Zeitschrift: Bulletin der Vereinigung Schweiz. Petroleum-Geologen und -Ingenieure
Herausgeber: Vereinigung Schweizerischer Petroleum-Geologen und -Ingenieure
Band: 62 (1995)
Heft: 140

Artikel: On the tectonics of Bangladesh
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DOI: https://doi.org/10.5169/seals-218425

Bull. Swiss Assoc. of Petroleum Geol. and Eng., Vol. 62, No. 140, July 1995 - p.29-48

On the Tectonics of Bangladesh

With 5 figures and 1 regional seismic line subdivided into tables 1 to 3

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Key words: Bangladesh, Burma, India, Sylhet, Haflong, geopressure, hydrocarbon kitchen, neotectonics, Tripura- Chittagong Foldbelt, Shillong Massif, Dauki fault, Kaladan fault, detachment, Swiss-French Jura, listric fault, petroleum

Special abbreviations used in the text: BD=Bangladesh, GP= geophone point, IBF=Indo-Burman Foldbelt, TCF=Tripura-Chittagong Foldbelt

Abstract

Within Bangladesh the following observations are reported, from west to east: 1. The enclosed seismic line PK-1, 173 km long, shows inside the "Basement" at least six complexes of "seaward dipping reflections" (Hinz 1981) which are interpreted as ?Cretaceous flood basalts. - 2. There is no structural "Hinge Zone" in the triangle between Ganges and Brahmaputra, only the Eocene Sylhet carbonate shelf edge with its seismic velocity effect. A contemporaneous reflector extends over a wide basinal area. - 3. Inside the Bengal Basin, near Faridpur, "clouds" are described from the seismic section. They compare well with US examples of geopressure zones; they would be the hydrocarbon "kitchens". - 4. In the central basin there are signs of duplex formation and neotectonics. - 5. At least the N end of the Tripura- Chittagong Foldbelt is explained as a detachment element (like the Swiss-French Jura chain), which is sliding westward along the S flank of the Shillong Massif.

Zusammenfassung

Innerhalb Bangladeshs von W nach E fortschreitend wird über folgende Beobachtungen berichtet: 1. Das eingeschlossene, 173 km lange Regionalprofil PK-1 zeigt innerhalb des "Grundgebirges" mindestens sechs Serien von "seewärts fallenden Reflexionen" (Hinz 1981), die als ?kretazische Basaltdecken gedeutet werden. - 2. Die sogenannte "Hinge Zone" ist im Dreieck zwischen Ganges und Brahmaputra nicht tektonisch bedingt, sondern wird durch einen seismischen Geschwindigkeitseffekt unter dem Rand des eozänen Sylhet-Karbonat-Schelfes vorgetäuscht. Ein gleichaltriger Reflektor lässt sich weit in das Becken hinein verfolgen. - 3. Im Bengalischen Becken bei Faridpur werden vom Seismogramm "Wolken" beschrieben, die mit einem US-Beispiel einer Geodruck-Zone übereinstimmen, sie wären die Kohlenwasserstoff-"Küchen". - 4. Im Zentralen Becken finden sich Anzeichen von Duplex-Bildung und Neotektonik. - 5. Zumindest der Nordteil des Tripura-Chittagong- Faltengürtel wird - ähnlich dem Schweizer und französischen Jura - als Abschergebilde gedeutet, das längs der S-Schulter des Shillong-Massives nach W rutscht.

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Résumé

De l'ouest à l'est du Bangladesh on peut faire les observations suivantes: 1. Le profil sismique régional PK- 1 de 173 km de longeur (annexé) montre l'éxistence dans le "socle" d'au moins six complexes de "réflexions inclinées vers la mer" (Hinz 1981) qui sont interprétées comme des coulées de basalte du ?Crétacé. - 2. Dans le triangle Gange / Brahmapoutra la "Hinge Zone" n'est pas d'origine tectonique; c'est l'effet du changement brutal des vitesses sismiques à l'aplomb de la terminaison des calcaires littoraux du Sylhet. Une réflexion contemporaine du Sylhet s'étend sur une grande partie du bassin. - 3. Dans le bassin Bengale profond, près de Faridpur, on voit sur la section sismique des "nuages", qui pourraient correspondre aux exemples americains de géo-pression; ce serait les "cuisines" d'hydrocarbures. - 4. Dans le bassin central on trouve des indices de la formation de duplexes et d'activités néotectoniques. - 5. La chaine plissée de Tripura-Chittagong est decollée de sa base (comme le Jura franco- suisse) au moins dans sa partie N qui se déplace vers l'ouest le long du flanc S du Massif de Shillong.

1. Introduction

Reviewing satellite images of the NE portion of the Indian Shield respectively of the Southasian subcontinent one is confronted with a sharp contrast (see for ex. the title page of "Nature", no. 366, of 1993): Towards N collision with Asia, leading to the formation of the E-W trending Himalayas; towards E a subduction process, leading to the formation of the roughly N-S trending curved Indo-Burman Foldbelt (from here onward "IBF") and its western part element, the Tripura-Chittagong Foldbelt ("TCF"). A conspicuous element in between is the Shillong-Mikir Massif, a basement horst, part of the Indian Shield. The sharp southern edge of the Shillong Massif is defined by the E-W striking Dauki fault. In between this rectangular E-W, N-S arrangement lies the Bengal Delta and in the underground the SW-NE trending outer edge of the Indian Shield (fig.1).

Recently two very different books with an identical title have been published, "Geology of Bangladesh", one by F.H. Khan (1992), and another by K.U. Reimann (1993). The first one stresses geological field observations and structural surface mapping. The second one relies on palynological studies plus seismic interpretations by the German Geological Advisory Group with Petrobangla; it contains a contribution about petroleum geology by Hiller.

Recent stratigraphic and sedimentological studies of Bangladesh (from here onward "BD") and the Bay of Bengal have been published by Salt et al. (1986), Lindsay et al.(1991), France-Lanord et al.(1993), and Curray (1994). Structural data with short interpreted seismic sections can be found in Salt et al.(1986), Murphy (1988), and Petrobangla (1988, revised in 1993).

2. Potential field maps

In 1990 a set of three 1:1 million maps of BD has been published by the Geological Survey in collaboration with the U.S.Geological Survey: Geology, gravity, and aeromagnetics. The geological map is of minor help to understand the structural frame of BD but the *gravity map* (M.A.Rahman et al. 1990a) shows a clear contrast between a heavier area in the SE, assumed to be underlain by oceanic crust, and a lighter one in the N and W, assumed to be underlain by the Indian Shield. The heavier area is called the Barisal gravity high. Its NW boundary extends from Agartala

