast underneath the mountains formed by the sequence of the Amran Limestone, the Kohlan Sandstone and the Akbra Shale. Presumably, the thickness of the Wajid Sandstone aquifer increases from the northwest to the southeast.

Wadi Alaf is located in the northwest of the Mahathir Plain. It is bounded by a NW-SE fault on the northeast and lies on Precambrian gneissic granite in the southwest. The Wajid Sandstone dips predominantly to the northeast and its thickness increases from the southwest to the northeast. Due to the small extent of the Wajid Sandstone here this area will be disregarded in the determination of saturated aquifer volume.

5.2 Characteristics of the Wajid Sandstone

The average porosity of the Wajid Sandstone ranges from 0.05 to 0.15 (Gamal et al, 1985b; Elewaut, 1985) and the average specific yield (effective porosity) is approximately 0.075. Results of aquifer tests reveal that the permeability is in the range of 0.1-0.3 m/day (Gamal et al., 1985b) and transmissivity values vary from 20 to 100 m²/day.

5.3 Level of the Wajid Sandstone Base

Results of geophysical surveys and exploratory drilling in the Sa'dah Plain carried out by the WRAY-3 Project (Van Overmeeren, 1985a and 1985b; Elewaut, 1985) reveal that the depth of the Wajid Sandstone base is in the range of 100-650 m. From these results, the elevation above mean sea level of the Wajid Sandstone base can be determined. (see Fig. 7.)

For the areas of Wajid Sandstone to the north, east and south of the Sa'dah Plain data on depth are not available.

However, using geological field data and the findings of Roland, 1979, the depth of the base of the Wajid Sandstone has been estimated. Contour maps showing the elevation above mean sea level in these areas are shown as Fig. 8, 9 and 10.

5.4 Groundwater Levels

Groundwater levels in the Wajid Sandstone were assessed by measuring depths to water in deep wells in the plains of Sa'dah, Mahathir and Abdin. Because of the small number of wells available, groundwater levels in other areas were obtained by extrapolating from the nearest wells and assuming that the groundwater level

approximately follows the topography. Figure 11, 12, 13 and 14 show the altitude of groundwater levels in the Sa'dah Plain, the regions north and east of the Sa'dah Plain, and the Mahathir Plain, respectively.

Groundwater in the Sa'dah Plain flows from the north, west, east and south to Wadi Marwan in the northeast of the Sa'dah Plain. In the Mahathir Plain groundwater flows from the northwest to the southeast underneath the mountains of the Amran and Kohlan Groups. In the Abdin Plain the groundwater divide is at the middle of the plain. This means that in the western part of the plain groundwater flows toward the Sa'dah Plain, while in the eastern part groundwater flows toward Wadi Madhab.

3.5.5 Volume of Saturated Wajid Sandstone

Data on the depth to the base of the Wajid Sandstone and groundwater levels were used to determine the thickness of the saturated aquifer and to compose isopach maps, which are shown in Fig.15, 16, 17 and 18.

By applying the average end area method the volume of saturated aquifer was estimated from the isopach maps. An average effective porosity or specific yield of 0.075, obtained from the studies of YOMINCO & TNO-DGV (1985), was used to compute the exploitable groundwater volume. The results of the calculation are summarized below.

	Location	Saturated Wajid Sandstone	Volume (Mm ³) Exploitable Groundwater
1.	Sa'dah Plain	105,000	8,000
2.	Northern Region	159,000	12,000
3.	Eastern Region	24,000	2,000
4.	Southern Region (Mahathir Plain)	4,000	300
	Total	292,000	22,300

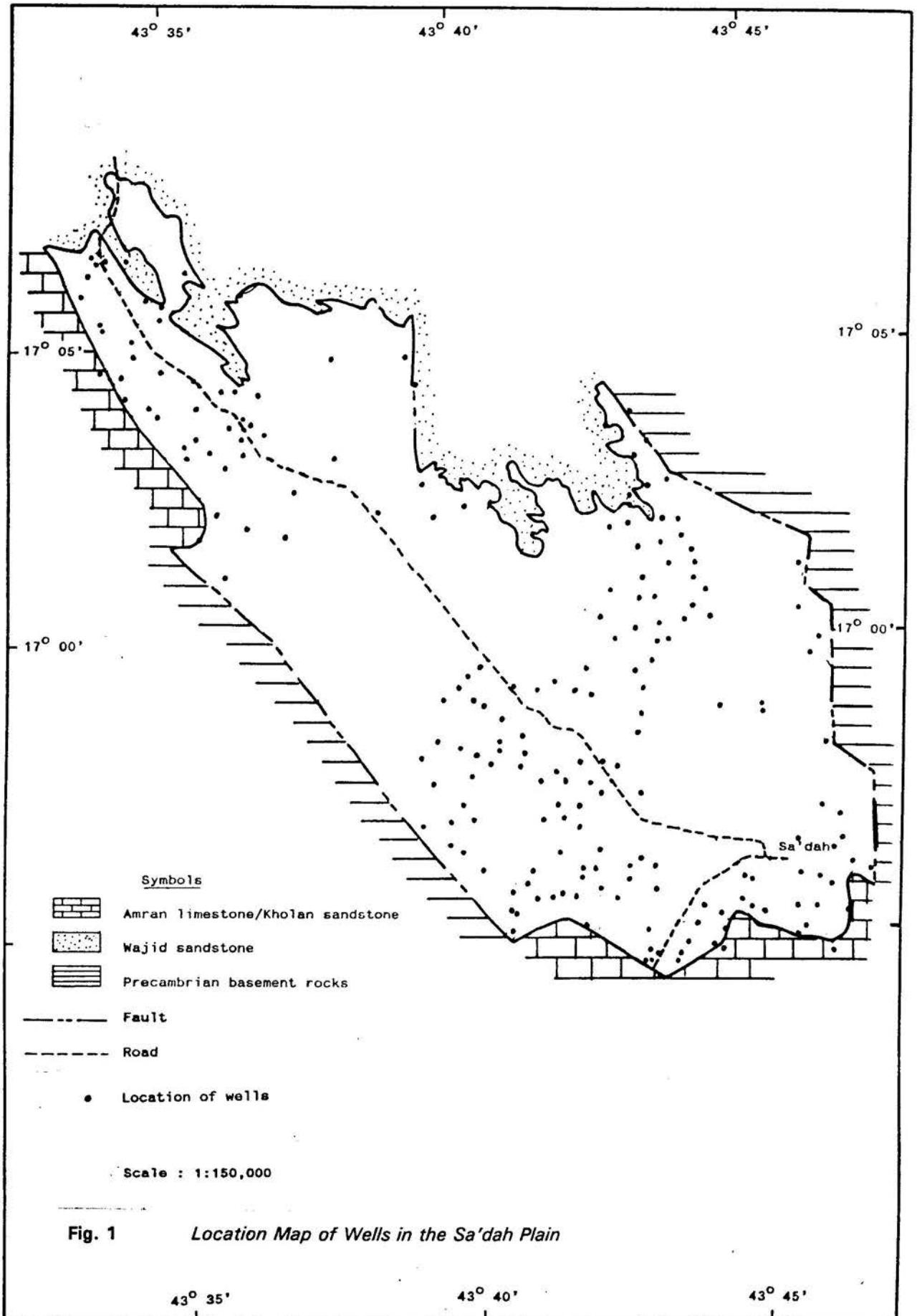
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APPENDIX 1
TABLES AND FIGURES

Table 1 Principal Stratigraphic Units and their Lithological and Hydrological Characteristics
(Source: Van Der Gun, 1985)

	GEOCHRONOLOGY	LITHOSTRATIGRAPHY	LITHOLOGY	HYDROGEOLOGY
PHONON-2	Quaternary	Recent unconsolidated deposits	gravels, sands, silts, clays	medium to high permeability; shallow aquifer pockets in/ along wadi beds; mostly unsaturated on the Sadah Plain
	Tertiary	Yemen Volcanics (Trap Series)	basalts, andesites, rhyolites, tuffs	variable, but generally low permeability; hydrogeologically insignificant in the Sada area
PHONON-1	(unconformity)			
	Jurassic	Amran Limestone	partly dolomitic or ferruginous limestone; alternating with shales and marls	poor aquifer, permeable zones limited to fracture zones
	Triassic	Kohlhan Sandstone	fine-grained quartz sands	potential aquifer
	Permian	Akbra Shales	glacio-marine laminated shales, containing boulders of basement rocks	low permeability (aquitard/aquiclude)
PHONON-3	Carboniferous	(Upper) Wajid Sandstone	crossbedded medium- to coarse-grained quartz sands with intercalations of clays and silts	
	(unconformity)			poor to moderate aquifer
	Ordovician	(Lower) Wajid Sandstone	crossbedded medium- to coarse-grained quartz sands; thin quartzitic ironstones; thin basal conglomerates	
PHONON-4	Cambrian	Basement Complex	granites, gneisses, schists, quartzites	impermeable bedrock; locally some water may be present in cracks, fissures and weathered zones near the surface



