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Oil Resource Potential of Eocene Limestones in Sulaiman Depression

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ABSTRACT

Habib Rahi limestone (primarily) and Pirkoh limestone are judged to be present and mildly to medium mature in the synclinal part of the Sulaiman depression. Stage of maturity and type of kerogen may have generated a gas-undersaturated oil. Based on hard field and laboratory data, volumetric calculation of the source rocks bodies followed by chance factor assessment including the probabilistic method, about 2.2 billion US barrels of oil could be expected as undiscovered potential resource sourcing from these two source rocks; however, this resource assessment is subjective and represents by no means more than an educated guess.

INTRODUCTION

Sampling of source rocks in the easternmost front of the Sulaiman Range and their quantitative geochemical analyses, both carried out jointly by the Hydrocarbon Development Institute of Pakistan (HDIP) and the German Geological Advisory Group (from BGR, Hannover), came up with the results, that the Habib Rahi limestone and the Pirkoh limestone intervals (both of Eocene age) have a substantial oil source potential in regional terms, especially the Habib Rahi limestone.

Based on these field and laboratory hard data and in combination with the seismic interpretation/mapping in the Sulaiman depression (Altenkirch et al, 1987) and well data, an assessment of the hydrocarbon potential (oil) and finally the undiscovered potential resource as sourced from the Habib Rahi and Pirkoh limestones has been carried out by a combined volumetric and chance (risk) discounting factor probabilistic method.

HANDLING OF FIELD DATA AND LABORATORY RESULTS

Source rocks from the Habib Rahi limestone sequence have been sampled at 16 different locations/areas comprising 43 geochemically conclusively analysed samples, the corresponding figures for the Pirkoh limestone are 9 locations with 11 conclusive analyses. Considering the 300 km north/south extension of the probed area it becomes quite clear, that we are dealing with real reconnaissance data (Figures 1-3).

When probing the Habib Rahi and Pirkoh limestones sequence in the field, the thickness of each section has been examined. At each section the thickness of bituminous rich sequences (Total Organic Content, TOC, above 2%), of the by and large bituminous sediments (e.g. marls with TOC between 1-2%) and of the sequence with TOC less than 1% have been indicated; however, this latter sequence has been omitted for any source consideration and is representing at places certainly an upside potential. This classification is in addition based on a re-check and re-calibration respectively after having obtained the laborabory results.

TOC (in %) and gP (Genetic Potential) in kilogram hydrocarbon per tonne source rocks as analysed by HDIP, show, as to be expected, in crossplots a reasonable dependence for the two individual source rocks, 1% of organic content equals a range of 5-7.5 gP (Figure 4) and the higher TOC corresponds to higher gP values.

The following assessments are based on the gP values only. Cross-checks based on a yield (Fisher assay) of 6.5 kg oil per tonne of source rock and 1% of TOC give, however, rather compatible results.

MAPPING OF gP x NET THICKNESS

Let us take for better understanding the field and laboratory data of the Habib Rahi limestone sequence at the Rakhni/Kingri location as example: The Habib Rahi limestone sequence comprises a thickness of 25m with: organically rich (TOC 2-7%) sediments of 15m thickness and ±bituminous marls (TOC 1-2%) of 10m thickness.

Three samples of the organically rich sequence come up with an average gP of 34 equalling to a gP×net thickness of 510 and 10m of ±bituminous marls with an assumed average TOC of 1.5% come up with a gP×net thickness of 90, thus the gP×net thickness at Rakhni/Kingri totals to 600.

For both Habib Rahi and Pirkoh limestone each sampled/analysed section has been handled, plotted and mapped accordingly (Figures 2, 3). These, on surface data

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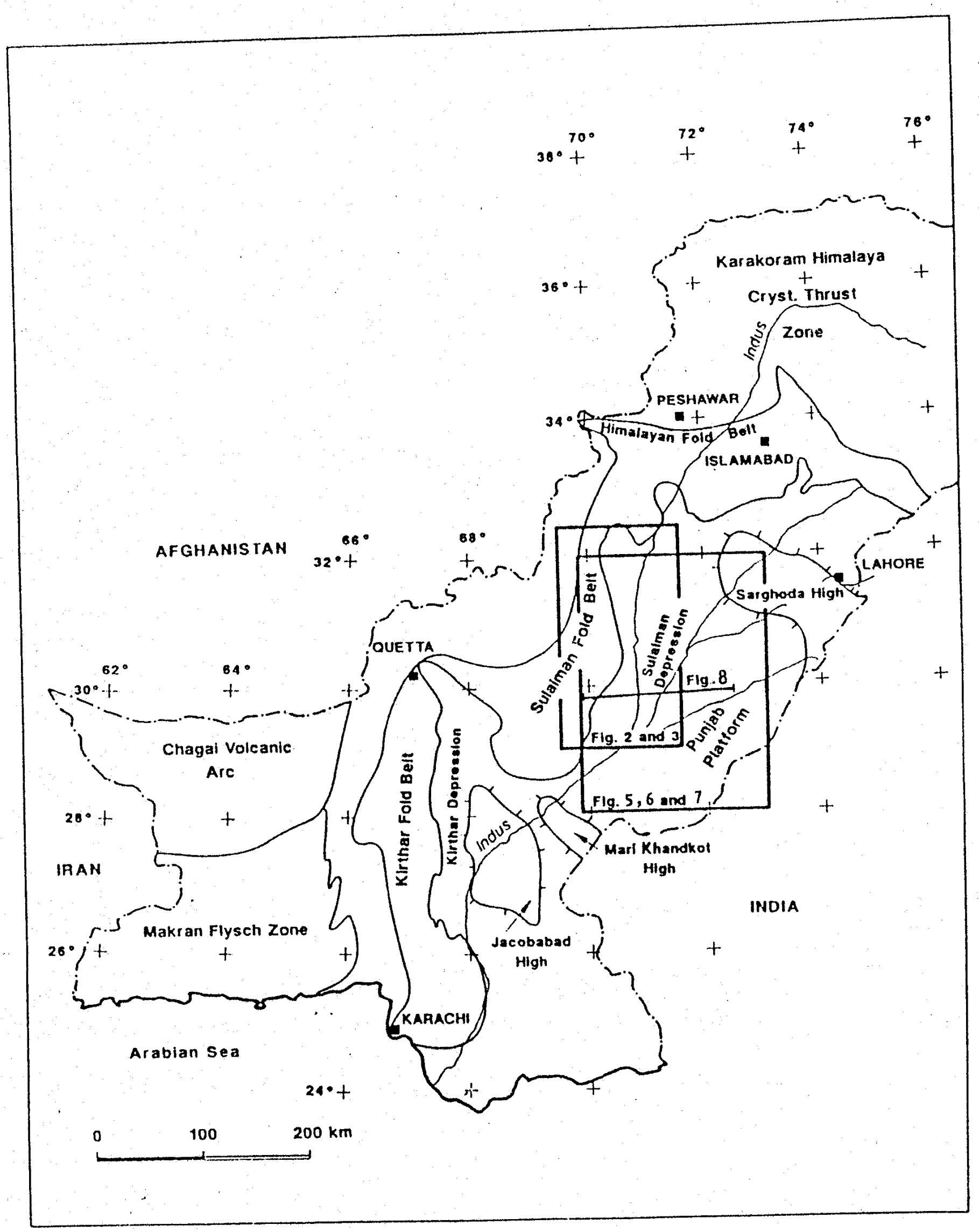