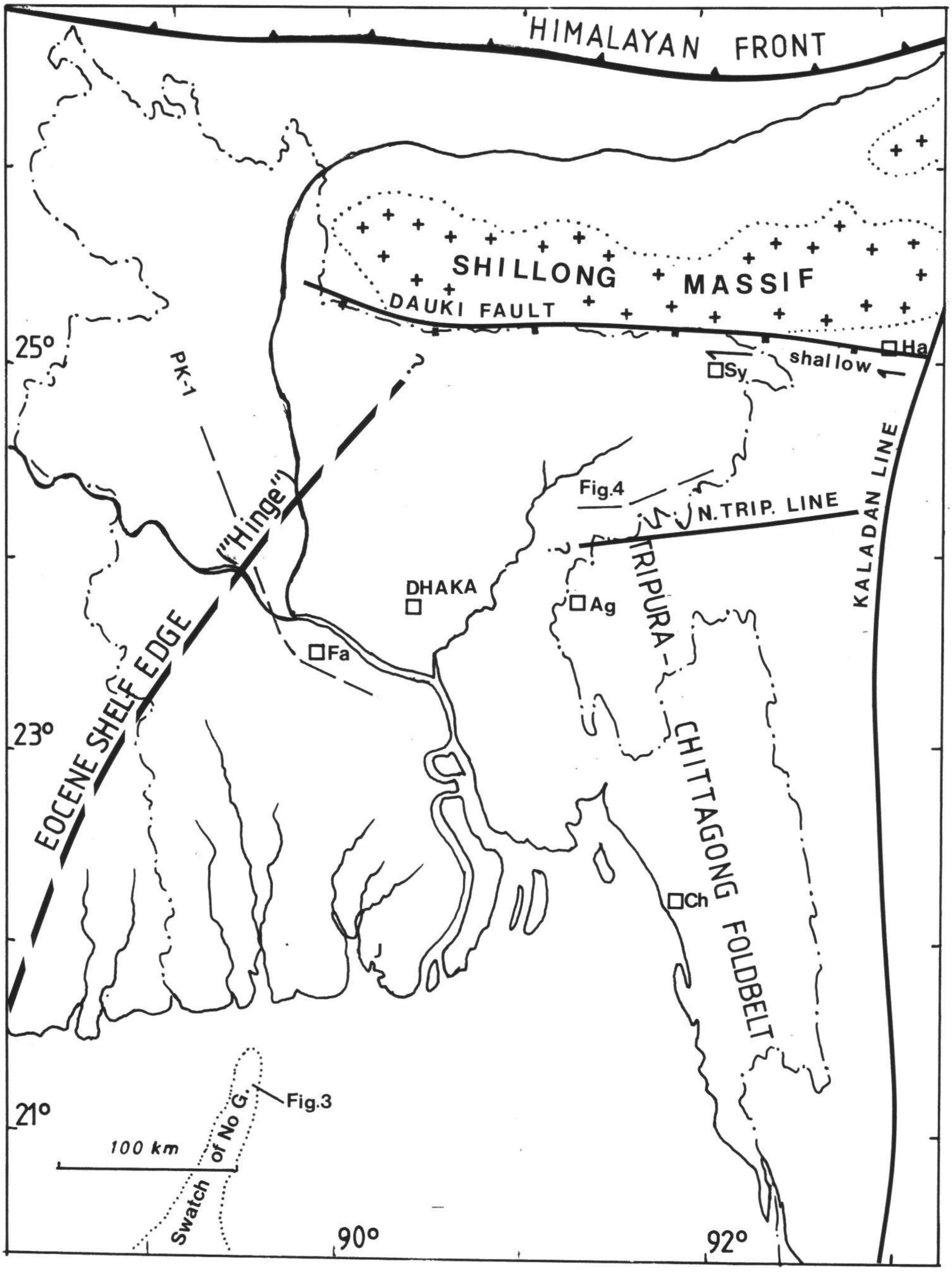

Fig. 1: Bangladesh's geological framework, with locations of three enclosed seismic lines. - Note the Dauki Fault with two kinds of symbols, for upthrust and strike-slip. - Abbreviations: Ag = Agartala, Ch = Chittagong, Fa = Faridpur, Ha = Haflong, Sy = Sylhet.

in the Indian Tripura state to Belabo, NE of Dhaka, and from there past the confluence of Meghna and Padma (= joint Ganges and Brahmaputra streams) in a straight line SW to the Sunderbans, there possibly joining up with the huge, NNE-SSW oriented "Swatch of No Ground" submarine channel.

The eastern boundary of the Barisal gravity high runs from Tripura state due SSW between Hatia island and Sandwip island into the Bay of Bengal. The space between the eastern boundary of the Barisal gravity high and the IBF leaves room for another crustal unit underneath. It has been explained by MURPHY (1988, fig. 2) as a detached oceanic slab of "Probable Early Mesozoic". This author adds: Why is it not a detached continental slab? The gravity values suggest so. Considering that BANNERT & HELMCKE (1981) explain the metamorphics of the Mt. Victoria region of western Myanmar as a part of the continental crust of the Eurasian Shield one might extend this interpretation even to SE-BD and the Hatia Trough (despite the contrary opinion of KLEINKOPF 1994). This would leave only the Barisal gravity high as an area of probable oceanic crust. As a factor supporting the existence of continental crust we can mention HILLER's (1988) petroleum geological map with its trend of a low geothermal gradient (2°/km) in E-BD.

Another observation stands out from the gravity map (RAHMAN et al. 1990a) or for that matter already from earlier gravity maps, perhaps in a rougher form (VERMA & MUKHOPADHYAY 1977; MIRKHAMIDOV & MANNAN 1981, in MIRZA, 1986): The Sylhet (or Surma) Trough or Basin is gravity- wise independent from the IBF. The Sylhet Trough reaches a minimum value of -110 mgal whileas in the Indo-Burman ranges, in NW-Myanmar at 94°30'E, 23° N, gravity reaches -170 mgal. All three gravity maps oblige us to postulate a separate geotectonic character for the Sylhet Trough, different from the IBF.

The difficulty is to define a southern limit of the Sylhet Trough against the adjacent Tripura-Chittagong Foldbelt (from here onward "TCF"), part of the IBF. The gravity values of this area show a strong undulation which may be explained by the lack of terrain corrections and/or by shale filled anticlines. It should be noted that the anticlines on the S edge of the Sylhet Trough are gravity minima. On the other hand, the Sitakund anticline near Chittagong is a maximum, despite its visible shale diapirism. The N side of the Sylhet Trough shows high gravity values which may be due to lateral influences of the adjacent heavy Shillong Massif and/or compressional tectonics plus magmatism.

KHATTRI et al.(1992, fig.4) resolve the problem of the southern limit of the Sylhet Trough by putting two south- directed overthrusts into their sketch map, first the Dauki Fault, and second another parallel one at 24°15'N, introducing a slab of continental crust S of the Shillong Massif and letting the oceanic crust start only S of 24°15'N. This is in good agreement with the gravity values and the magnetic map does not contradict. This additional fault, which this author proposes to call the *North- Tripura Fault* (see fig.1) strengthens the somewhat lone position of the E-W trending Dauki upthrust on the Indian Shield: it would be a sign that the NE portion of the Indian Shield suffered one or two regionally restricted Neogene part-collisions. It would demarcate the S limit of the Sylhet Basin. The North-Tripura Fault is supported by satellite image interpretation, according to which it runs more or less along the northern borders of India's Mizoram and Tripura states, separating the latter from BD. Another minor support comes from HILLER's (1988) petroleum geological map and its stripe of low geothermal gradients (2° Celsius per km) extending from the offshore Hatia Trough past Sandwip island to the southern margin of the Sylhet Basin where it turns towards NE.

Using the *aeromagnetic* map (RAHMAN et al. 1990b) we can derive less information for the regional framework. Eastern BD is only partly covered, especially the Chittagong Hill Tracts are without any observation. NW-BD shows the small anomalies typical for shallow basement. The most outstanding feature of the entire map is the coupled zone of a strong maximum and a strong minimum which run SW-NE, side by side, approximately from Pabna- Kushtia on the western Ganges to Sherpur-Jamalpur near the SW central Shillong Massif. This anomaly couple has been related to the so-called "Hinge Zone" which is actually located further SE. It seems to posess a more a NNE strike.

Further SE of the anomaly couple there are only smooth aeromagnetic anomalies, typical for a deep sedimentary basin, but with a dominance of E-W stretching. Such E-W stretch is not infrequent in magnetic maps of equatorial regions, it casts some doubt on the reliability of the map. This doubt is corroborated by the E-W stretched magnetic anomalies of NW-BD which stand in strong contrast against rounded gravity anomalies over the same area. RAHMAN et al.(1990b) mention the possibility that the magnetic E-W stripes could be seafloor stripes of alternating polarity. GOPALA-RAO et al.(1994) say however: "Seafloor spreading type magnetic anomalies are not reported till date for Bay of Bengal region".

A further point of dispute relating to this magnetic map are the depth calculations for magnetic basement because they turn out to be too shallow in comparison with reflection seismic evidence: The aeromagnetic survey company, Hunting Ltd., determined for the Sylhet area a magnetic basement depth of around 6 km. Confronted with Prakla's seismic measurements which show the Sylhet limestone reflector (Eocene deepwater limestone or its equivalent) at close to 15 km depth (HILLER & ELAHI 1984) they left NE-BD blank without any depth contouring (see fig.1 accompanying RAHMAN et al. 1990b). Hunting Ltd. suggested in their report that an intra-sedimentary layer might appear as magnetic basement.

