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Regional Seismic Studies in Northern Part of Kirthar Depression, Pakistan

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ABSTRACT

This article is based on HDIP-BGR regional seismic studies in the northern part of the Kirthar depression. The aim of the study is to delineate the structural framework of the study area for hydrocarbon exploration. Depth maps of Base Miocene, Base Tertiary and Base Cretaceous, all related to Mean Sea Level, are included.

An attempt is made to correlate, according to the seismic signature, the different Eocene limestones which are possible reservoir rocks of the investigated area. According to these studies, the Pirkoh, Habib Rahi, and the Sui Main limestones are spread all over the main parts of the mapped area.

The areas of Pirkoh and Loti structures, Jacobabad High, and the Kotrum Fold are recommended for further exploration.

INTRODUCTION

The study was carried out as a part of the HDIP-BGR collaboration project (Phase II). The study area extends between latitudes 28° N and 30° N and longitudes 67° E and 70° 45´ E (Figure 1).

Previously Amoco, BP, OGDC and PPL seismically explored the area in many vintages. More than a dozen exploration wells have been drilled in the investigated area. Seven gas fields have been discovered: Jandran (Amoco), Khandkot (PPL), Loti (OGDC), Pirkoh (OGDC), Sui (PPL), Uch (PPL), and Zin (PPL).

Our study includes mapping in time and depth of Base Miocene, Base Tertiary, and Base Cretaceous as well as the thickness of Paleogene plus Cretaceous and of the Cretaceous. In the Pirkoh and Loti structures, Base Eocene instead of Base Miocene was mapped as Eocene sediments are exposed in the area. Correlation of seismic horizons was extremely difficult and time consuming because of incomplete seismic coverage, lack of availability of certain important seismic lines, variable seismic datum and time scales, and incomplete well information.

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The seismic reflection times were reduced by constant time shifts to a Mean Sea Level (MSL) datum except in the Pirkoh and Loti structures, where the seismic datum at 800m above MSL was used.

DISCUSSION OF RESULTS

In comparison with the other mapped areas of the Northern Kirthar depression, the Pirkoh and Loti Area is, on a small scale, extremely structured by intensive synclinal and anticlinal faulting and overthrusting. The seismic lines of the area show extended zones with almost no reflections. The reasons for this effect are unknown. Zones of bad coupling of seismic sources and/or receivers are a possible explanation.

Well velocity surveys were available only for the wells Jhal-1, Pirkoh-9, and Loti-2. The latter two wells are only representative for the Pirkoh and Loti area and not for the main parts of the mapped area. In other words, only one deeper well with velocity informations from well logs, Jhal-1, located marginally in the west of the area was available for the whole area of more than 30,000 sq km southwest and east of the Pirkoh and Loti structures. Therefore, for the locations of the most exploratory wells an attempt was made to use rather unreliable stacking velocities to correlate the drilled depths with the reflection times. Amoco lines of the Jacobabad High totally lack the stacking velocity information. In Khandkot and Sui areas (PPL), seismic lines were not available to us. Only two OGDC lines near the well Khandkot-1 could be used to develop time-depth relations.

The depth conversions of the time maps were calculated entirely from stacking velocities. These stacking velocities were transformed into instantaneous velocities by a variation of the Dix formula (Dix, 1955; Durbaum, 1954; Krey, 1951).

The instantaneous velocities, as function of reflection times, were the basis of the calculation of time-depth relations. These time-depth relations had to be smoothed areally, actually by mapping of depth equivalents of distinct practical TW-travel times, i.e. for 500 msec, 1500 msec, 2500 msec, 3500 msec, and 4000 msec. These maps of depth equivalents of constant TW-travel times show lateral trends and variations. For TW-travel times less than about 2000 msec, the regional lateral trend is a decreasing depth from