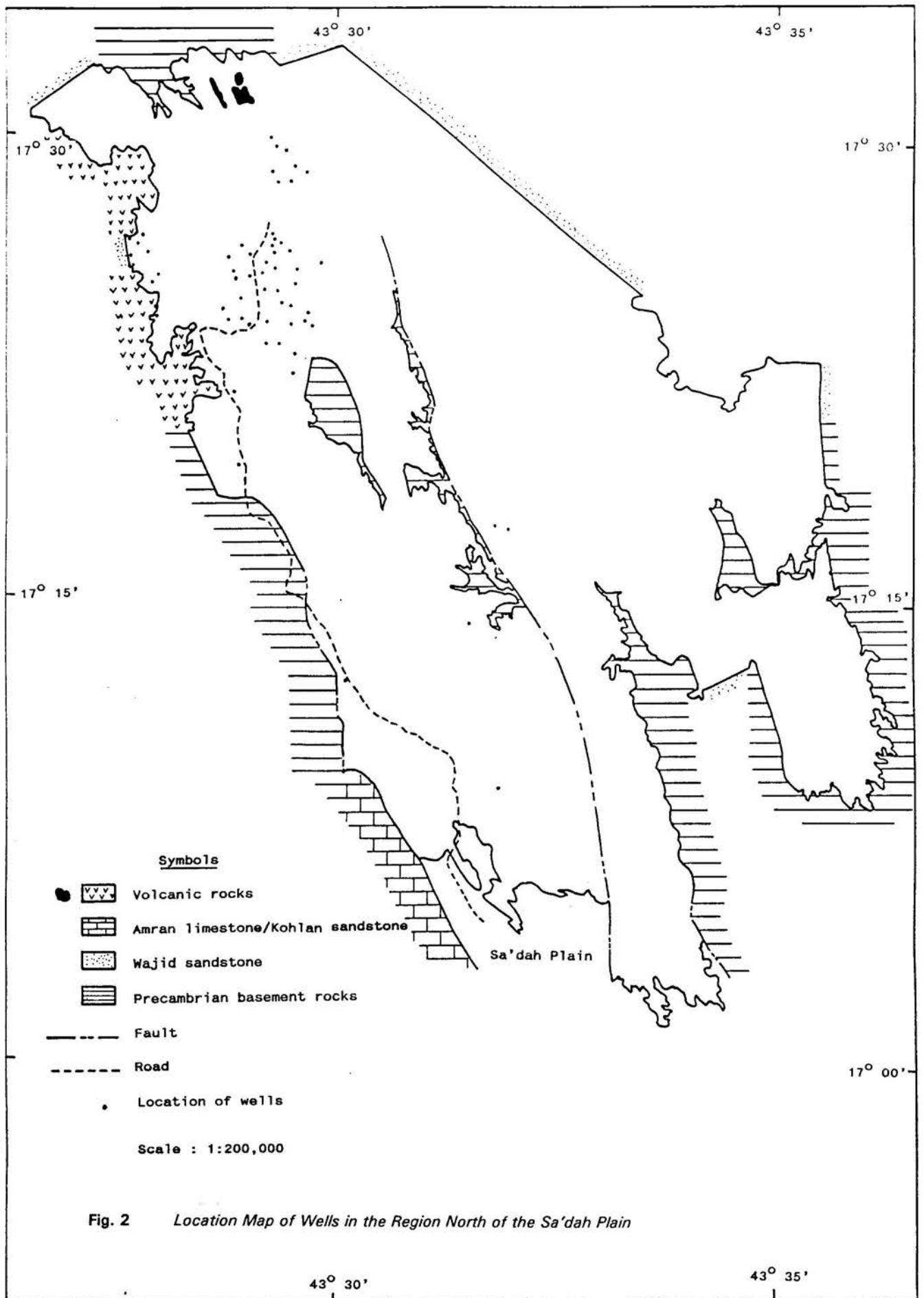
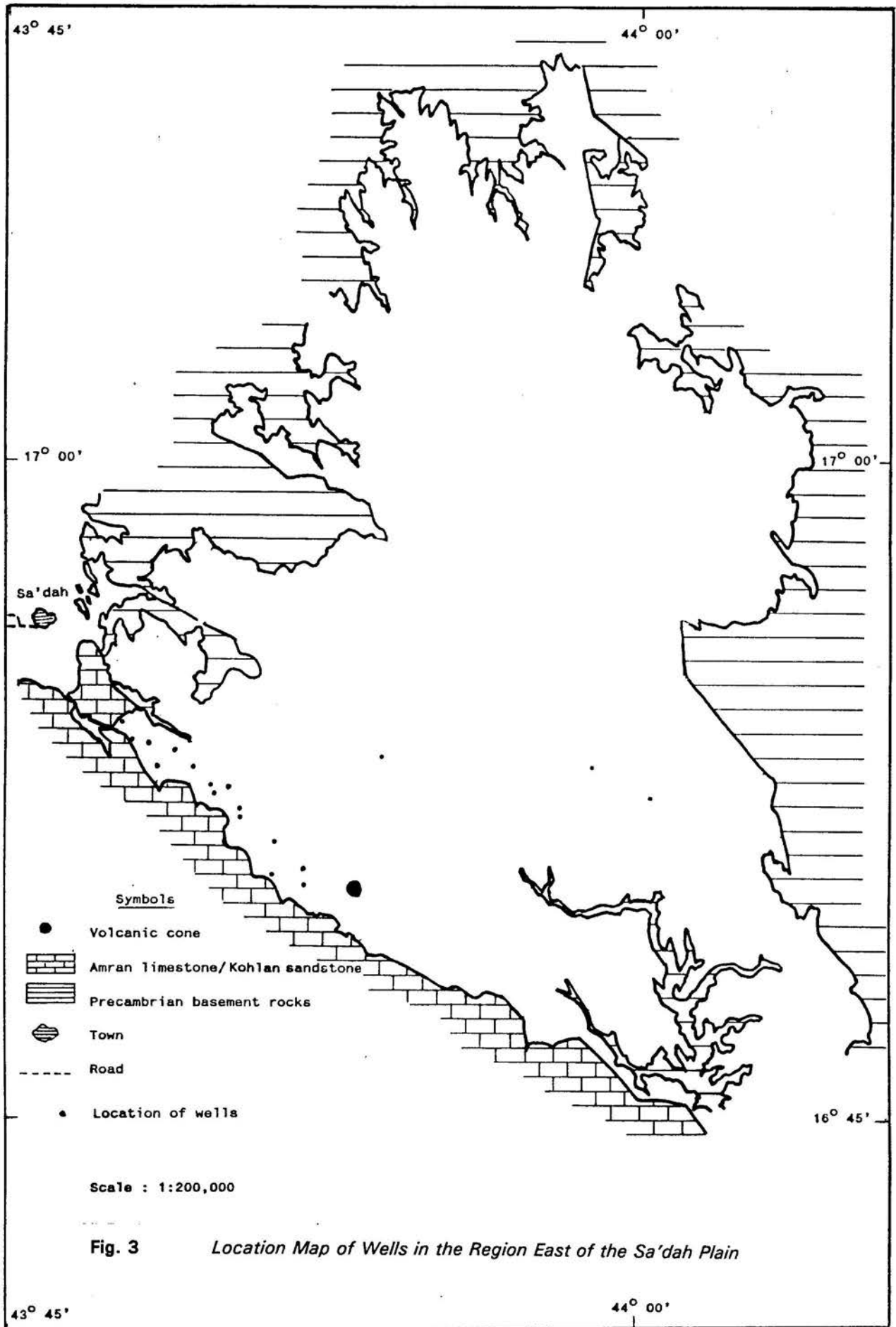
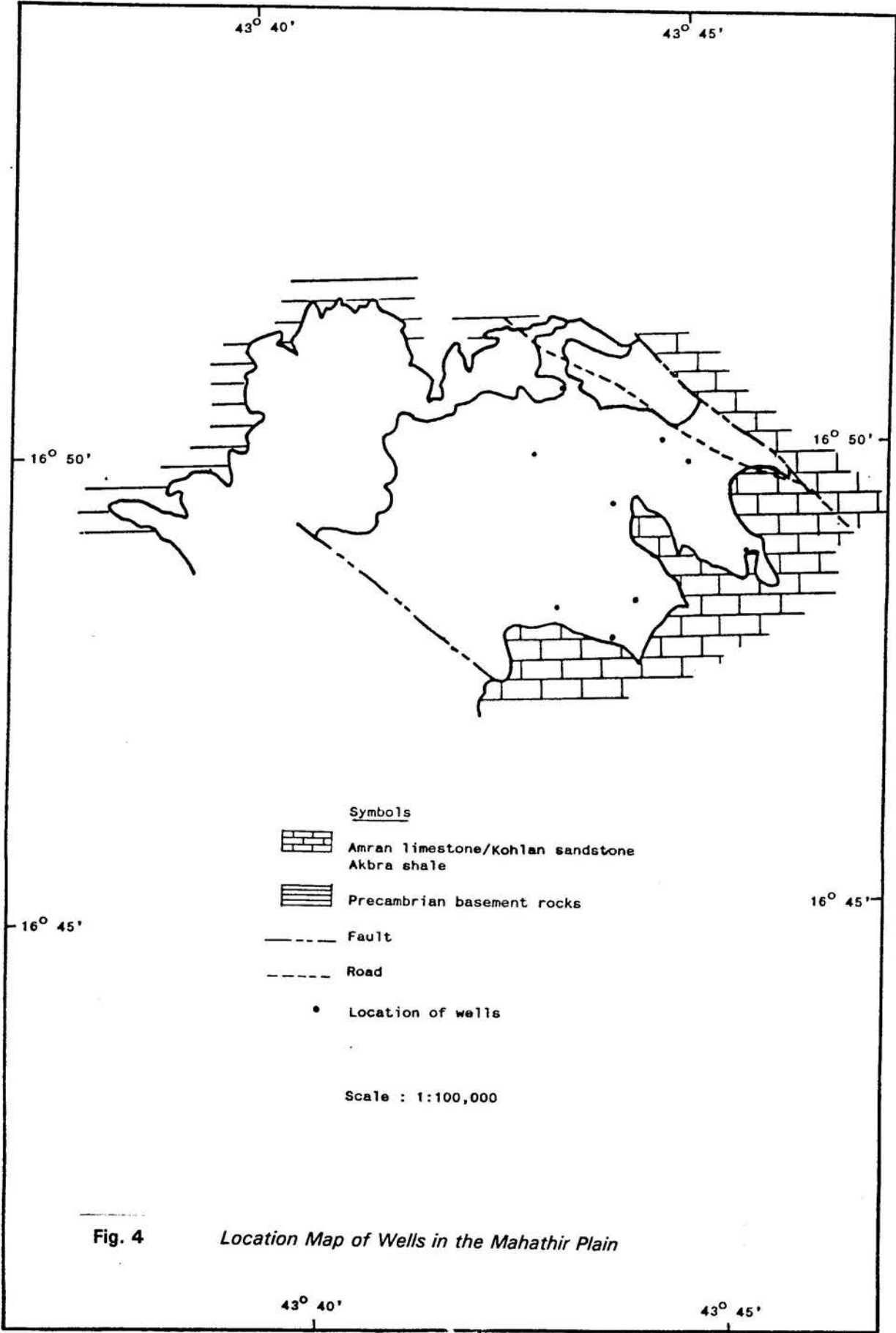