Even with the reservation that the E-W stretch of the aeromagnetic anomalies is suspect we can still see a 150 km long E-W maximum running from Pathuakali to the border with India's West Bengal. As a speculation for its origin one could think of a trend of recent or subrecent hydrocarbon seepage which led to the precipitation of magnetic minerals (the gravity minimum at the Passur river could then be explained as shale accumulation fostering the hydrocarbon emanation). The same seepage explanation might apply to the three magnetic maxima, near the confluence of Ganges and Meghna, N of Belabo, and at Moulvi Bazar (= Maulavi Bazar) on the S edge of the Sylhet Trough.

Elements of the geological framework of BD (fig.1) are a) the Indian Shield in the W and NW, b) the Shillong-Mikir Basement Massif (part of the Indian Shield) in the NE, c) in the E the IBF (=subduction zone) and its contiguous TCF on its W side, and d) towards S the Bengal Delta which is open and transitional into the Bay of Bengal, part of the Indian Ocean. The Indo-Burman Foldbelt is - sometimes with, sometimes without the TCF - partly or wholly called Arakan Yoma Foldbelt. - We shall now review certain tectonic aspects of BD, proceding from W to E, mainly based on two regional seismic lines.

3. The Bogra Shelf

Fig. 1 shows that the extreme NW part of BD belongs to the Himalayan Foredeep. The western (?)prolongation of the Shillong Massif is usually called the Rangpur Saddle. REIMANN (1993) indicates the locations of several shallow coal exploration boreholes. From there towards SE we have a large area of regional SE dip, the Bogra Shelf (named after the homonymous town close to the Jamuna river).

Our main tool to understand the Bogra Shelf is seismic line PK-1, shot for Petrobangla by Prakla-Seismos in 1978/79 as a German aid project. The line is 173 km long (see attached tables 1 to 3 which are continuous and overlapping). For orientation purposes it carries geophone points ("GP") which are 55 m apart from each other. Seismic processing did not include any migration procedure. Its orientation (see fig. 1) is directed from borehole Singra-1 (89°10'50"E, 24°29'52"N, TD 4100 m in Gondwana beds) on geophone point 485 towards SSE, towards the confluence of Ganges and Brahmaputra (= Jamuna) and from there, after crossing the Ganges river, due SE. PK-1 gives an impression of the rather smooth sedimentary Bogra Shelf respectively of this part of the E flank of the Indian Shield.

The Basement reflector starts at its NNW end (geophone point 130) at 1400 msec, perhaps 2 km depth. An important break occurs at GP 370 where the Basement reflector is extensionally downthrown from 1700 to 2400 msec (i.e. about 1 km throw, down to 3.5 km?). This is presumably the Bogra Fault mentioned in the literature. The shallow 300 msec portion of PK-1 regrettably has been muted out in seismic processing. However, it should be noted that the Bogra Fault and also a shallower graben element further NNW reach all the way up to the 300 msec mute limit, implying rejuvenations into subrecent times. If a reprocessing job were done it would be desirable not to mute these data at all thereby allowing to observe how close these displacements get to the surface resp. how young these movements are.

On the down-thrown side of the Bogra Fault commences a Gondwana graben, its bottom about 18 km wide (GP 390-710) and consisting of several small compartments where both Basement and Gondwana beds are affected by faulting. From GP 730 (2500 msec) continues the Basement Top reflector with only minor irregularities all the way down to the SE end of the line near Faridpur where it appears near 6800 msec, c.14 km depth.

PK-1 allows us to make some observations about internal basement events: Inhomogenities crop out at the Basement Top reflector at GP 1120, 3300 msec; GP 1270, 3600 msec; GP 1530, 4200 msec; GP 1750, 4900 msec; GP 2040, 5700 msec; and GP 2230, 6100 msec, ending at GP 2370. If there is a further continuation cannot be decided from PK-1. The foregoing time values describe the "Basement" Top as a smooth reflection. At each subcrop point there is a steep NW slope and a soft SSE slope, the typical "Trap" (Dutch for "staircase") morphology. In between the subcrop points there are wedges of no notable seismic character. Provisionally, we may call these wedge fillings "basalt wash", in analogy with "granite wash".

This writer interprets these six complexes as "seaward- dipping reflections" in the sense of HINZ (1981; 1995, p.570). He interpreted comparable events offshore Argentina as layers of flood basalt. Then the six inhomogenities would be indicative for six phases of continental break-up, getting younger from W to E. Where is their counterpiece, with the symmetrical eruptions? - The aeromagnetic map of BD (RAHMAN et al., 1990b) does not show any direct correlation with this interpretation.

Going stratigraphically upward we must mention the Eocene Sylhet limestone and structural conjectures connected with it. Most publications mention extensively the SW-NE striking (Calcutta-Mymensingh) "Hinge Zone". PK-1 shows clearly that there is no structural hinge in this area. There is a sedimentary shelf edge of the Sylhet limestone, with its edge top at GP 1600 at 3350 msec and with a fore- reef talus reaching down to 4650 msec under GP 1850. We disagree with HILLER (1988, p. 12) who claims that the Sylhet reflector disappears and only later reappears at greater depth. Basinward the Sylhet equivalent (a dense basinal limestone, perhaps with chert layers? This could explain its strong contrast within a clastic sequence) continues as a regional reflector, beginning as a 300 msec reflection band and decreasing towards SE. The Sylhet reflector is still visible at the SE end of PK-1, that is SE of Faridpur, at a time value of 6500 msec. It is also discernible in the region of the Kamta gasfield near Dhaka and under the SW coast of BD, S of Khulna where MIRZA (1986, p. 75) describes it at 6450 msec, perhaps 14.5 km depth.

Further examples of the Eocene shelf edge can be found in SALT et al.(1986, fig. 6), LINDSAY et al.(1991, fig. 4), MURPHY (1988, fig. 9), or PETROBANGLA (1993, fig. 36). For a basinal expression of the Sylhet reflector see MURPHY (1988, fig. 8) respectively PETROBANGLA (1993, fig. 38): Line PK-MY-8403 shows it at 3850 msec (around 6 km deep) between the SW corner of the Shillong Massif and Mymensingh, 15 km away from the Dauki Fault. Vague indications of the Sylhet reflector are visible as far E as the town of Sylhet (the type locality of the Sylhet limestone is a few km N of the homonymous town, on the slope of the Shillong Plateau). According to HILLER & ELAHI (1984, fide RAHMAN et al. 1990b) basement is there more than 7500 msec resp. 15 km below sea level, with the Sylhet formation some km above it. Aren't the time values larger and thereby the depth values even deeper?

As shown in fig.1, where or how the Eocene shelf edge continues in N-BD is not known because there is no seismic coverage. This author speculates that it turned E over what is today the Shillong Massif.

Going stratigraphically upward from the Sylhet limestone on seismic line PK-1 we notice two major regional phenomena: a) A strong foreset series, and b) the *Hazipur unconformity*. The foreset series develop more or less out of the Sylhet sedimentation. The top layer of the foreset series is a mappable seismic reflector but obviously a diachronous one: As the basin fills up and builds southward so the foreset habitat will move into younger and younger beds (MIRZA 1986). The same author has named the Hazipur unconformity after the homonymous borehole, located 100 km NW of Dhaka. The Hazipur unconformity is described to be the boundary between the Upper Pandua Sandstone formation and overlying gray, silty clays. From the seismic sections of the Hazipur area MIRZA described the unconformity as the erosional activity of mud-loaded waters leaving box-shaped hills behind. Line PK-1 shows examples, for ex. from GP 740 at 1500 msec to GP 840 at

1650 msec, or from GP 930 at 1850 msec to GP 970 at 1900 msec. Basinward the Hazipur unconformity looses character. It seems that a broad channel (channel basis at 3900 msec, between GP 2600 and 2800) is part of the Hazipur erosion.