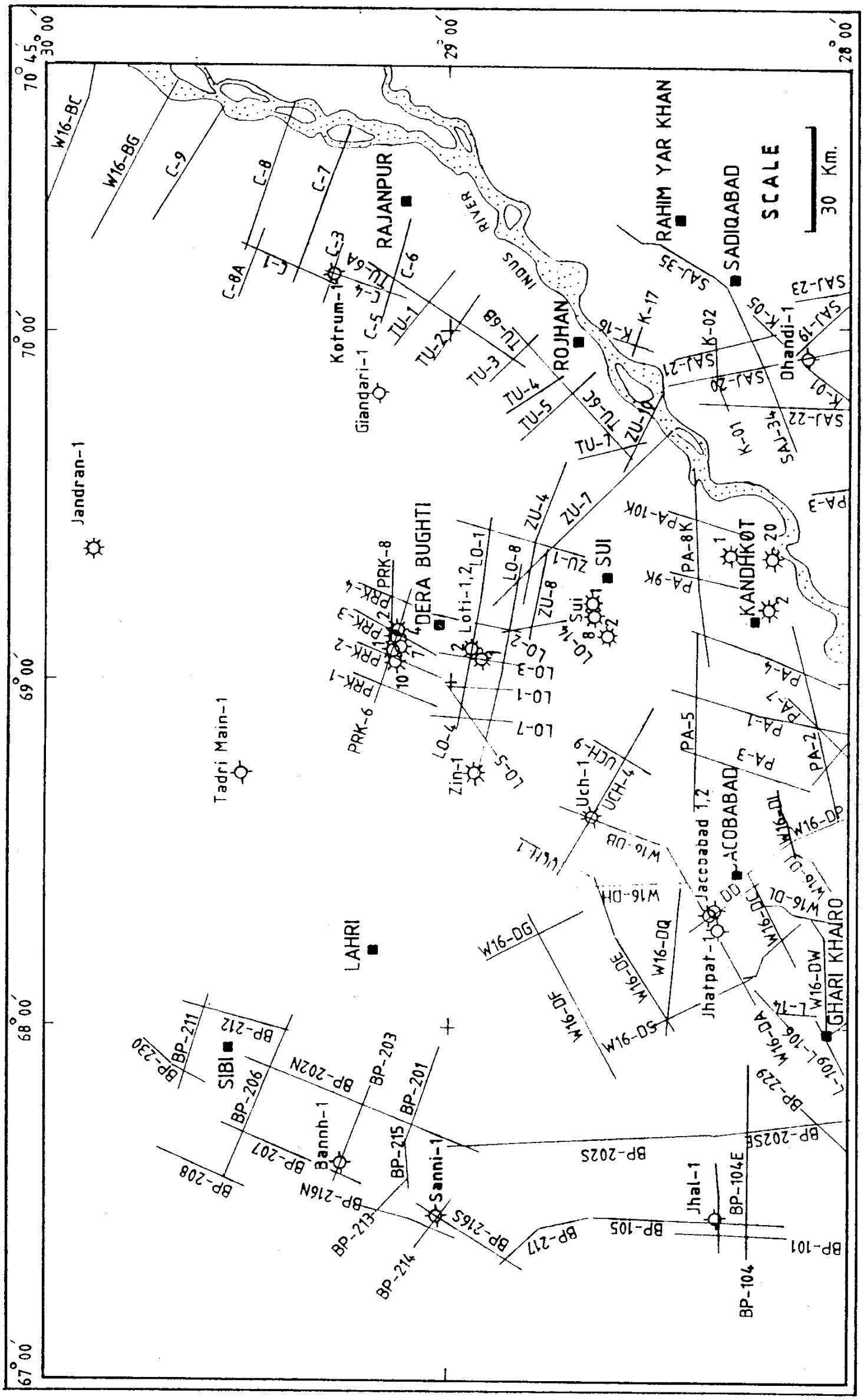

Figure 1— Index map showing seismic line locations.

the west towards the easternmost parts of the map, the Sulaiman depression. This trend is equivalent to a decreasing average seismic velocity in the same direction, from west to east. Lithologically, this observation may indicate a better average compaction of the sediments in the west in comparison with the sediments in the east, or an increasing sandy composition of the sediments towards the east, or an increasing average content of carbonates towards the west. Structural highs show higher velocities than neighbouring structural lows because older and more compacted sediments, i.e. sediments with higher seismic velocities, are shallower in the structural highs than in the lows.

The actual depth transformation of the three horizons i.e. Base Miocene, Base Tertiary, and Base Cretaceous mapped in reflection times were performed by linear interpolation between a suitable pair of the depth maps of the constant travel times mentioned above. The Pirkoh and Loti area is excluded from the depth calculations because of structural complexity which creates additional difficulties in the process of the depth transformation.