Fig. 2 Location Map of Wells in the Region North of the Sa'dah Plain





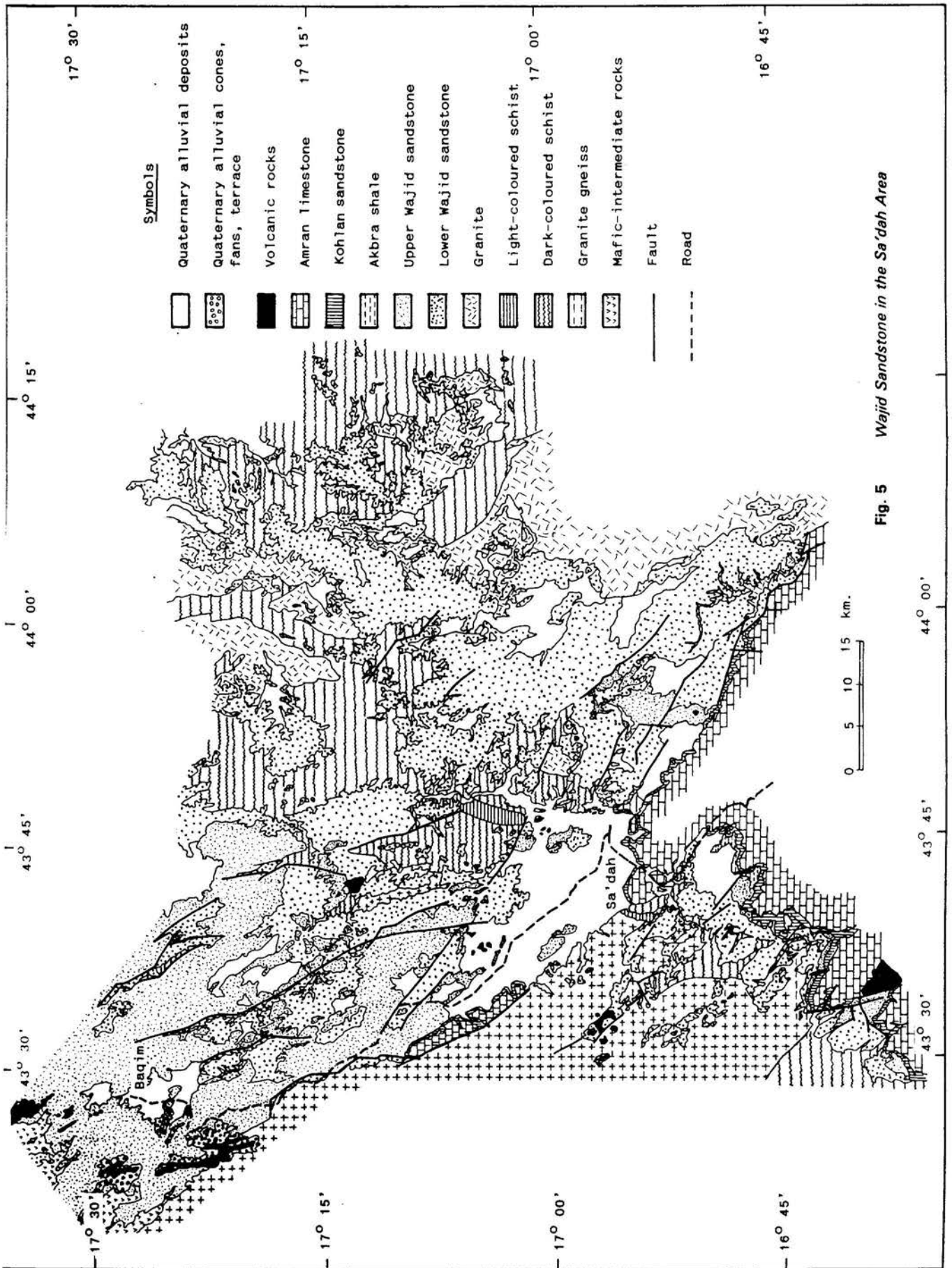


Fig. 5 Wajid Sandstone in the Sa'dah Area