This unconformity has been earlier described, for ex. by SALT et al.(1986) as "R-11", or by LINDSAY et al. (1991) as an unnamed eustatic low stand event at 10.5 M.y. It was probably also meant by CURRAY & MUNASINGHE (1989) with their "latest Miocene unconformity" which they attribute to the onset of N-S compression of the Indian Shield. A pre- or early Miocene Himalayan sediment contribution to the Ganges-Brahmaputra system has been reported by FRANCE-LANORD et al.(1993) based on deepsea drilling data from near the equator.

An interesting outlier of the Bogra Shelf is the Dhaka-Madhupur elevated block with its present rise and E tilt (MORGAN & MCINTIRE 1959). The small Kamta gasfield could be the sign of a wider gas prospectivity.

Summarizing the structure of the Bogra Shelf and slope we can say: Line PK-1 is similar to PETROBANGLA's line Hor- 85-21 (1993, fig. 11). Both exhibit a quiet, slightly extensional regime without any folding. On both lines there is no tectonic "Hinge Zone". The term has been created by seismic interpretation, not by outcrop geology. This writer claims that the "hinge" of the Ganges-Brahmaputra triangle is only a seismic velocity effect: A basinward fast increase of post-Sylhet overburden with low interval velocities (and beginning geopressure zones) leads to an apparent downward-bending of the Basement reflector. - Also, on the same two lines there is no serious sign of crossing the outer edge of the Indian Shield, for ex. by fundamental change of structural style. From GP 2360 onward the Sylhet reflector turns more or less horizontal, with some signs of block faulting.

As a southern continuation of the Bogra Shelf we have to mention the *Bengal Delta*, the confluence of the Ganges and Brahmaputra river systems, which opens southward into the Bay of Bengal. CURRAY (1994) has compiled a new sedimentary isopach map for the latter, together with some onshore values. He shows a maximum of 21 km at 90°E, 21°N, immediately E of the Swatch of No Ground. Remarkable in his map is the very reduced thickness on the Ninety Degree East Ridge respectively its N prolongation, the Carpenter Ridge, which stops suddenly at 92°E, 18°N. He implies an irregular sediment thickness distribution under onshore BD, an idea supported by the gravity and aeromagnetic maps.

4. Geopressure's seismic expression

STUART (1970, fide JONES 1980) defined geopressure as that part of the formation fluid pressure which reflects some part of the overburden rock load. To express it in other words: There are underground compartments which have the character of a pressure vessel. They carry a part of their overburden's weight. Such conditions present a serious drilling hazard. They can also be indicative of a) on- going hydrocarbon generation, b) present geological stress, and/or c) very fast sedimentation (for discussions and examples see for ex. BODMER 1994; BOUR et al. 1995; GRETENER 1989; ROBERTS & NUNN 1995; YASSIR & BELL 1994).

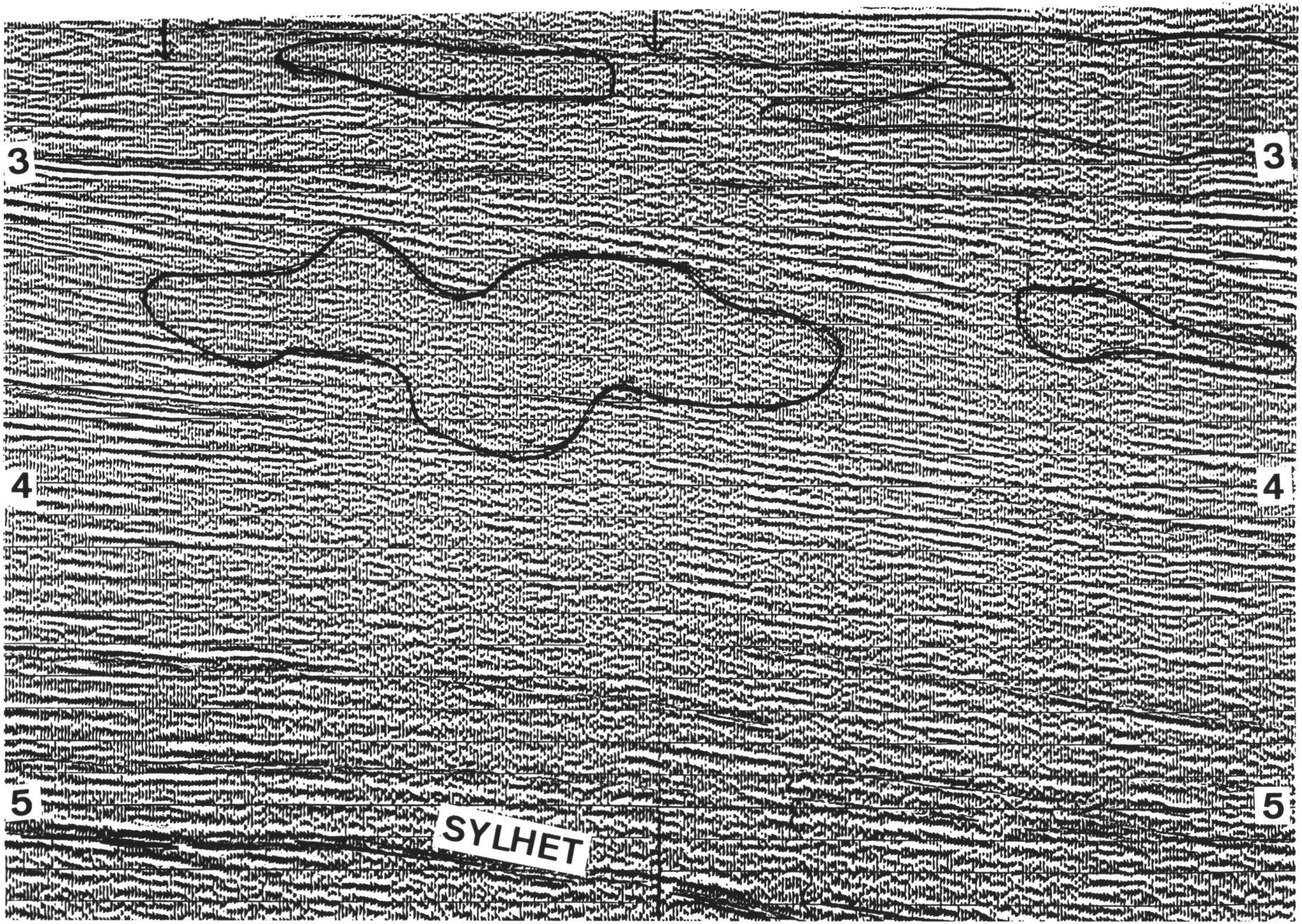

Fig. 2: A 9 km segment of seismic line PK-1, GP 1970-2150, with geopressure "clouds" and their cementation zones in foreset series. The arrows indicate velocity analyses. - Ganges region, 75 km W of Dhaka.

Fig. 2 is a segment out of PK-1, 2550-5350 msec, GP 1970-2150, that is close to the Ganges crossing. It is a raw processing version, different from table 2. It contains four "cloud-shaped bodies" in the interval 2600-3900 msec. The newly created term refers to recognizable, restricted local areas of poor seismic processing quality, i.e. where the interval velocities used are wrong, in my view too high. Surrounding layers, also to the right and left of the "clouds", show proper reflectors of normal quality. There is a slight sign of a rim surrounding the "clouds". This writer interprets the "clouds" as zones of present geopressure.

As can be seen on PK-1 the clouds are contained inside foreset series; this would support the claim for very fast sedimentation. The more probable area of "cloud" presence is between GP 1860 and 2500 in the time interval 2700 to 4000 msec, roughly 4 to 7 km depth. SE of GP 2400 the major erosional channel already mentioned above in connection with the Hazipur unconformity cuts down into the foreset series, thereby possibly releasing the geopressure (although it may contain a "cloud" in its own upper part). Facit: poor seismic processing may help to determine the presence of geopressure clouds.