The differences between the depths of geological horizons taken from the wells and the depths based on the stacking velocities are generally within a 10% frame.

Figure 2 indicates that none of the exploration wells except the well Uch-1 is located on a clear horizontal closure in the Base Miocene level.

Figures 3 and 4 show that only the well Jhatpat-1 and the Jacobabad wells are positioned on top of horizontally closed structures at the Base Tertiary and Base Cretaceous reflectors.

The above results show that the Jacobabad wells are located in a structurally high position, if there are no considerable lateral variations in that part of the Jacobabad High which may dislocate the center of the High. Since only the Jacobabad-1 well detected some gas, it could be concluded that the Jacobabad High in the vicinity of the wells has no favourable hydrocarbon reservoir conditions or no effective seal.

On top of the Jacobabad High the main parts of Cretaceous are eroded or not deposited.

Distribution of Eocene Limestones

Eocene limestones are the main reservoir rocks of the northern part of the Kirthar depression. Therefore an attempt was made to correlate, according to the seismic signature, the different limestones. The results are mapped in Figure 5. The seismic signature, having strong reflection amplitudes, was used as a lithologic indicator. Strong reflection amplitudes are interpreted as amplitudes of reflections originating from limestones. The surrounding areas, where no strong reflections are indicated, are interpreted as areas where the limestones are replaced by shales.

Three limestones, the "Pirkoh limestone", the "Habib Rahi limestone", and the "Sui Main limestone", are spread all over the main parts of the mapped area.

According to the map (Figure 5), in the westernmost part of the investigated area as well as in the topmost part of the Jacobabad High, only the Sui Main limestone can be considered a possible reservoir rock. North and northeast of the well Bannh-1, the Sui Main limestone is less developed.

On top of the Jacobabad High as well as on top of the Uch structure, the Pirkoh and the Habib Rahi limestones are either eroded or not deposited.

In the northern and northeastern parts, only the Pirkoh and the Habib Rahi limestones can be expected, where as in the easternmost parts only the Pirkoh limestone may be present.

According to drilling reports, Sui Main limestone is missing in Pirkoh structure. Due to the poor quality of the seismic lines available, and in the Loti area, also due to thinning out of the limestones, the limestones in the Pirkoh and Loti area could not reliably be recognized as strong reflections on the seismic lines.

At the southern margin of the Loti structure, extended over an area in the order of 100 sq km, are some indications of Eocene reefs (line 826-LO-8, eastern end; line 826-LO-14, northern end; line 81-LO-2, southern end; reflection times between 0.6 sec and 1.3 sec, equivalent to depths in the order of 600m to 1500m below seismic datum which is 800m above MSL in this area). The quality of the seismic data was by no mean sufficient to delineate single reef structures. Zakauddin Malik et al (1988) referred to reef indications in the same area.

The three wells on the Jacobabad High, Jacobabad-1 and 2, and Jhatpat-1, tested the hydrocarbon reservoir quality of the Sui Main limestone. Jacobabad-1 had a gas blow-out. In the well Jacobabad-2, structurally 60 feet deeper than Jacobabad-1, the Sui Main limestone produced only water. Since the Jacobabad-2 is close to the Jacobabad-1, the hydrocarbon volume of the reservoir tested by the Jacobabad-1 must be considered uneconomic.

Concerning the hydrocarbon reservoir conditions of the total area of the Jacobabad High, these conditions may improve towards the southern parts of the Jacobabad High culmination. According to Figure 5, the Pirkoh and the Habib Rahi limestones could be the effective reservoir rocks of this area. Additionally, since sequences of poor reflections in a seismic section are indicating shale sequences south of the Jacobabad crest, the sealing shale contents in the Paleogene sediments are probably increasing towards the south.

A similar increase of the shale content of the Paleogene sediments were encountered in the Uch area.