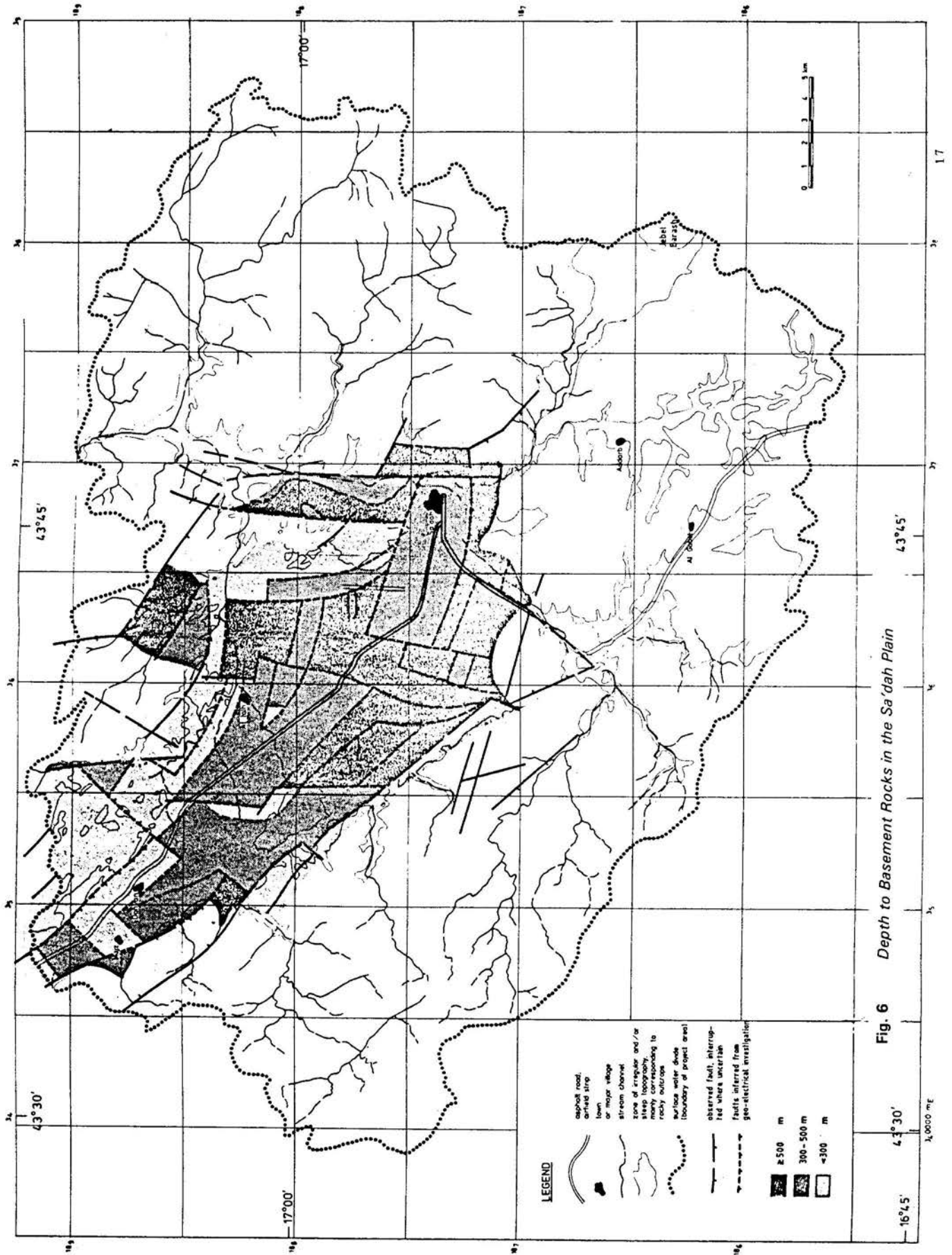
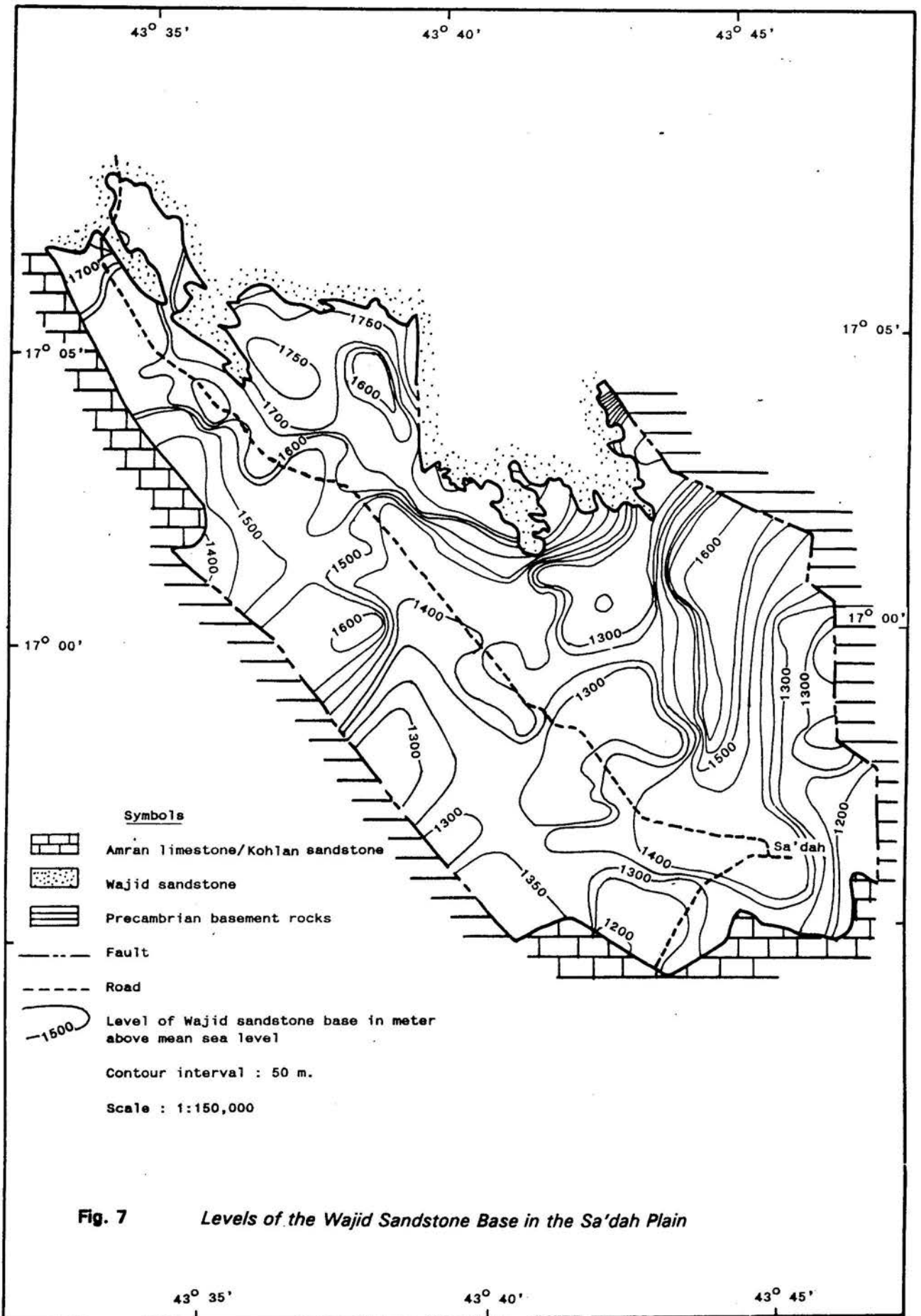
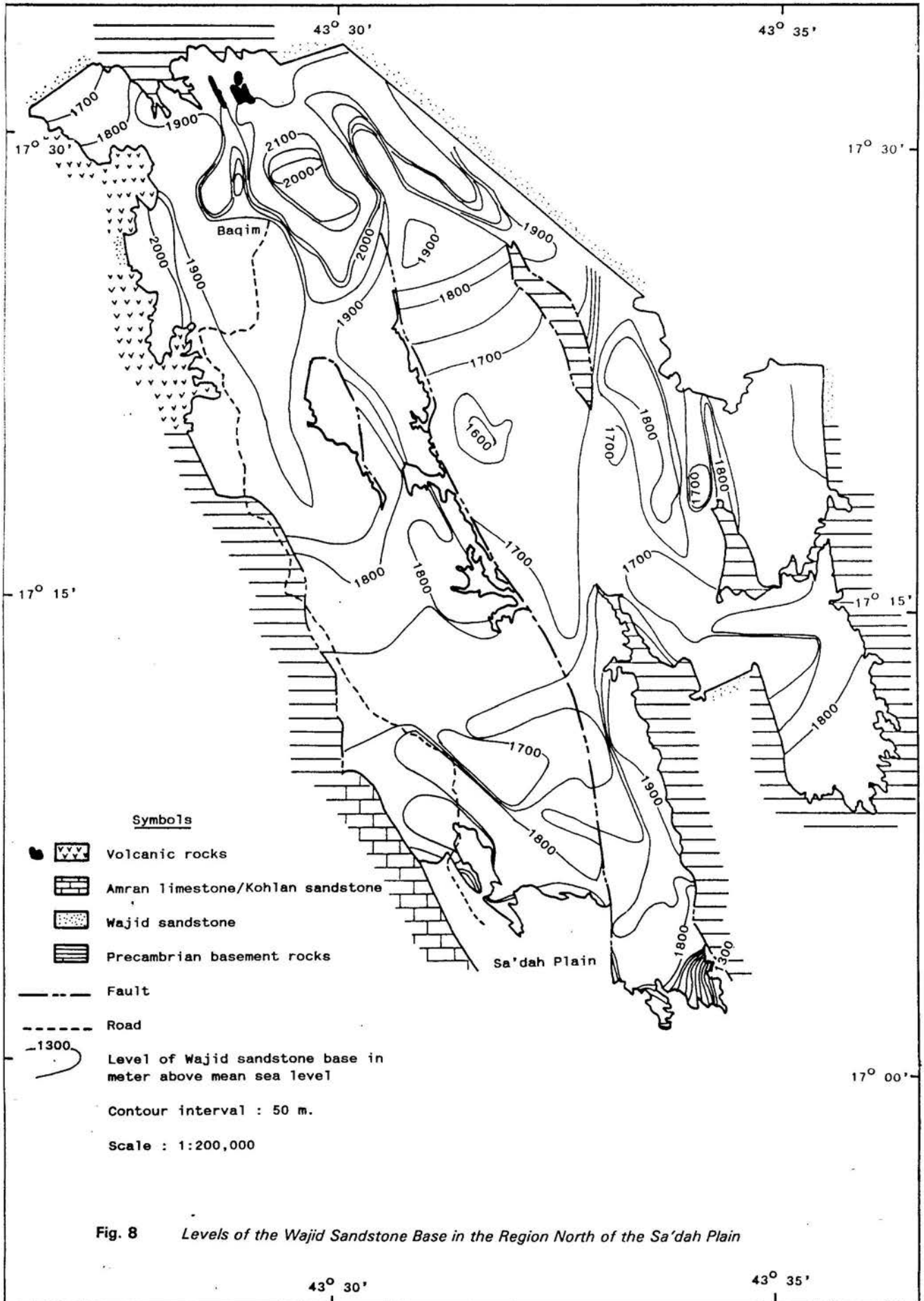