An example of cloud-shaped distribution of interval velocities in connection with geopressure zones based on very high processing quality has been published by DAVIS & FAVRET (1994) from Wyoming (no location or formation age given), observed in a zone of foreset-bedding, that is of fast sedimentation (same situation in BD). The "clouds" occupy various depth levels and are not tied to one fixed layer. In Wyoming the geopressure zone seems to act as the seal of a gas field. The "clouds" with low interval velocities are enclosed by high-velocity rims, which this writer interprets as cementation zones. Such hardened "clouds" are postulated as forming the nuclei of the compartments required for duplex generation. But it could also be the other way around, i.e. the liquid shale after a cloud collapse could serve as a lubricating separator between two duplex units.

LAUBSCHER (1992) shows how he imagines the initial development stage leading to duplex formation as a series of inhomogenity plains penetrating the lubricant formation plus its overburden. Under external influences (compression, tilt, geopressure release, perhaps erosion) the "clouds" of Faridpur could become structural duplexes.

5. Duplex formation and neotectonics

Only very few and short seismic sections have been published from central BD. One (fig. 3a), from PETROBANGLA (1993), refers to an undrilled structure in the nearshore area under the E flank of the Swatch of No Ground (location see fig. 1). Starting with the shallow beds of its NW portion one can observe a large slump of well stratified surface beds into the Swatch of No Ground. Between 1.1 and about 2.3 sec there are several erosional channels and slump features visible. At about 3.2 sec under S.P.600 a "direct hydrocarbon indicator" is recognizable and immediately below it - in this writer's opinion - an incipient duplex formation (fig. 3b). Its thickness could be about 500 msec (3.3-3.8 sec) or more than 1000 m. In the same publication (PETROBANGLA 1993) there is another indication of possible duplex formation, in this case between 2.8 and 3.5 sec, at Shabajpur near Muladi island. For lack of data it remains unresolved if this is a present or a fossil process of possible duplex formation.

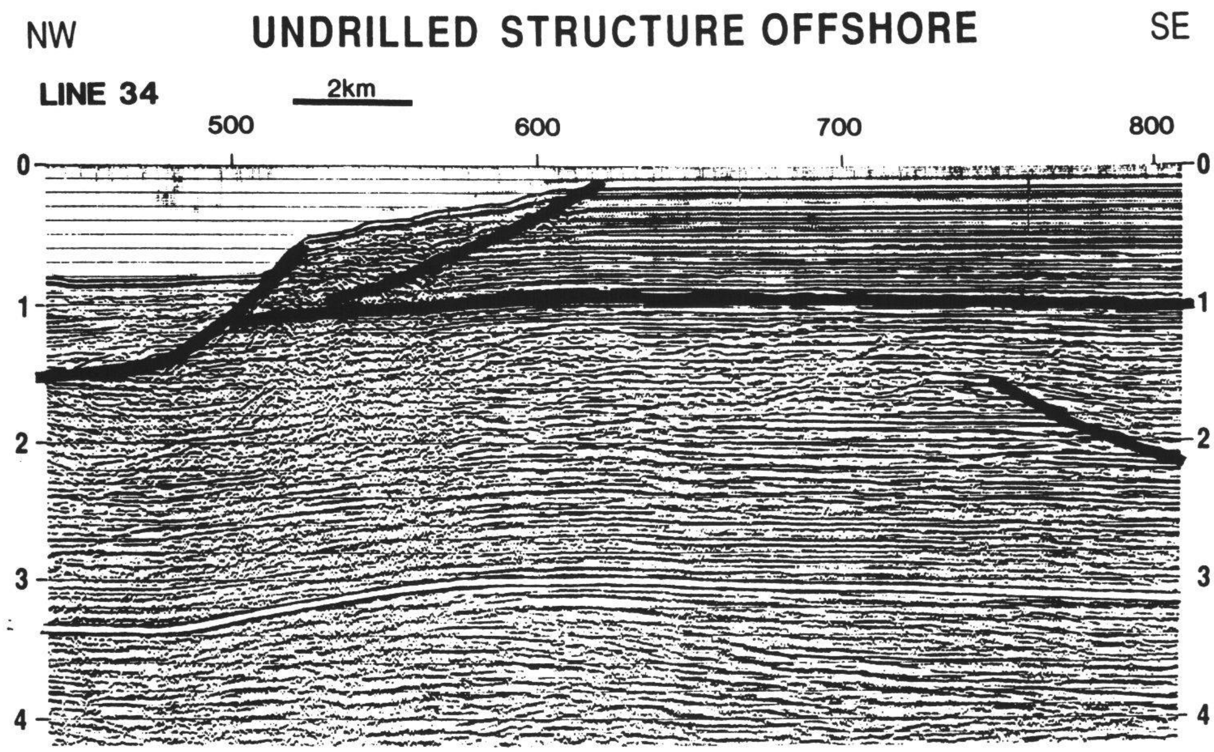

Fig. 3a: Seismic line 34 with undrilled offshore structure under E shoulder of Swatch of No Ground, with Petrobangla interpretation (from PETROBANGLA 1993).

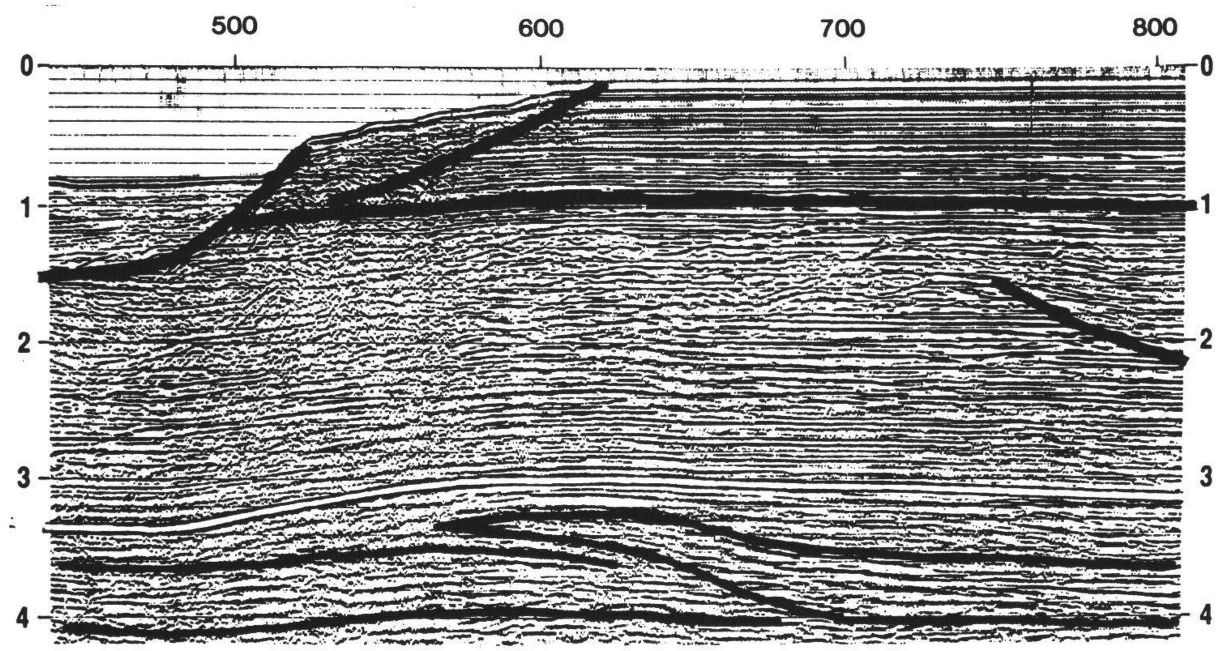

Fig. 3b: Same seismic line with this author's interpretation of incipient duplex formation below 3 seconds TWT.