Figure 1—General setting and location of investigated area.

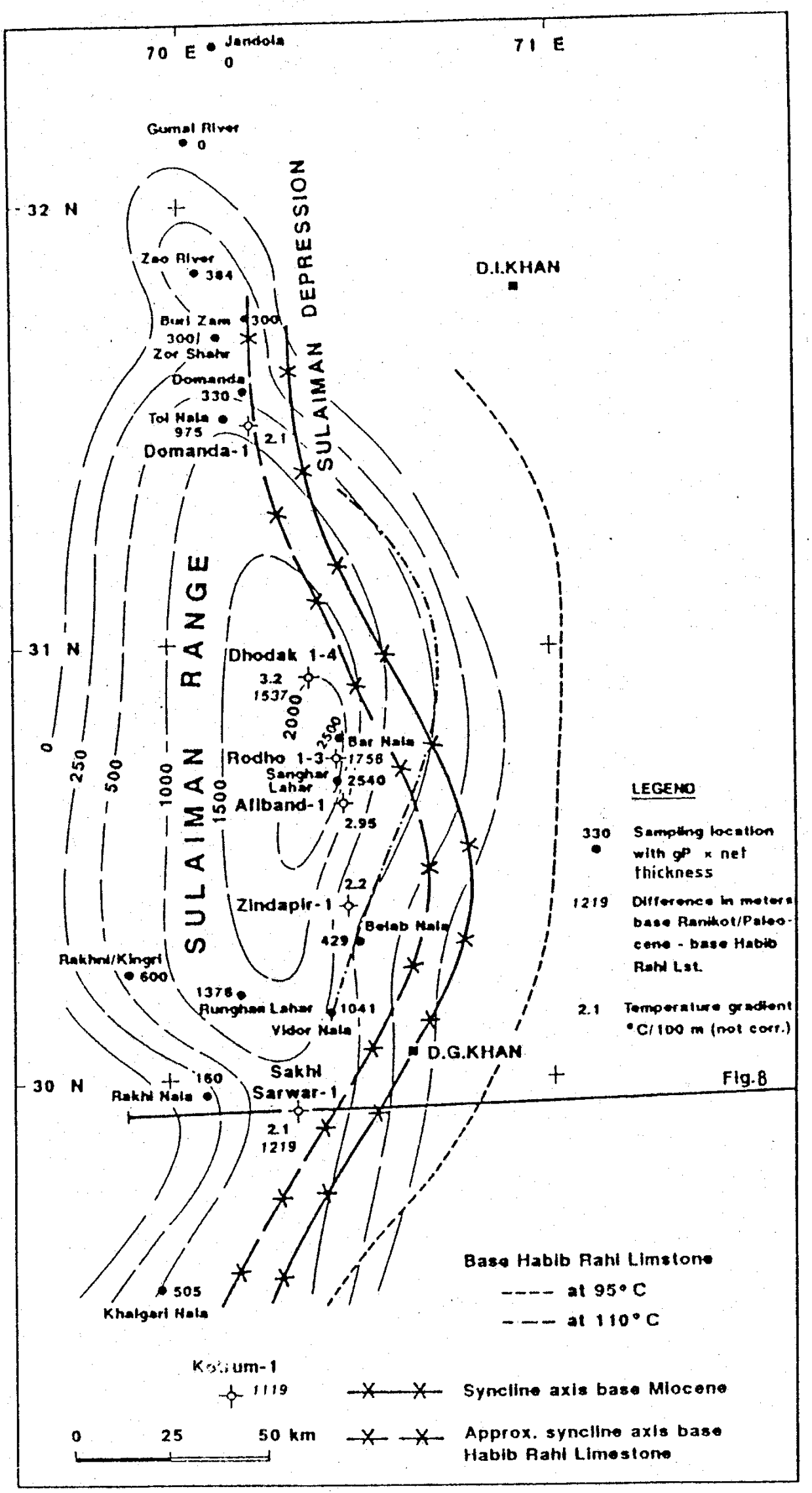

Fig.8

Figure 2—Isolines of Habib Rahi limestone gP x net thickness, Sulaiman depression.