Fig. 6 Depth to Basement Rocks in the Sa'dah Plain





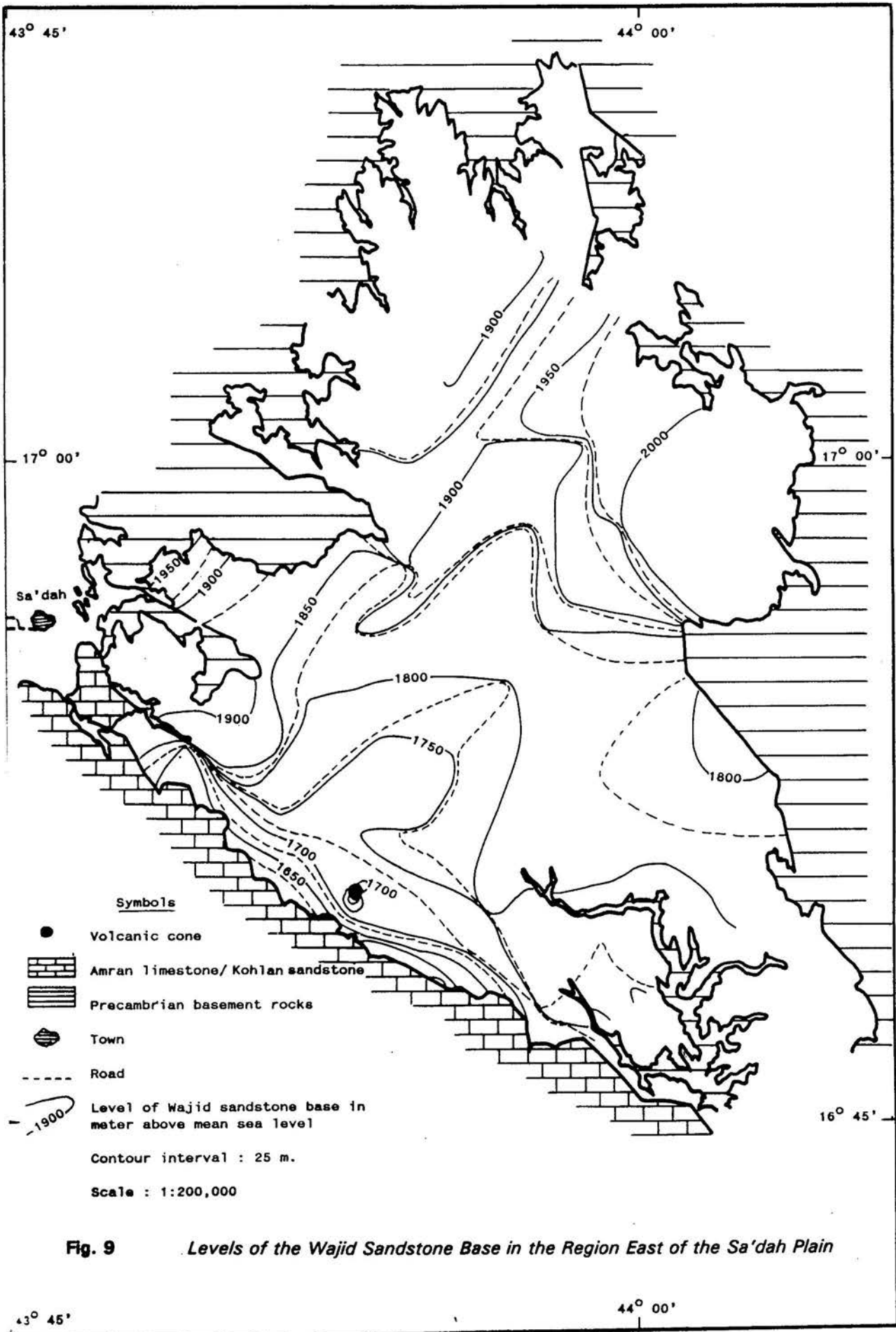


Fig. 9 Levels of the Wajid Sandstone Base in the Region