We see indications of possible duplex formation in three places, on the SE side of the Swatch of No Ground, on Shabajpur island, and at Habiganj (fig.4). This alignment agrees with MURPHY (1988), PETROBANGLA (1988 and 1993) and their separating line between "Attenuated continental crust" in the NW and "Oceanic crust" in the SE, that is with what they consider to be the outer edge of the Indian Shield. Along this same line this author has found on satellite images of 1:100'000 scale a number of indicators for young uplift:

a) At Sarail, at the upper Meghna river, the water from the Madhupur forest tract was flowing in the past due S, via Comilla to the Bay of Bengal. A young barrier of NE-SW orientation seems to have redirected a major part of the water SW, into the Meghna, whileas only a smaller portion flows S, in the Titas river.

b) Immediately SW of the confluence of the Meghna with the Padma stream (combination of Ganges and Brahmaputra) there is a little plateau, perhaps 10 m high, of 10 by 10 km extent: on its WNW edge, at Naria, we see a little escarpment of NNE-SSW orientation, possibly the result of recent uplift. Regrettably we posess no ground control for this.

c) SW of Naria, on trend with the "escarpment", the rivers Arial Khan and Kumar show a sudden water turbidity. This could be due to present uplift and erosion.

d) E of Khulna, on both sides of the Madhumati river, there are sizeable peat areas under stagnant water. Their SE limit could be formed by a recent NE-SW barrier or bulge, on trend with points b) and c). This lineament has already been mentioned by MORGAN & MCINTIRE (1959, fig. 3).

e) Extending this alignment to the SSW we arrive at the Swatch of no Ground, the important seawater channel at the head of the Bay of Bengal.

Is it a coincidence or just a case of data availability that possible duplexes and neotectonic movements appear along a certain trend?

6. Shillong-Mikir Massif and Dauki Fault

Immediately adjacent to the Sylhet Basin is the Shillong- Mikir Basement Massif, separated from it by the E-W trending Dauki Fault. From a geotectonic point of view a major question arises, already discussed by several authors (for a recent summary see KHATTRI et al. 1992): What is the relationship across the Dauki fault, between the Shillong Massif and the Sylhet Basin? Or to phrase it differently: Satellite images show a continuous and tightly folded IBF E of the Shillong Massif, running undisturbed past the Shillong Massif. S of the Shillong Massif there is a loose, less densely folded and irregular collection of N-S anticlines, the TCF, running more or less at a right angle against the Dauki fault. How is this possible?

First we have to look at the history of the Shillong Massif: Satellite images of the area N of Sylhet town show a peneplain of Basement rocks very recently undercut by S directed streams. As this is one of the rainiest spots on earth (the Shillong Plateau is politically called "Meghalaya state" and Meghalaya means "cloud home") this southward erosion (and the uplift making it possible) must be very young indeed. For the post-Sylhet (Eocene) history of the S central part of the Shillong Massif this means (from bottom to top):

Very young uplift
Sedimentation
Subsidence
Peneplainisation
Total erosion of Sylhet limestone

On the satellite image mosaic from "Nature" (vol. 366, 1993) it appears that the Mikir crystalline posesses an overburden different from that of the SE flank of the Shillong Massif.

To determine the age of the Shillong Massif we may refer to BAKSI (1974) who described the facies changes within the late Cretaceous to Eocene series. SAH (1974) distinguished within the Paleogene sediment cover between the Paleocene-Eocene Jaintia Group (including the Sylhet limestone) with shelf facies and the (?)Oligocene Barail Group of geosynclinal facies (according to his description apparently a flysch turbidite) which appears only in the SE part of the plateau. A possible interpretation could be that these Barail beds were tectonically deposited on the Shillong Massif by the Disang-Haflong thrusts. To this writer's restricted knowledge one could argue that the Shillong Massif started to rise in as early as late Eocene time or after the Disang-Haflong thrusts, i.e. in late or post-Oligocene time. However, assuming a more or less contemporaneous rise of the eastern Himalaya and of the Shillong Massif this would induce one to correlate the main uplift to the *strongest unconformity* of the Bengal Delta, to the Hazipur unconformity of *Miocene age.*

EVANS (1964; fide KHATTRI et al. 1992) interpreted the Dauki Fault as a strike-slip along which the Shillong Massif moved E relative to the Indian Shield by between 150 and 300 km.

RAHMAN et al. (1990a) mention the Dauki Fault as a highangle reverse fault with a lateral component, but without indicating any age relationship. REIMANN (1993, p. 81) describes it as a scissors-type fault with first movements at the end of Oligocene and main displacement in Neogene time. As already discussed above in chapter 2 this author sees the Dauki Fault and its southern parallel, the North-Tripura line, as compressional elements giving evidence of a special collision of this NE corner of the Indian Shield.

The age of the uplift of the Shillong Massif ought to be documented by nearby coarse sediments in its southern neighbourhood. This writer was unable to find any firm literature evidence for this, with the possible exception of the Barail Group of SAH (1974). In the following chapter we shall attempt to explain the whereabouts of the coarse clastics.

7. Thin-skinned detachment in the Tripura-Chittagong Foldbelt (TCF)

Only one regional seismic line (our fig.4) has been published from eastern BD, by PETROBANGLA 1993. It runs WSW-ENE along the S edge of the Sylhet Trough, from Habiganj via Rashidpur and Maulavi Bazar to the border with India's Tripura state. It shows gentle folding with no specific fold convergence but with a flower structure (= wrench tectonics) at Maulavi Bazar.