The correlation of the different limestones between the Jacobabad High and the westernmost parts of the mapped

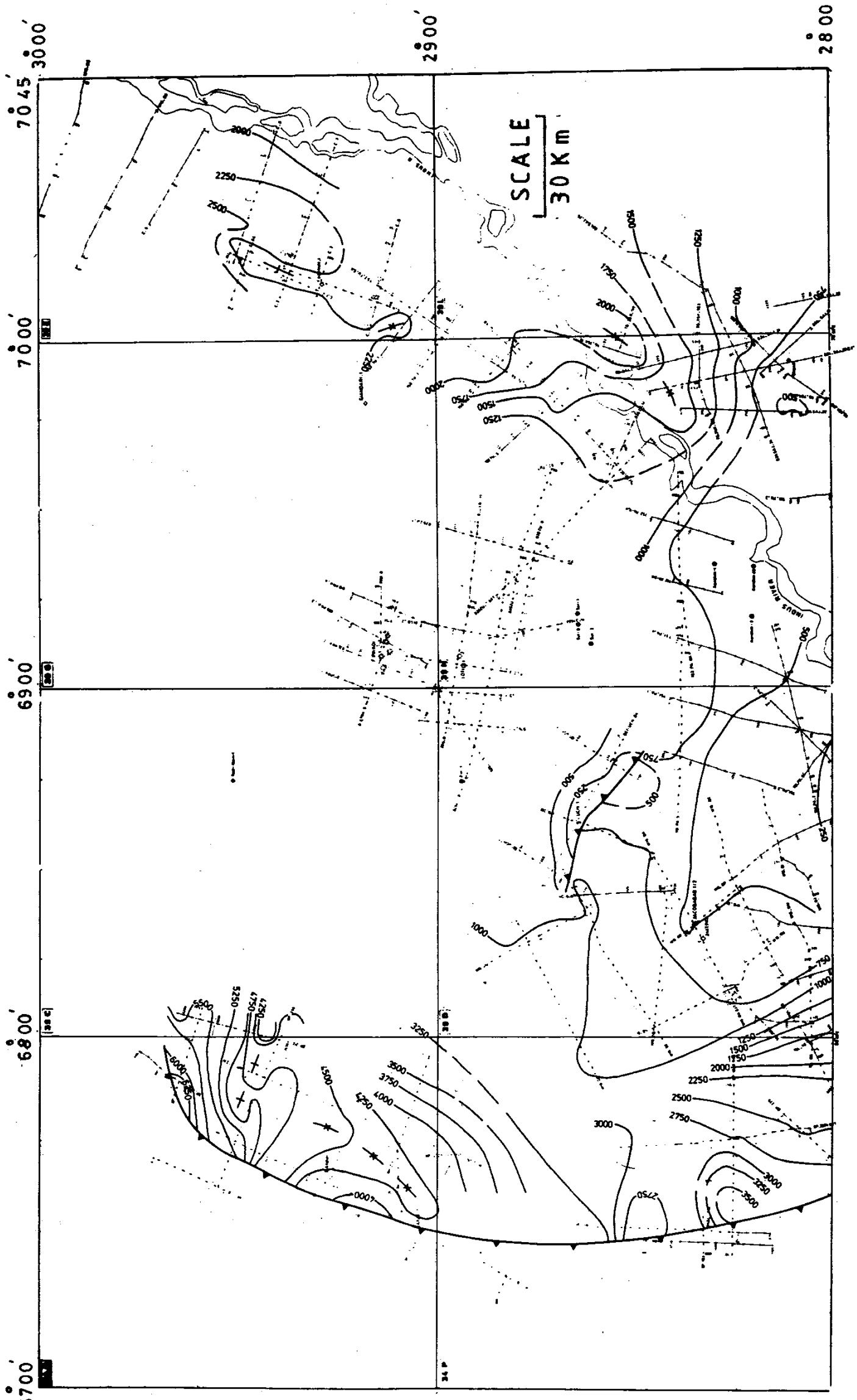

Figure 2— Depth contour map at base Miocene (contour interval 250m, depths below mean sea level).