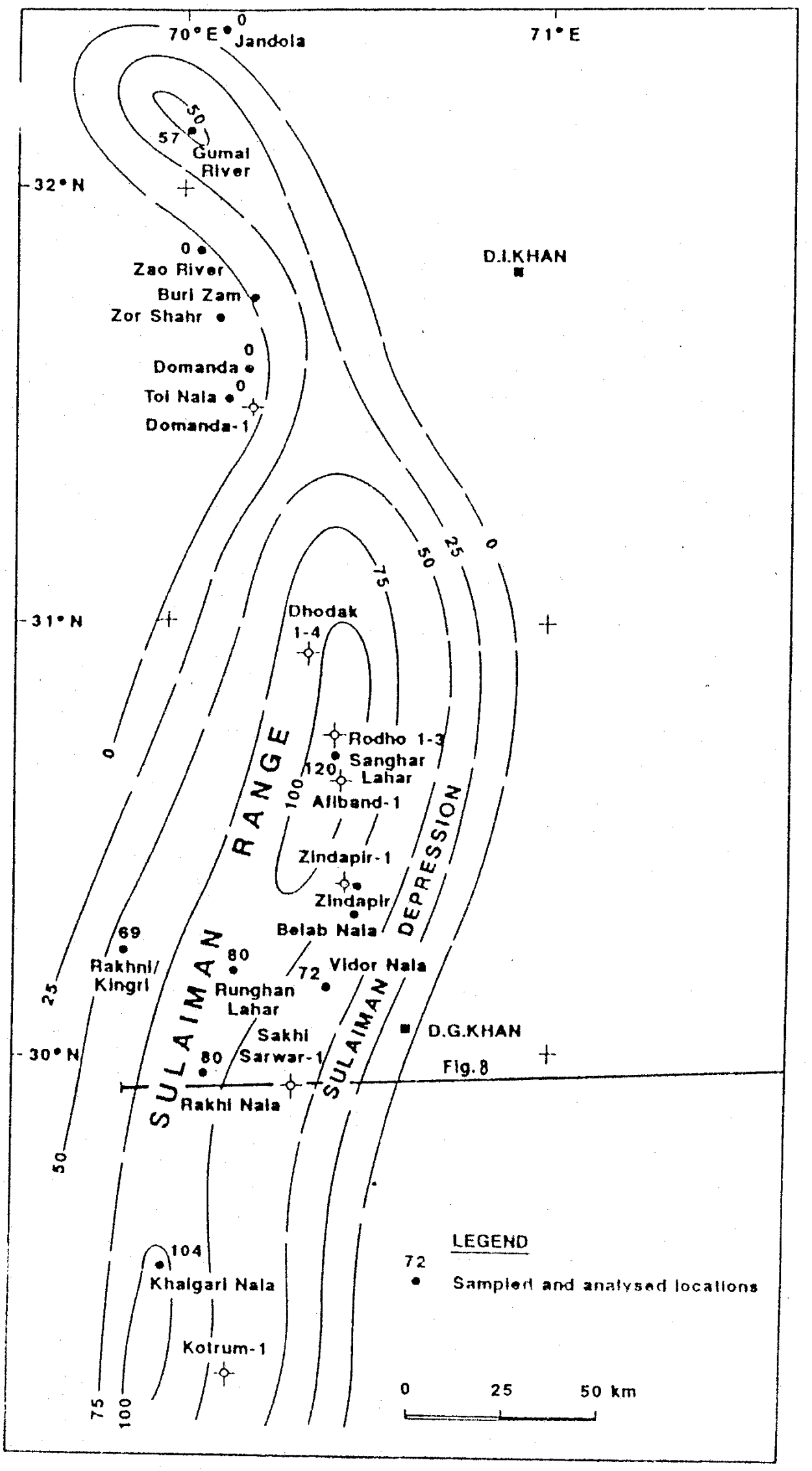

Figure 3—Isolines of Pirkoh limestone gP x net thickness, Sulaiman depression.