East of the Sa'dah Plain

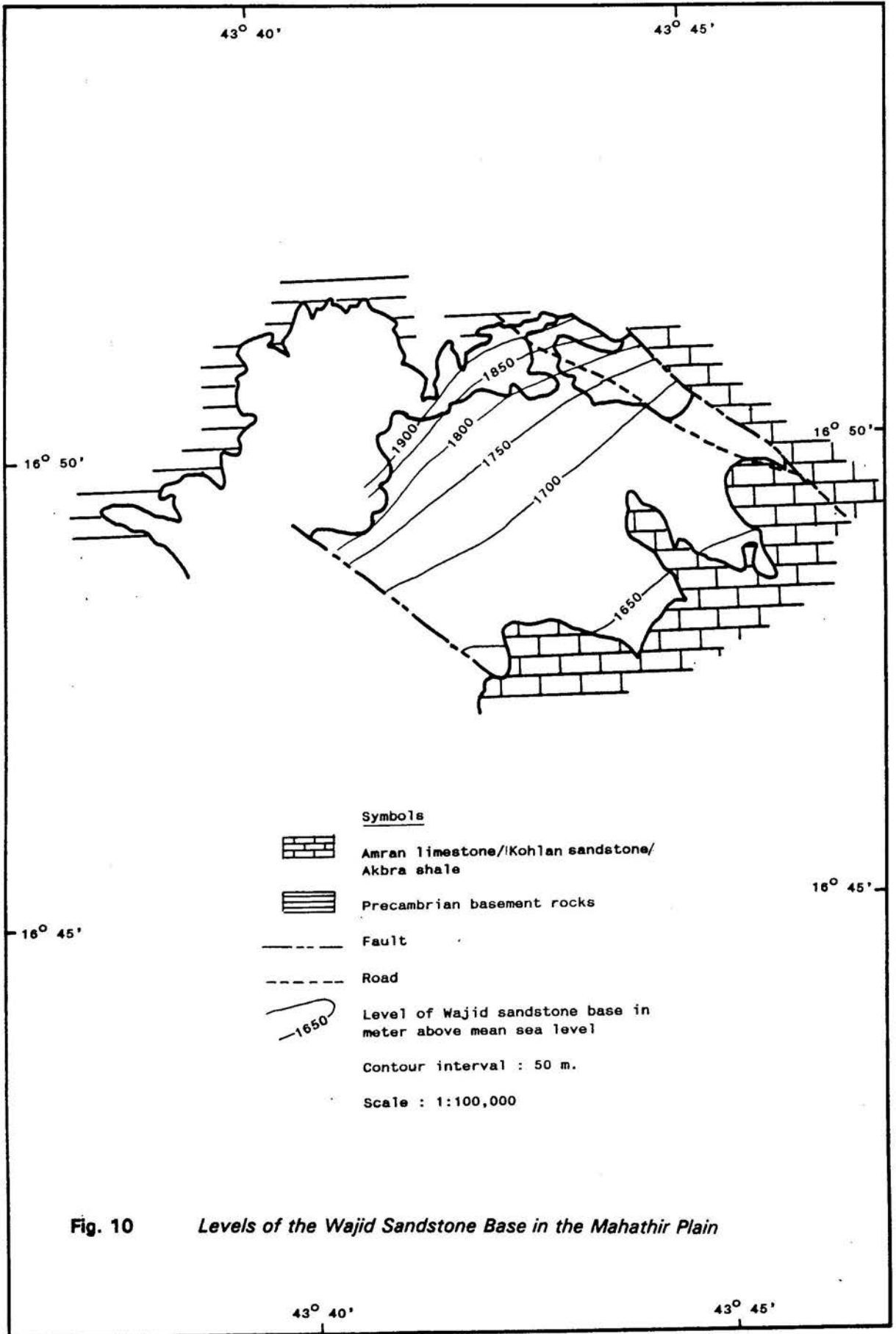
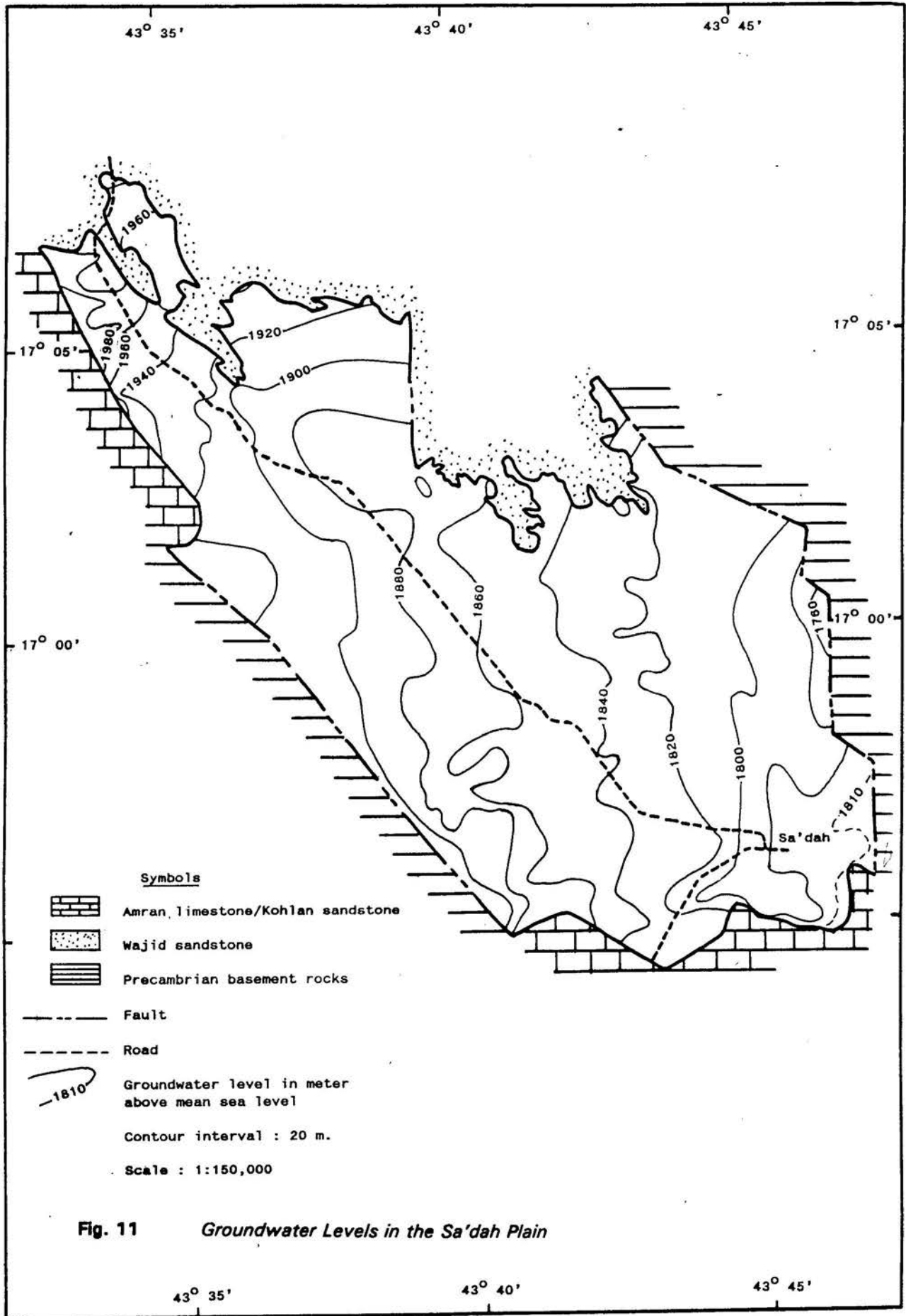
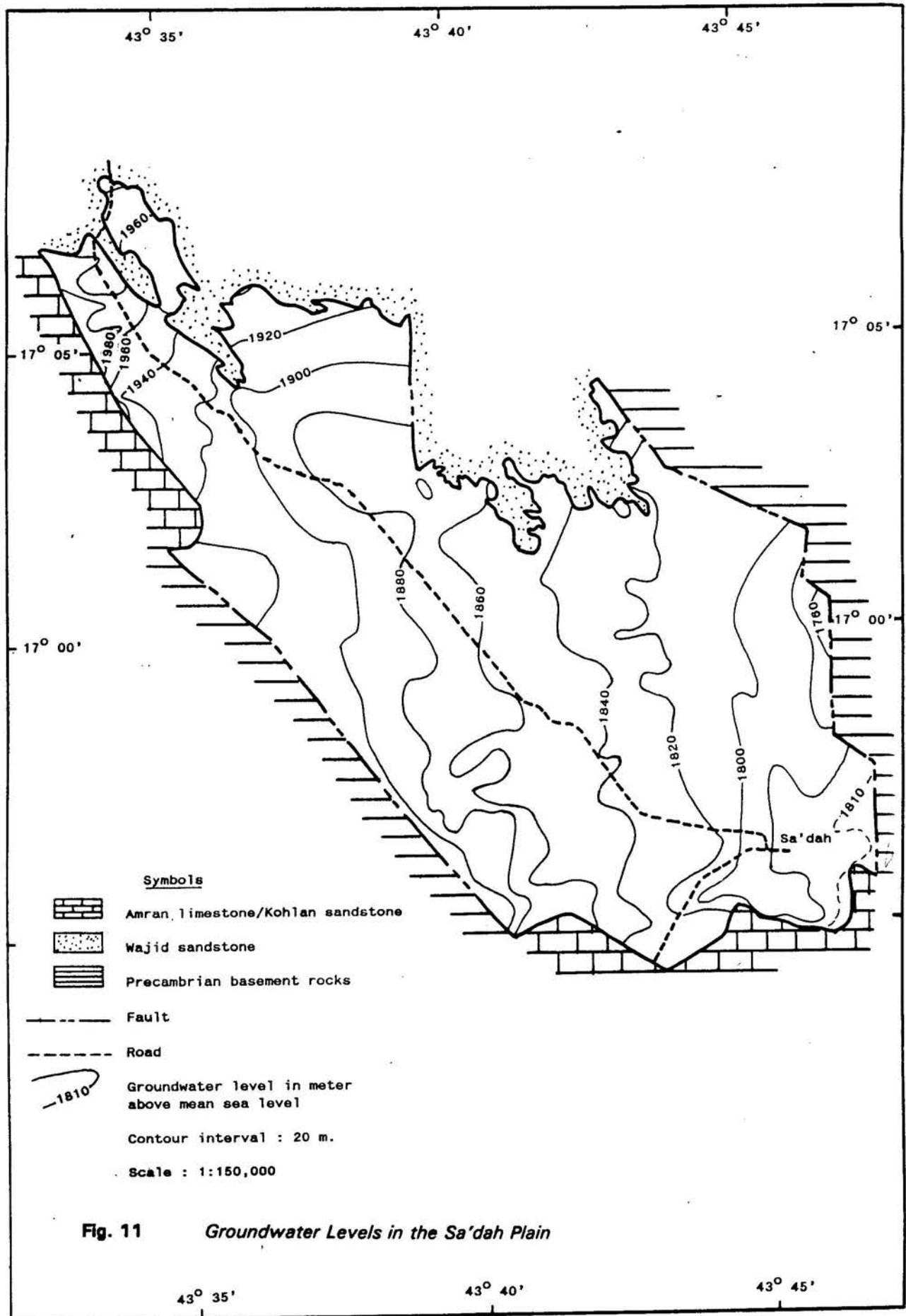