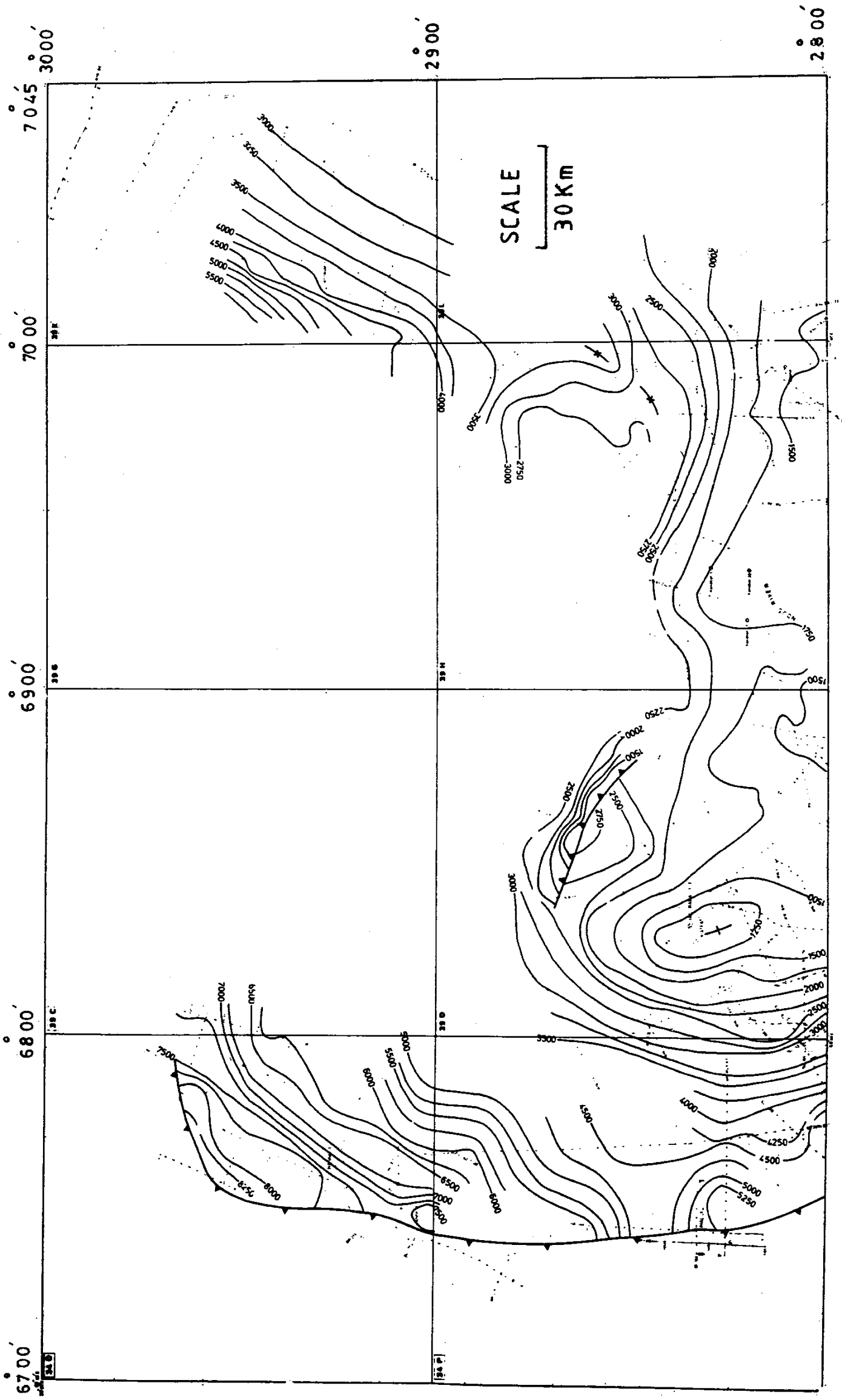

Figure 3— Depth contour map at base Tertiary (contour interval 250m, depths below mean sea level).