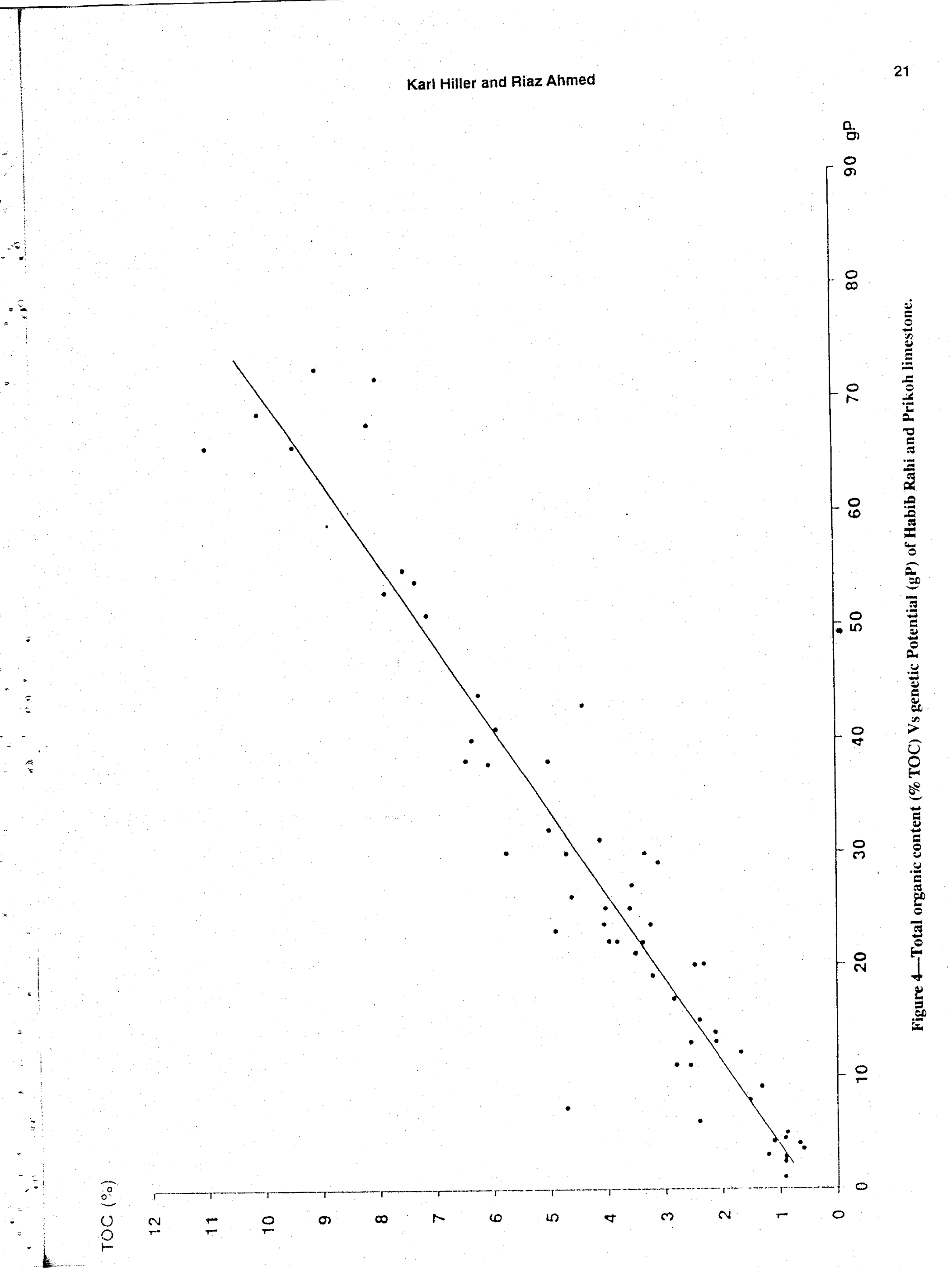

Figure 4—Total organic content (% TOC) Vs genetic Potential (gP) of Habib Rahi and Prikoh limestone.

of the easternmost Sulaiman Range based gPxnet thickness maps are overriding the regional tectonic situation (thrust situation) and are projected into the subsurface; this is certainly a critical working premise.

gP x NET THICKNESS MAPS AND DELINEATION OF THE GENETIC POTENTIAL

Both, the Habib Rahi and Pirkoh limestone gPxnet thickness maps (Figures 2, 3) indicate a clear north/south axis with maximum values around Sanghar Lahar/Bar Nala. The mapping of the Habib Rahi limestone gPxnet thickness clearly shows the much higher potential with its maximum over 2500 as compared to the maximum of about 120 for the Pirkoh limestone.

Both source rock sequences are with respect to the base of the Habib Rahi limestone and to the Pirkoh limestone within a thickness interval of approximately 300-360m (according to Dhodak, Sakhi Sarwar and Kotrum well results). Their values for maximum potentials coincide with the thickest Paleogene sequence (Altenkirch et al, 1987) or where the Sulaiman depression is with the present seismic control at its deepest part as well (Figures 5, 6). Contouring of the gPxnet thickness in east/west direction, however, is rather subjective and it implies a frontal overthrust (Malik et al, 1988) and not, what could be possible, an east bound substantial thrust. However, the considerable north/south extension of about 300 km or even more for both source rock intervals certainly may be connected with a wide east/west extension as indicated also by the following observation: the course of the axes at the area of maximum gPxnet thickness for the source intervals are parallel to subparallel (Figure 6), the axis of the younger gPxnet thickness of Pirkoh limestone is, however, shifted about 6 km updip to the east; the syncline axis of base Tertiary (Figures 5, 7) is further to the west and beyond this seismic control, whereas the axis of the base Miocene (Figure 7) is shifted further to the east and updip as compared to the above source rocks' axes. This stratigraphically upward and eastward (updip Punjab platform) oriented succession of the axes (Figure 6) indicates an eastward prograding shift of sedimentary maxima common for depressions and might support the subsurface projection as mentioned above.

The contour intervals of the two gPxnet thickness maps have been planimetered and based on the volumetric/pyramid method and a specific weight of the source rock of 2.5 tonne/m^3 (possibly slightly on the high side) the genetic Potential (gP) is as follows: gP of Habib Rahi limestone between Khalgari Nala and Gomal River is 313 billion barrels oil[1]; gP of Pirkoh limestone between Khalgari Nala and Jandola: 22.6 billion barrels oil[1].

[1]Common factor: 7.3 US barrels equal to one tonne.

These gP values are the total amount of the genetic Potential under the premise that the entire source rock bodies have reached the end or passed the oil window respectively.

It becomes obvious from the field probing and the laboratory data and the gPxnet thickness maps that the Habib Rahi limestone sequence is the dominant Eocene source rock.

ASSESSMENT/JUDGEMENT OF GENERATED POTENTIAL OIL

The amount of effectively generated oil depends on how much the source rock interval of Habib Rahi and Pirkoh limestones is (or has been) within the oil window which is set to be within a temperature range of 95-140 °C. In order to handle this problem the following approaches have been made:

Temperature Gradients/Temperature Isolines at Base Paleocene

According to Khan and Raza (1986) the temperature gradients in the Sulaiman depression and its gentle eastern flank are on the low side.

Based on the depth contour map of base Paleogene (Figure 5) as prepared by Altenkirch et al (1987) and assumed temperature gradients of 2.0, 2.5 and 3.0 °C/100m, temperature isolines at 95 °C (postulated beginning of oil window) have been incorporated in the Habib Rahi limestone gPxnet thickness map (Figure 2) with respect to base Paleogene. Base Tertiary reaches within the seismically surveyed area a maximum burial temperature in the front of the thrust of about 150-170 °C.

Temperature Isolines for Base Habib Rahi Limestone

According to Altenkirch et al (1987, Figure 6) and other sources (see also Figure 8), the Paleogene sequence is thickening downdip Punjab platform very considerably towards the Sulaiman Range, reaching more than 2.0 km in thickness. From wells (e.g. Dhodak, Rodho, Sakhi Sarwar and Kotrum) reliable data about the thickness of interval between base Tertiary and the base of Habib Rahi limestone are available (1499 and 1569 m at Dhodak, 1544-1756 m at Rodho, 1218 and 1119 m at Sakhi Sarwar-1 and Kotrum-1 respectively).