Fig. 10 *Levels of the Wajid Sandstone Base in the Mahathir Plain*





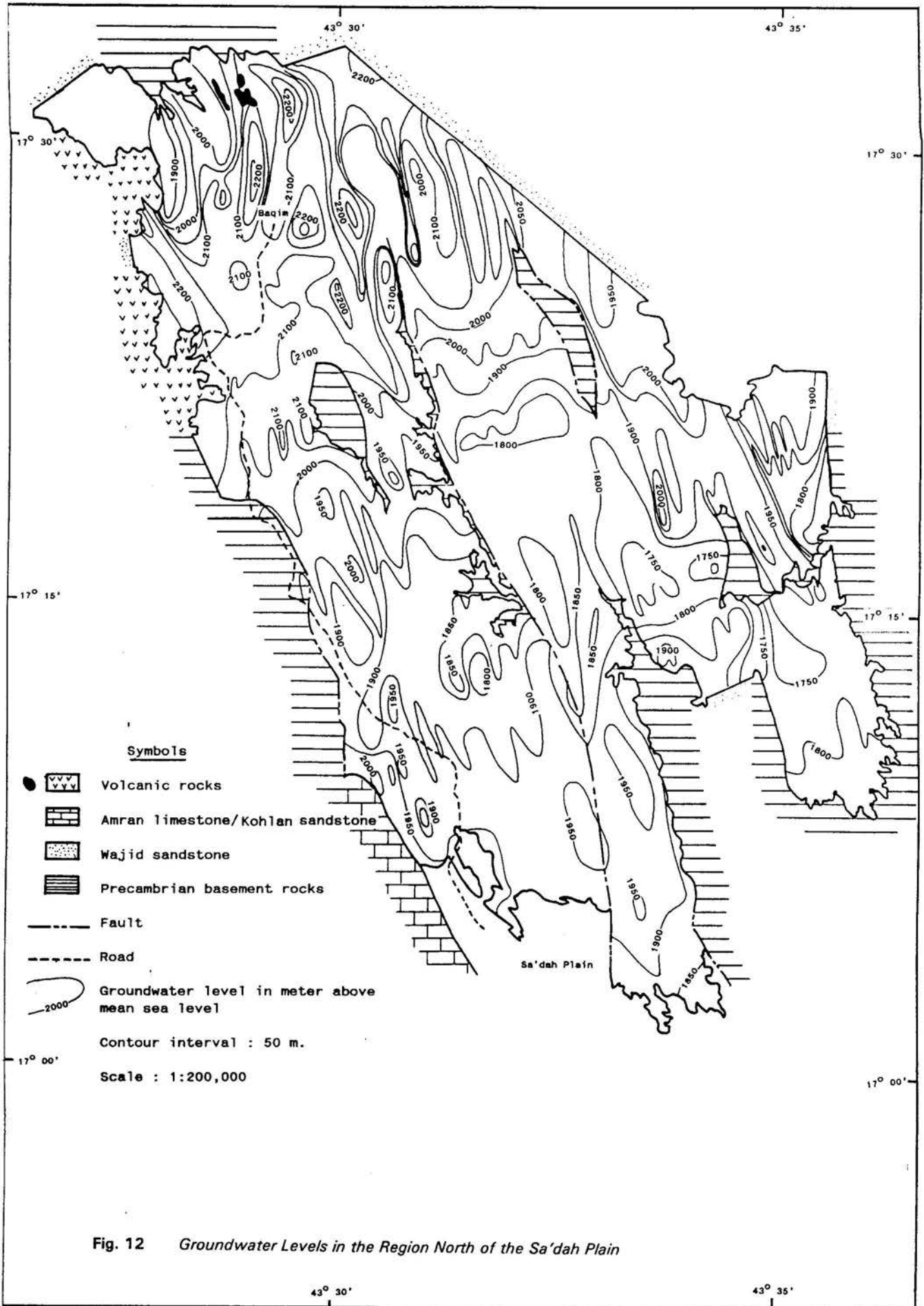


Fig. 12 Groundwater Levels in the Region North of the Sa'dah Plain

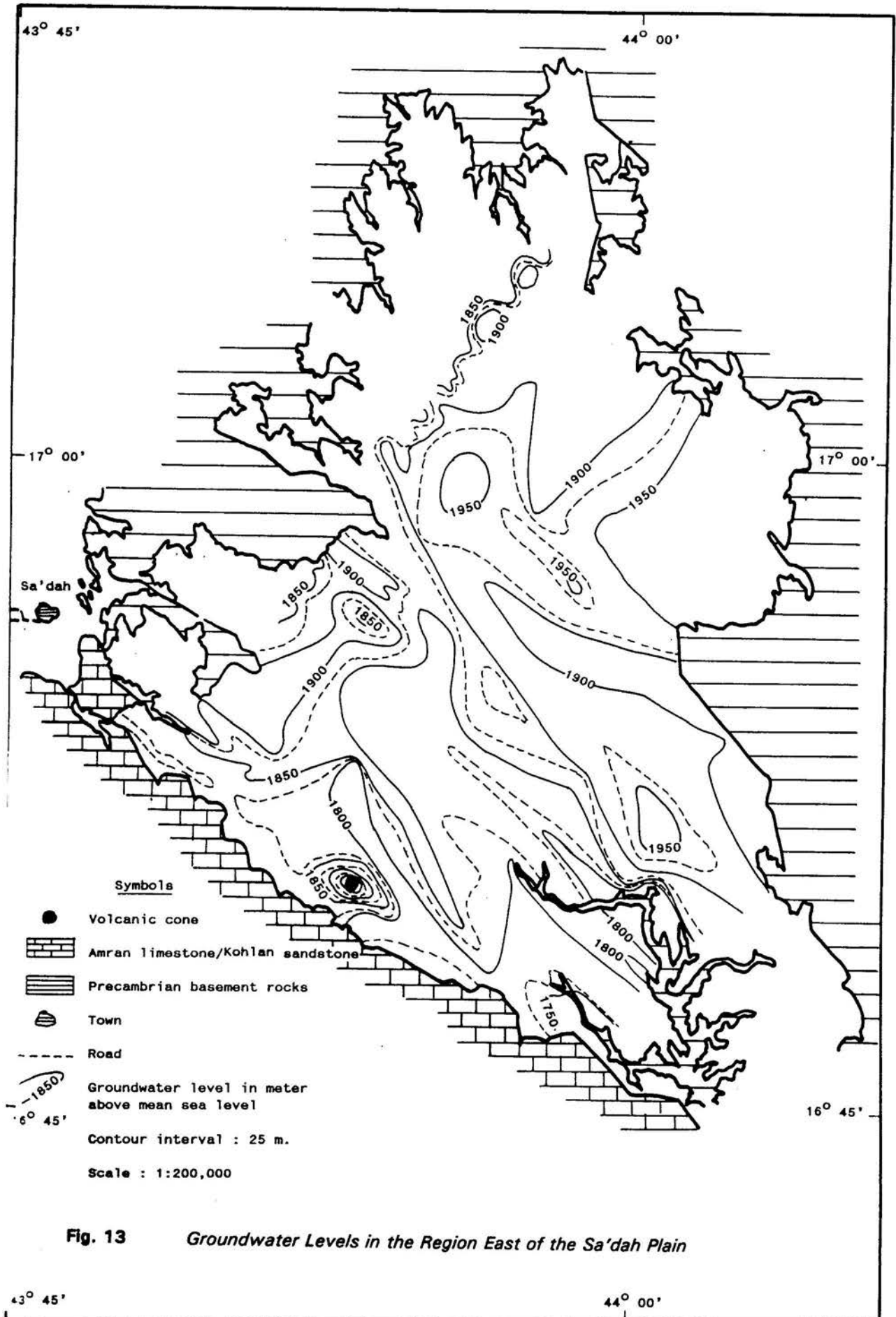
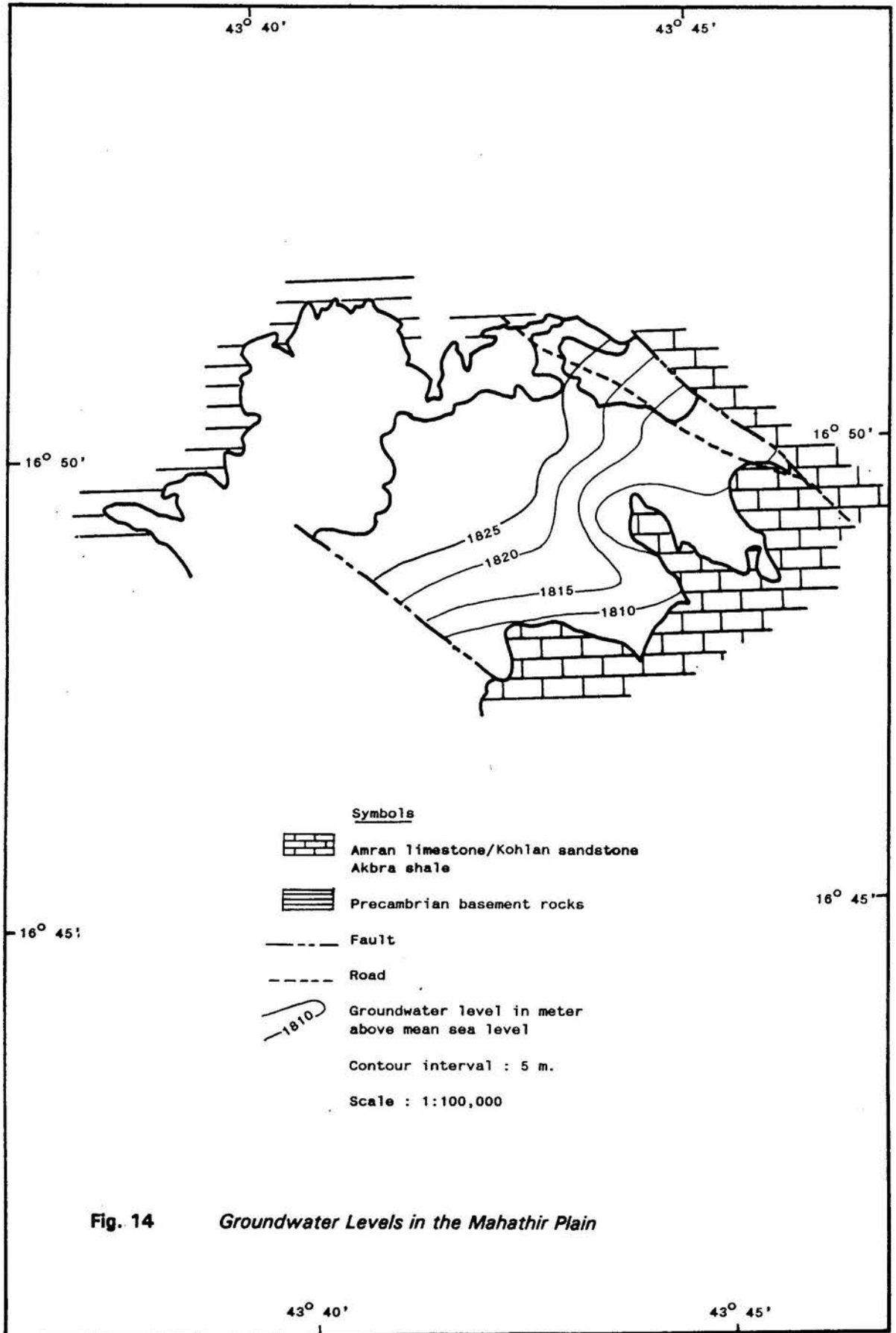
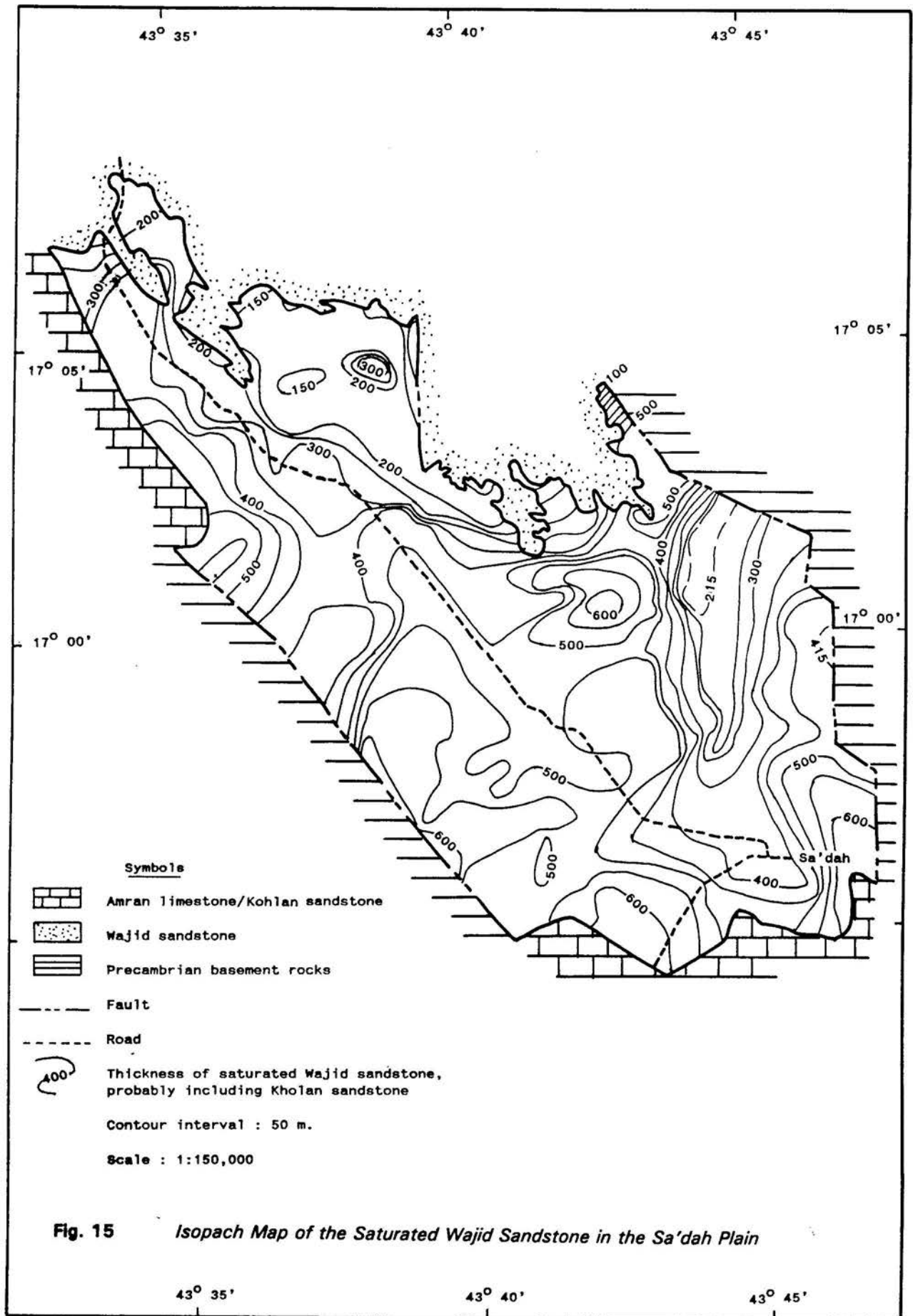