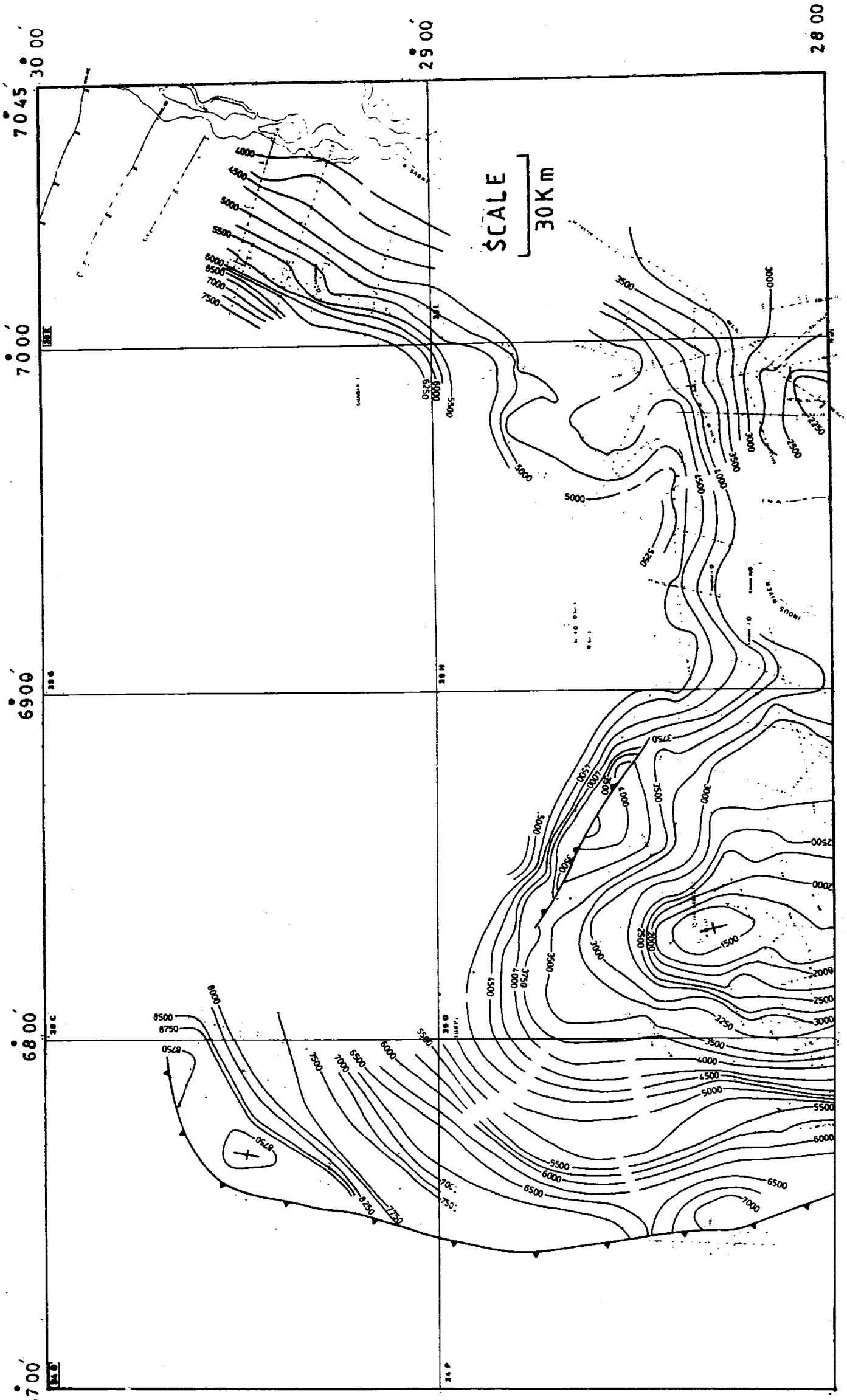

Figure 4— Depth contour map at base Cretaceous (contour interval 250m, depths below mean sea level)