Based on these thickness data (Figure 6), secondly based on the depth contour map of base Tertiary (Figure

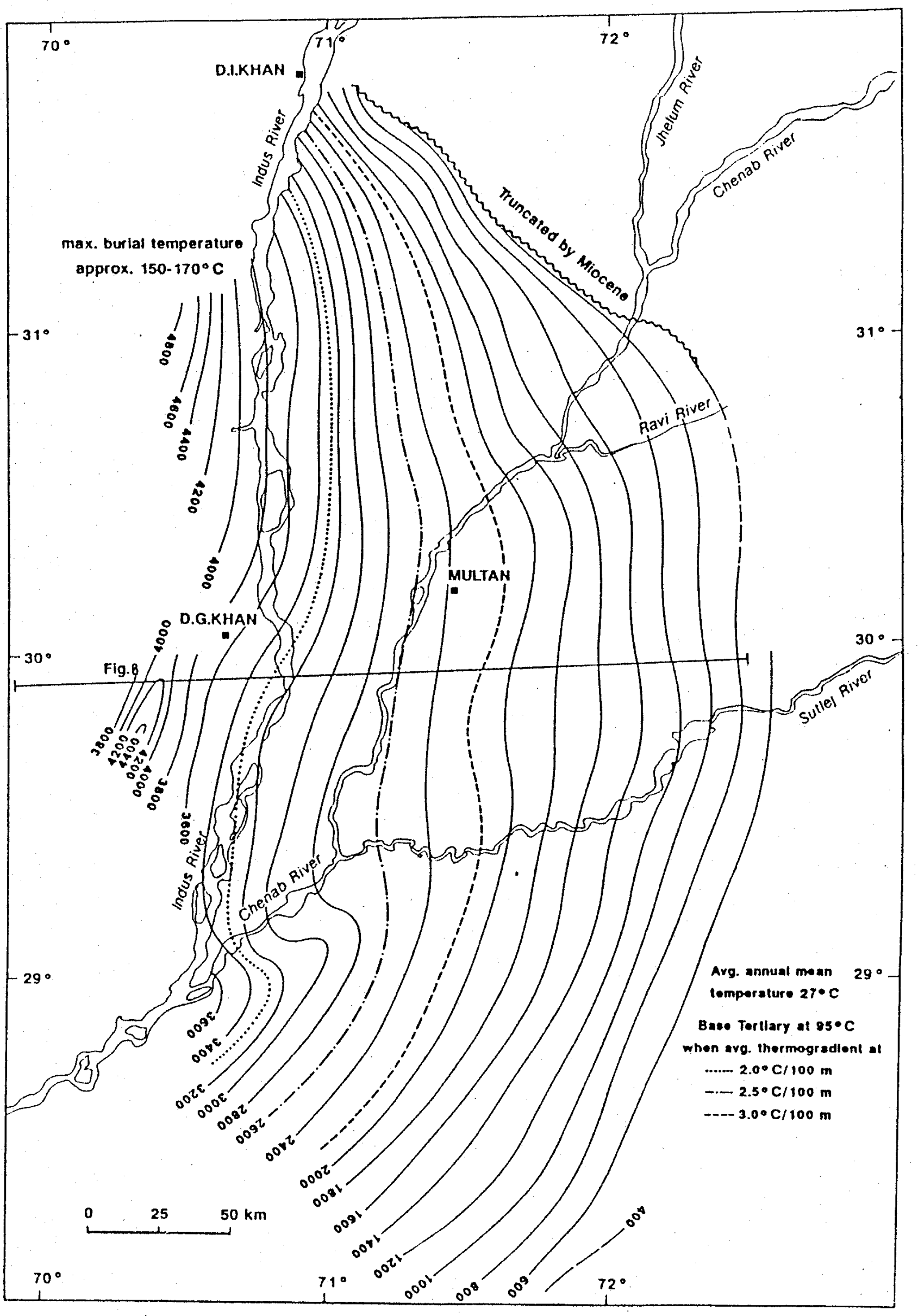

Figure 5—Depth Base Tertiary (b.s.l.), Sulaiman depression (After Altenkirch et al, 1987).