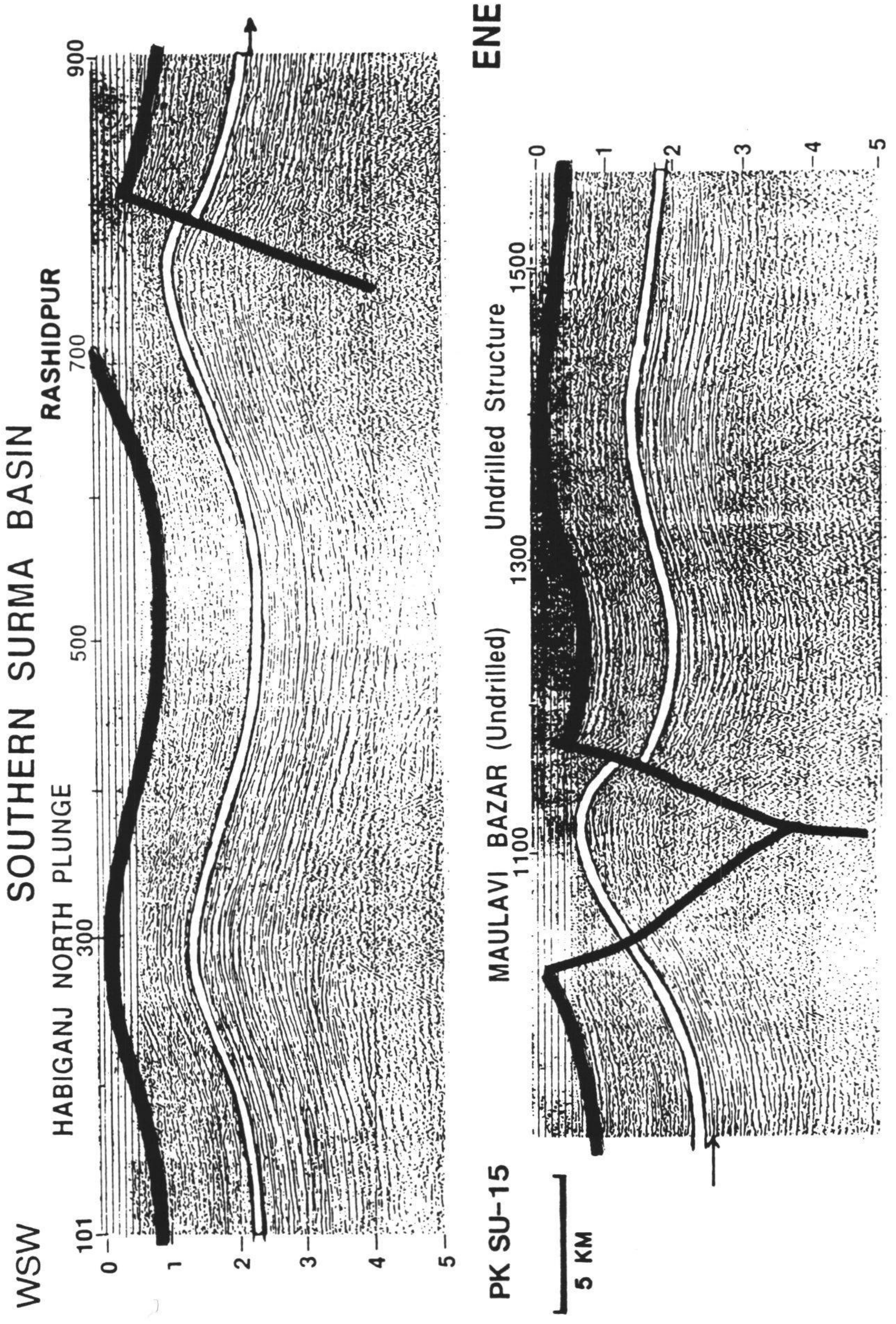

Fig. 4: Regional seismic line PK-SU-15 (in two pieces) from southern Surma (= Sylhet) Basin, 83 km long, with Petrobangla interpretation (from Petrobangla 1993). - Note the lack of oriented folding, a possible detachment plane below 4 seconds, and shale accumulations in anticlinal cores.

This author does not want to argue with the shallow horizons as marked by PETROBANGLA. The deeper reflectors, between 3 and 4 sec TWT, allow a more complicated interpretation for Habiganj, with at least one duplex being formed in the core of the anticline. Or is it a shale injection?

To convert the foregoing seismic travel times we need a time/depth curve. Published is only the "Surma Basin" curve by ASSMANN et al. (in HILLEr 1988 and also in REIMANN 1993). Its time resp. depth range goes only down to 4.2 sec resp. 6.8 km. Near surface velocities are more variable and therefore have a stronger effect on total depth values than deep formation interval velocities. Therefore this writer has extended the above curve to 15 km resp. 7.5 sec (value from HILLER & ELAHI 1984, fide RAHMAN et al. 1990b) to get at least an order of magnitude of depth values for measured seismic travel times (fig.5).

Now a look at some area definitions: A review of the topographic map (in this case of the TIMES atlas) shows a marked difference between the IBF and the TCF. The former exceeds in places 3000 m elevation, the latter rarely reaches 1500 m. Both, maps and satellite images suggest a tectonic "cornerstone" (not a triple junction) in the area of Haflong in southern Assam state: The whole quadrant SW of Haflong

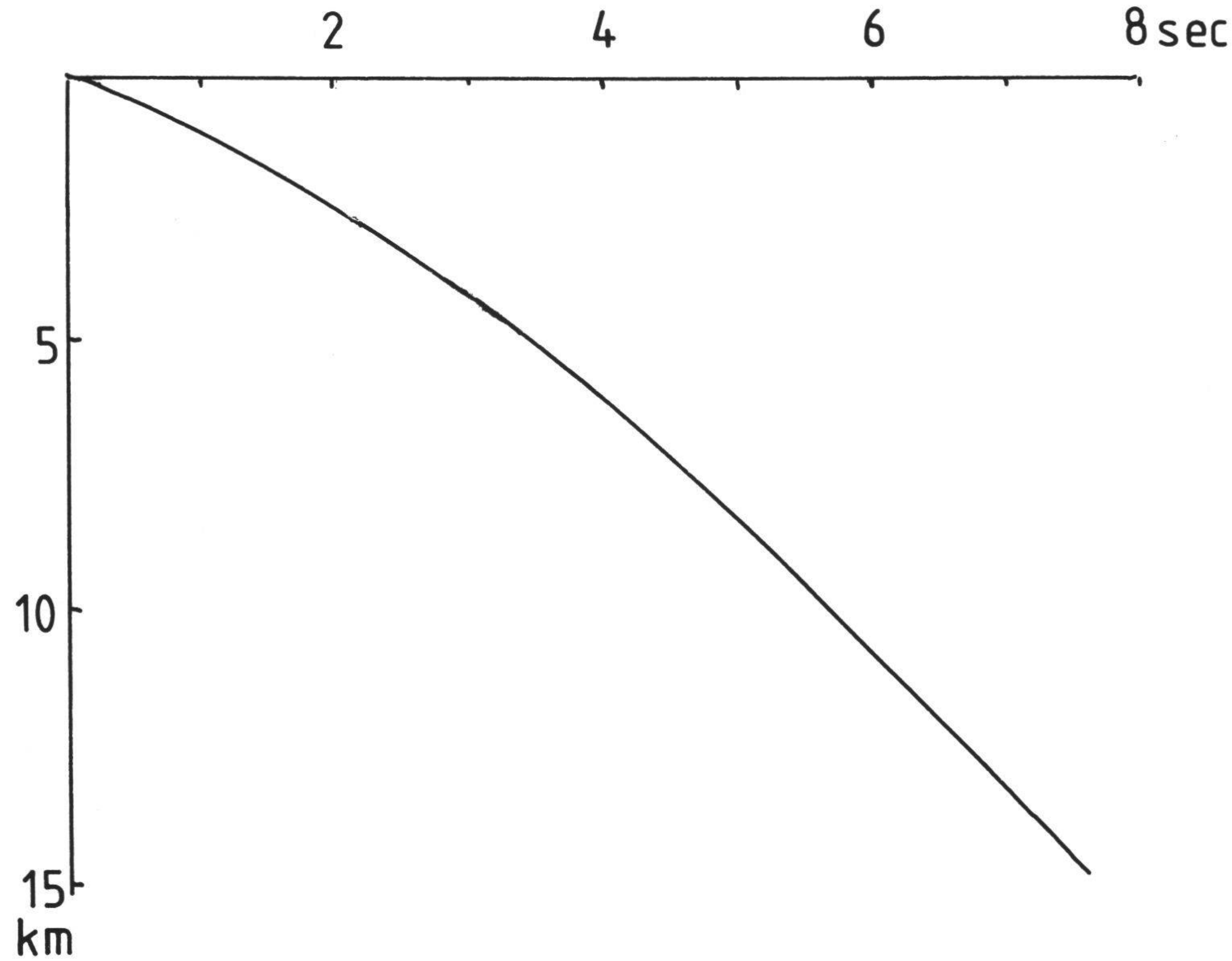

Fig. 5: Time-depth conversion curve for NE-Bangladesh, based on "Surma" curve by Assmann et al. Plus extrapolation (see text)

pertains in this writer's opinion to the TCF, the quadrant's northern demarkation being the Dauki Fault, its eastern demarkation (Kaladan line on fig.1) running parallel with the Kaladan river to the Arakan coast of Myanmar (where there are mud volcanoes on Ramree and Cheduba islands). Satellite interpretation maps by BANNERT and HELMCKE in BENDER (1983) do not prove nor disprove the existence of a major tectonic element along the lower Kaladan river in Myanmar. BENDER's sketch map (1983, p. 17) shows something like a Kaladan line around 50 km E of the BD border line. PETROBANGLA (1988 and 1993) have drawn their "Kaladan" fault right on the eastern border of Bangladesh's Hill Tracts. The Kaladan river is about 25 km further E. Only E of it one encounters the normally folded IBF.

Similarly, RAM & VENKATARAM 1984 (cited in REIMANN 1993, p. 21) have already suggested a subdivision of the IBF into two belts, the Mizo Foldbelt in the E and the TCF in the W, separated from each other by the NNW-SSE striking Kaladan Fault.

This author believes that at least the northern parts if not all the TCF (W of the Kaladan line) are an area of W directed thin-skinned detachment. The detachment would occur along geopressured shale levels (the French term is "décollement" which means "un-glueing"). The force behind this movement could be the mentioned elevation difference between IBF and TCF and/or the subduction process between the Indian and the Eurasian plates. One could even imagine that geopressure zones progressing from the deeper trough to the foreland of a foldbelt and their collapse were the moving force. GRETENER (1989) describes the short existence of the right conditions for such detachment and its possible connection with hydrocarbon generation. ROBERTS & NUNN (1995) claim that a fluid expulsion phase from a geopressured formation takes less than 100 years. The wide-spread presence of geopressure in boreholes and a number of mud volcanoes (past and present) in the TCF attest to the probability of shale tectonics.