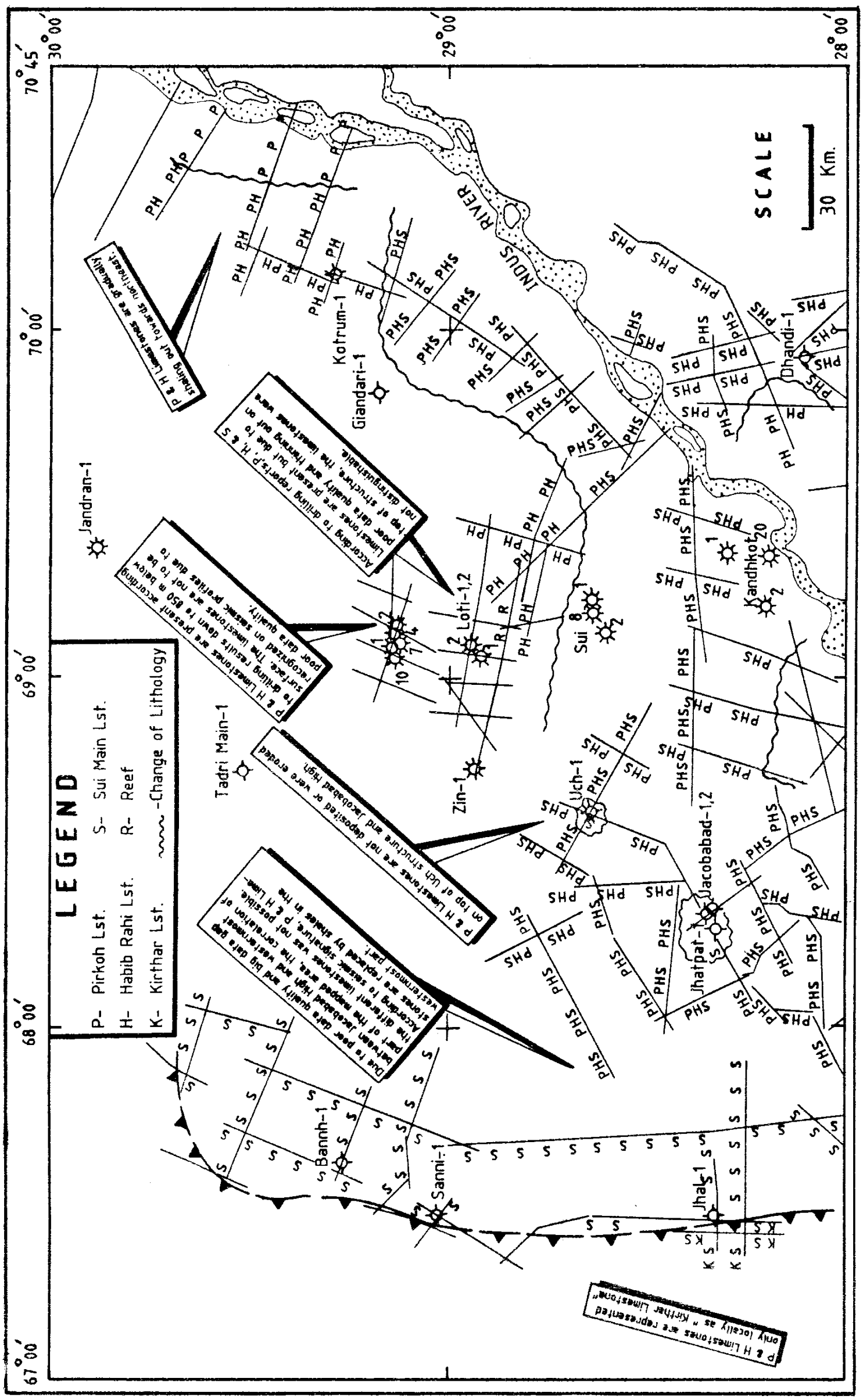

Figure 5— Eocene limestones distribution map.

area was not possible in a proper way because of a big gap of seismic data between the two areas. According to the seismic signature in the westernmost parts, the Pirkoh and the Habib Rahi limestones are replaced by shales and intercalated thin limestone bands. Only locally in the southwest, around the location of the well Jhal-1, the two limestones are represented as "Kirthar limestone".

In the eastern and northeastern parts of the mapped area, in the southern Sulaiman depression, the different limestones are gradually replaced by shales towards the east and northeast. At first the Sui Main limestone, the deepest, and then the shallower Habib Rahi limestone, and probably finally, the Pirkoh limestone too, the shallowest of the three limestones are replaced by shales.

EXPLORATION TARGETS AND RECOMMENDATIONS

The following areas and/or targets can be recommended for further exploration.

- Indications of Eocene reefs at the southern margin of the Loti structure.
- The southern part of the Jacobabad culmination.
- The southwestern flank of the Pirkoh structure where Paleogene and/or older sediments are wedging out towards the north, these sediments could form hydrocarbon reservoirs in a flank position provided the reservoirs are sealed in lateral and vertical direction.
- The western slope of the Jacobabad High where the conditions are similar to those at the flank of the Pirkoh structure.
- Along the north-south extended Kotrum Fold in the east of the mapped area, sediments wedges, and deep Tertiary onlaps, directed towards the east, may form stratigraphic traps for hydrocarbons.

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