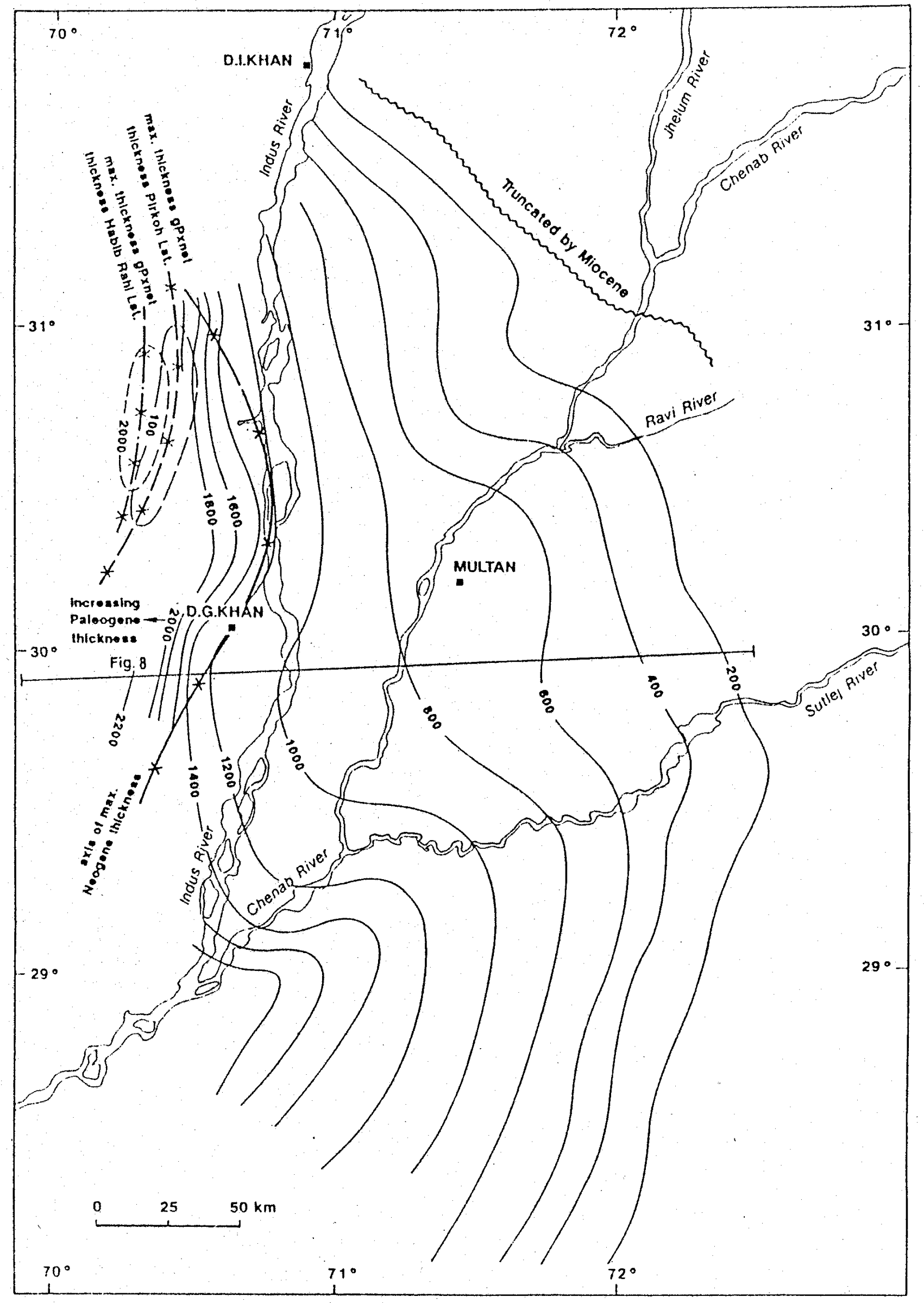

Figure 6—Thickness Paleogene (in m), Sulaiman depression (After Altenkirch et al, 1987).

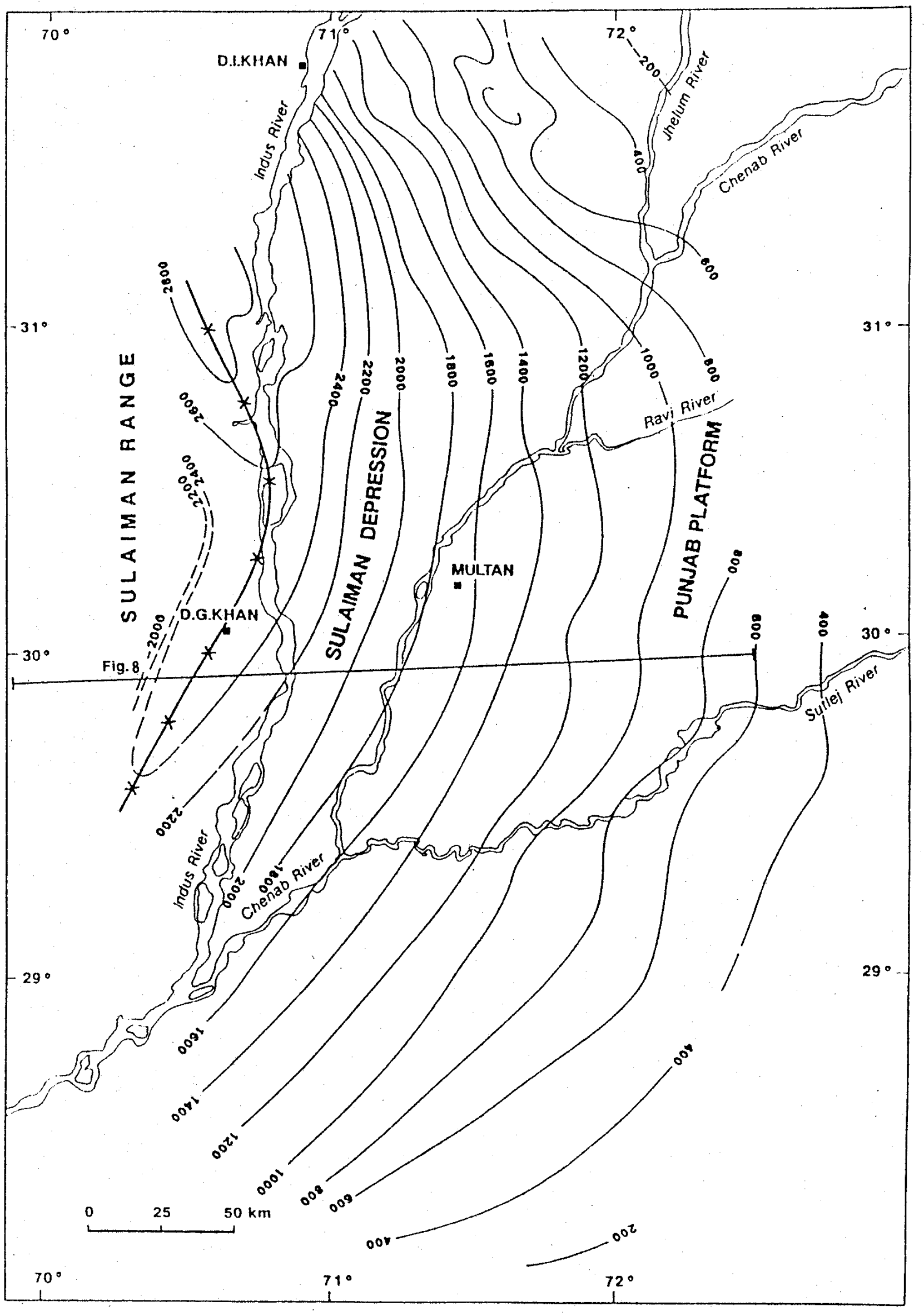

Figure 7—Depth Base Miocene (b.s.l.), Sulaiman depression (After Altenkirch et al, 1987).