Fig. 13 Groundwater Levels in the Region East of the Sa'dah Plain





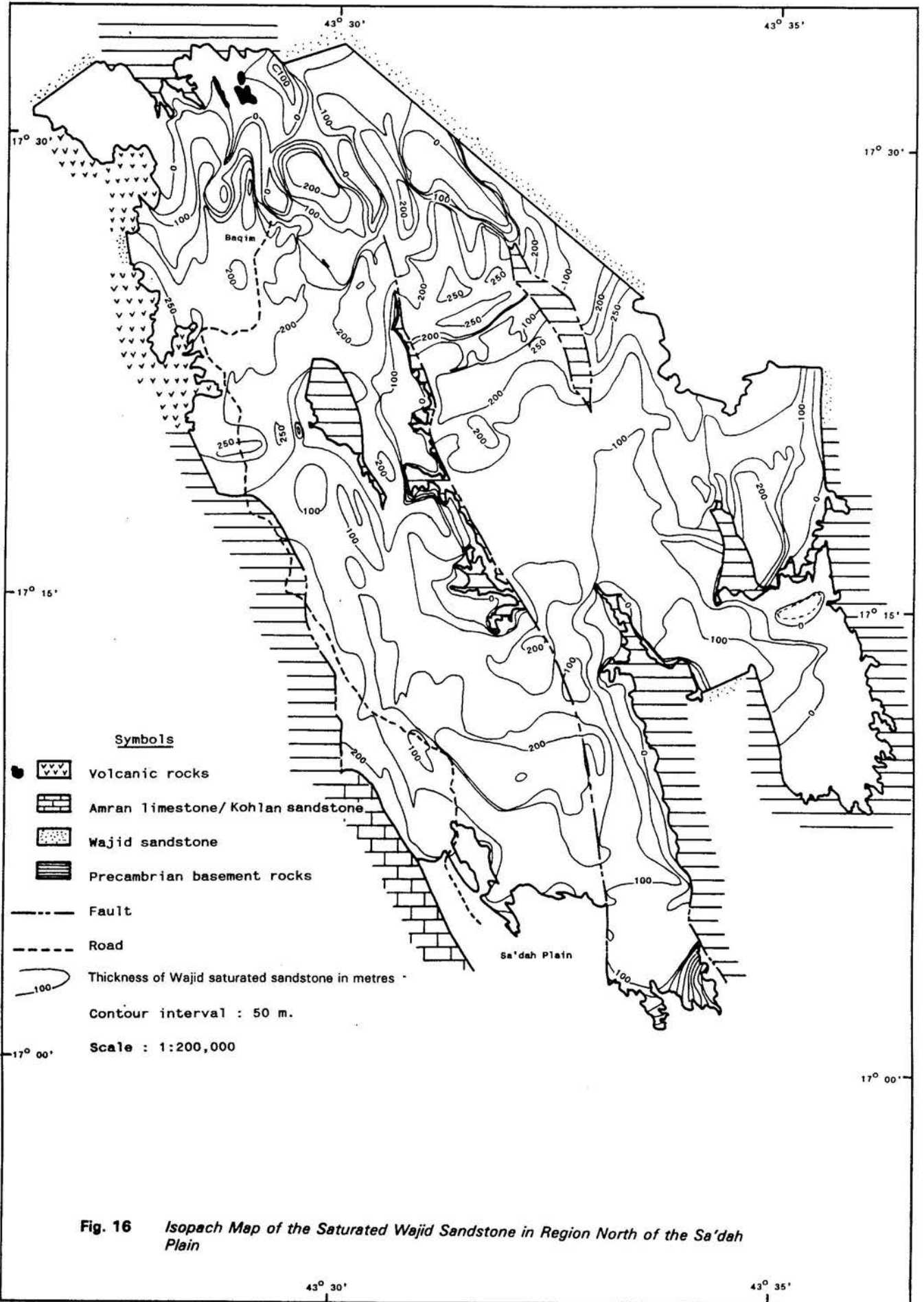


Fig. 16 *Isopach Map of the Saturated Wajid Sandstone in Region North of the Sa'dah Plain*