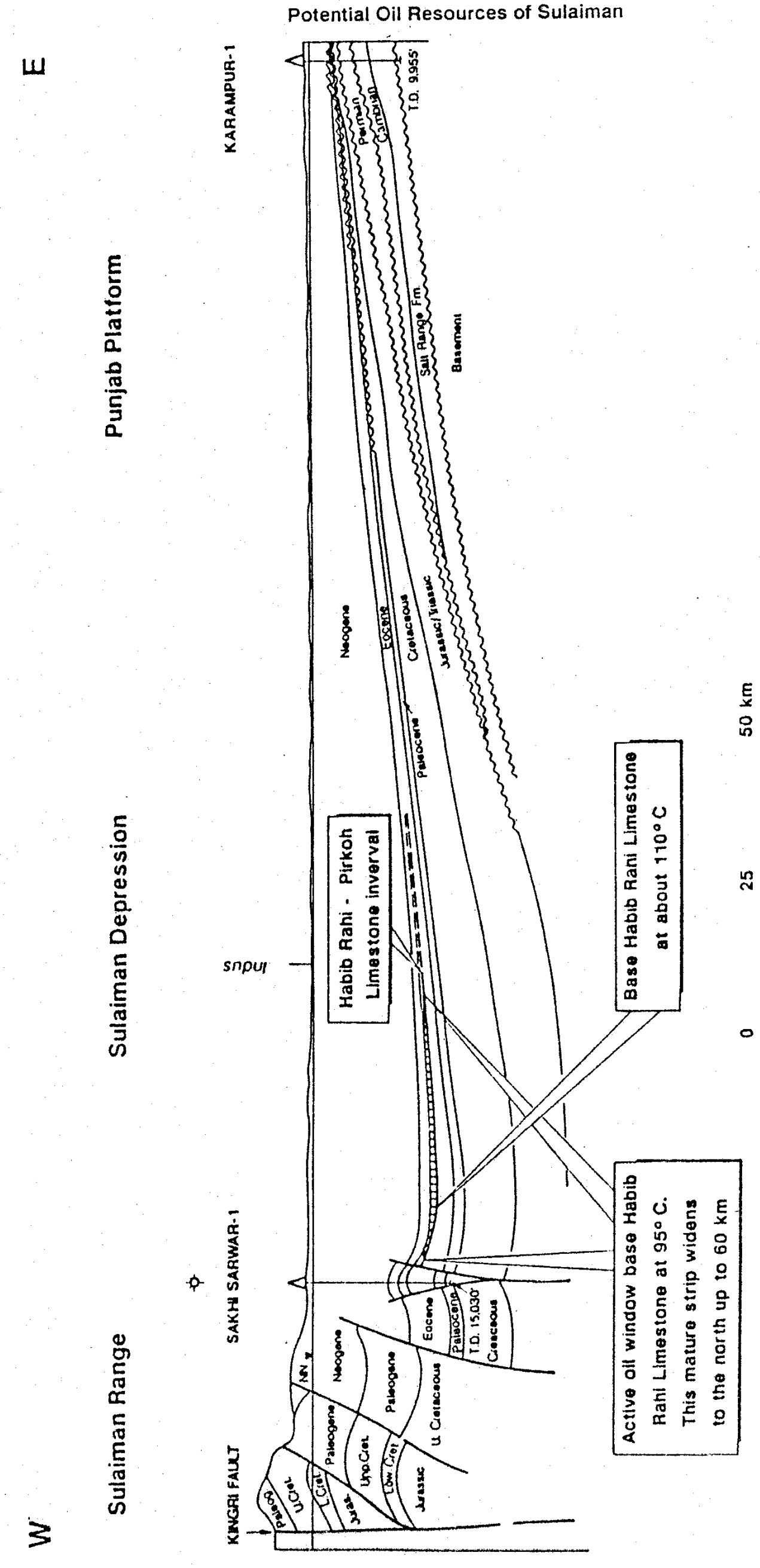

Figure 8—Geological cross section with incorporated Habib Rahi – Pirkoh limestone interval and and mature active section. (Source: partially PSPDE).

5), thirdly under the premise of an average temperature gradient of 2.5 °C/100 m and fourthly under the rationale that the interval base Tertiary/base Habib Rahi limestone is reduced updip in the same relation as the Paleogene sequence (Figures 6, 8), the 95 °C isoline of base Habib Rahi limestone has been constructed approximately and incorporated in Figure 2 accordingly. Due to a very gentle dip of the base of the Habib Rahi limestone in the proper depressional range, it turns out that burial temperature of the Habib Rahi limestone might not exceed 120 °C.

Judgement of Effective Maturity and the Generated Potential Oil Sourced from Habib Rahi and Pirkoh Limestones

It is speculative and debatable, whether the Eocene source rocks have reached a good effective maturity before the onset of wrenching/thrusting in the course of the creation of the Sulaiman Range. The few measured vitrinite reflectance values of not more than 0.6% in the Eocene source rocks, however, are supporting this doubt and reservation. For further consideration, therefore, the area east of the line Domanda-Dhodak- Rodho-Sakhi Sarwar is taken only, because active oil generation is judged there much more likely. This means that the genetic Potential under this maturity and areal premise (see Figures 2, 3) has to be discounted by approximately 50% to 157 billion barrels oil sourcing from the Habib Rahi limestone and to 11.3 billion barrels sourcing from the Pirkoh limestone. Habib Rahi and Pirkoh limestones could be in the most favourable case not far from the peak of oil generation in the deepest part of the Sulaiman depression; this area additionally coincides with favourable gPxnet thickness values.

Assessing the present day overall burial temperature of the Habib Rahi limestone, the effective overall maturity is judged mild to medium with a minimum of 0.25, a maximum of 0.5 and a most likely value of 0.35 for the maturity chance (risk factor)[1]. Since the younger Pirkoh limestone sequence is at a slightly lower burial temperature regime, the chance factor range is set at 0.2/0.3/0.4.

With the probabilistic method[2] the generated potential oil (area east of Domanda-Sakhi Sarwar only) calculates for the Habib Rahi limestone to a probabilistic mean value of 56.9 billion barrels oil and for the Pirkoh limestone to 3.4 billion barrels oil or cumulatively to 60.3 billion barrels oil.

[1] Chance factor ranges from 0 to 1.0 and serves to discount risks.

[2] Probabilistic mean value is obtained by addition of minimum, maximum and two-time the most likely chance factor divided by four and serves to eliminate random figures.

UNDISCOVERED POTENTIAL OIL IN PLACE AND UNDISCOVERED POTENTIAL RESOURCE

The generated potential oil has to be expulsed from the source rocks, migrate through carriers and accumulate at timely available traps (coincidence) with reservoirs; furtheron, a post accumulation destruction of traps (chance factor "Conservation") is possible.

The chance factor for expulsion is set at a range of 0.4/0.5/0.6, which might be, however, conservative and, therefore, on the low side with respect to the partially high TOC of the Habib Rahi limestone.

The efficiency for migration is seen at a chance factor range of 0.6/0.7/0.8.

The assessment of trapping efficiency, i.e. the timewise coincidence of maturity, migration and available traps with reservoirs is problematic: certainly, the maturity of both Eocene source rocks is very young, presumably of Pliocene age to recent. At that time stratigrpahic traps on the eastern gentle dipping Punjab flank of the Sulaiman depression were ready for quite some time, however, traps created in connection with the Sulaiman Range wrenching and thrusting could be of the same age or even younger as compared to the beginning of oil maturation. Accordingly, there might be a wider range for the coincidence chance factor which is set, therefore, at 0.25/0.55/0.75.

The chance factor for conservation of oil pools is judged to be in the range of 0.4/0.65/0.85, the highest value corresponding to the Punjab platform play.

Taking the range of these four chance factors: expulsion, migration, trapping and conservation into account and applying them to the generated potential oil, we come up with following mean probabilistic values for undiscovered potential oil in place sourcing from:

Habib Rahi limestone:	6.7 billion barrels
Pirkoh limestone:	0.4 billion barrels
Together :	7.1 billion barrels

The undiscovered potential (recoverable) reserve is set with primary recovery at 25%, with secondary recovery at 30% and with ultimate recovery at 40%. This calculates to a mean probabilistic value of undiscovered potential oil resources at about 2.2 billion US barrels oil.

DRAINAGE PATTERN AND POSSIBLE LOCATION OF POOLS

Inferred from the syncline axis of base Miocene (Figures 6, 7), the syncline axis for the base Habib Rahi limestone is shifted possibly about 10-12 km westwards (Figures 3, 6). Taking this syncline axis as separation line for a migration directed towards the east (updip platform)

and towards the west (updip Sulaiman Range) into consideration, it looks as if in the northern part of the study area the major migration is directed updip platform.

Considering the outstanding asymmetric shape of the Sulaiman depression with its very young and high relief frame of the Sulaiman Range in the west, the migration paths could be modified by a deep seated hydraulic transport of oil towards the east, thus upgrading the prospectivity of the gentle flank of the depression.

Pools may be expected updip on the gentle Sulaiman depression flank in stratigraphic traps primarily, fault closures are less likely, however, can not be excluded. Since faults are, under the present knowledge, not common on the gentle flank of the Sulaiman depression, juxtaposition might be rare and certainly within a narrow stratigraphic range. Traps, therefore, might be looked for in the Paleocene/Eocene sequence primarily.

A second play could be associated with low relief anticlines and fault closures in the deep syncline part created in the course of the Sulaiman Range thrusting/wrenching.

A third promising play is seen in narrow, elongated fault closures in front of the Sulaiman Range thrust in low block position.

CONCLUDING REMARKS AND RECOMMENDATIONS

The Eocene Habib Rahi and Pirkoh limestones are both judged to be present in the deepest part of the Sulaiman depression as mildly to medium matured oil generating source rocks. These two source rock intervals might have generated substantial amounts of oil east of the front of the Sulaiman Range over an area of about 300 km in length (north/south) and up to 60 km in width.

Taking the chance factors for maturity, expulsion, migration, trapping and conservation into account, about 2.2 billion barrels oil of undiscovered potential resource can be expected sourcing from the Habib Rahi limestone (primarily) and Pirkoh limestone. The oil could be reservoired immediately east of the Sulaiman Range thrust front in fault closures in the low block position, as well as in stratigraphic traps in the gentle eastern flank of the Sulaiman depression or within possibly low relief anticlines and fault closures in the deep syncline part.

The foregoing assessment is subjective and can be doubted or objected from several points of geological reasons, e.g. with respect to the distribution of source rocks and the judging of some of the risk factors, especially the maturity.

The presented assessment, therefore, is not more than an educated guess, however, the prospectivity of the Sulaiman foredeep is judged to offer rewards.

The geological set up and the wide variety of controlling parameters and their interplay and interdependence would be a useful example for a computer basin study model.

Further source rock sampling and subsequent geochemical investigations of the Habib Rahi and Pirkoh limestone intervals at additional locations as well as a high density sampling at each location can certainly improve the reliability of such a study based on reconnaissance data only - a comparable study for the Cretaceous Sembar formation as source rock is due to be carried out for the Sulaiman depression. In order to carry out a similar study for the Potwar depression, more basinwide samples (wells, northern outcrops) must be collected and analysed accordingly.

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