The SE-Shillong cornerstone at Haflong, the "smeared" stripe of Tertiary sediments along the SE flank of the Shillong Massif (W end 40 km NE of Sylhet town), and the loose, irregular folding of the TCF imply to this author an incipient detachment stripe of about 200 km E-W width and perhaps 600 km N-S length. Seismic sections of the Chittagong Hill Tracts show shear-off tectonics at less than 3 sec (= 4 km) depth where shale filled anticlines sit above older synclines, a case of disharmonic folding (and an explanation for past disappointments in petroleum drilling). With this interpretation we do not want to exclude wrench tectonic influences (as can be seen on some published seismic sections) but they are considered to be of secondary importance.

The concept that the deformation of the northern Indoburman Ranges is decoupled from the underlying Indian plate was already proposed by CHEN & MOLNAR (1990). Two questions: Is it really the Indian plate? Wouldn't decoupling permit deep NNE-SSW compression and simultaneous shallow E-W movement? In this context we have to answer the questions raised by COWARD & RIES (1994) about the distinction between thick- and thin-skinned tectonics. This author believes they can be answered in the affirmative sense for a thin-skin explanation.

Accepting the northern TCF as a thin-skinned detachment area we can draw the following conclusions: 1) The Dauki Fault is for the deeper underground a (reverse) fault but near the surface an apparent E-W strike-slip. - 2) The Shillong Massif was a structural high at the time of the TCF detachment and served as a shoulder to its westward movement. - 3) It is no surprise that we see no important coarse clastics from the rise of the Shillong Massif in subrecent sediments. They are hidden under the TCF. Another explanation might be that its uplift is too young to have generated much coarse material.

8. A comparison with the Swiss-French Jura chain

The starting point for this author to propose detachment tectonics for the TCF is a comparison with the Swiss-French Jura Foldbelt (for recent summaries see BURKHARD 1990 and LAUBSCHER 1992): In middle to late Miocene time there was a strong west-directed push within the already folded Alpine belt of Switzerland. This led to regional detachment towards NW, roughly 250 km long (area of Zürich to area of Chambery in Savoy, France) and up to 100 km wide. There was an obstacle towards NNW, the Black Forest Massif of SW Germany, which prevented the slide towards N. This is the same bulwark function which the Shillong Massif had vis-a-vis the west-directed TCF detachment.

As additional remarks we may make here: LAUBSCHER (1992) thinks that the Black Forest is the isostatic compensation for the Jura detachment. This writer is not convinced. The Rhine Graben was definitely in existence during the Jura detachment because on satellite images the eastern main fault of the Rhine Graben "shines" through the Jura folds, as well as other transverse elements. What kind of elements to expect has been shown by PAVONI (1961); his concept of halfstar shearing seems to be applicable to the TCF. Inside the Rhine Graben local detachment units have advanced further (N in this case) than on the adjacent eastern shoulder. Also they have formed overthrusts at the front which have been proven by drilling.

In the case of the Swiss-French Jura Foldbelt the detachment took place along Triassic evaporite horizons, in contrast to the shale levels of the TCF.

9. Petroleum aspects

PK-1 leads us to believe that there is present hydrocarbon generation taking place in the depth interval 4 to 7 km of the Faridpur region. Whatever hydrocarbons are being formed, they would migrate towards NW. On the Bogra Shelf though there is a shortage of proven and reliable sealing formations.

Past hydrocarbon exploration in eastern parts of BD was successful looking for shallow gas but not for oil. Accepting the concept of a major detachment in the TCF, for oil exploration it will be necessary to recognize the detachment level's position and to select deeper, unbreached structures below it. The presence of oil is documented by several seeps. Drilling activities and seismic processing plus interpretation will have to take more care with shale diapirism, shale extrusion, collapse features, and mudflow canyons. R. MURPHY (kind personal communication) stresses the importance of discovering sand-filled E-W channels which run across later N-S anticlines thereby restricting the prospective areas. - The Dhaka-Madhupur Quaternary high seems to be underexplored.

10. Some open questions

Two major deltas of Tertiary age, Mississippi and Niger, show a pronounced tendency to form synsedimentary listric faults with their typical roll-over structures. There are a few indications of listric faults in north central BD but why are there so few and only in a restricted area? Is it that only fluvial deltas can form them?

There are signs of neotectonics and duplex formation in central parts of the Bengal Delta. Do they relate to the outer edge of the Indian Shield and if so, how?

In this paper we have restricted ourselves to the term "Kaladan line". It would be desirable to make a joint effort by the three involved countries, Bangladesh, India, and Myanmar, to define the character and the location of this element/these elements. This would be a stepping stone to better understand the contact between the Indian and the Eurasian plates.

Usually one speaks of a subduction zone somewhere in western Myanmar or west of it, but certain authors claim that this subduction has ceased whileas others believe it is active only S of 18° latitude.

Acknowledgements

PETROBANGLA, the Bangladesh Oil, Gas and Mineral Corporation, and its subsidiary BAPEX kindly permitted the publication of seismic line PK-1. My sincere thanks go to them and to G. Hildebrand of BGR, the Federal Institute for Geosciences and Resources, Hannover, Germany.

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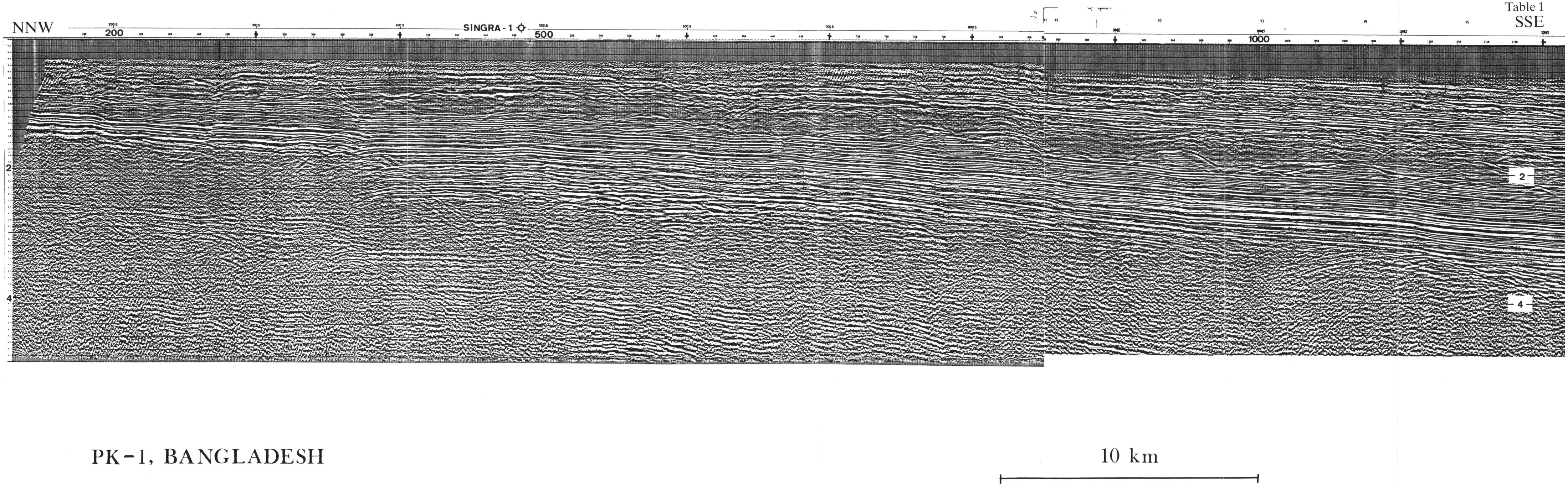
Table 1



PK-1, BANGLADESH

Table 2

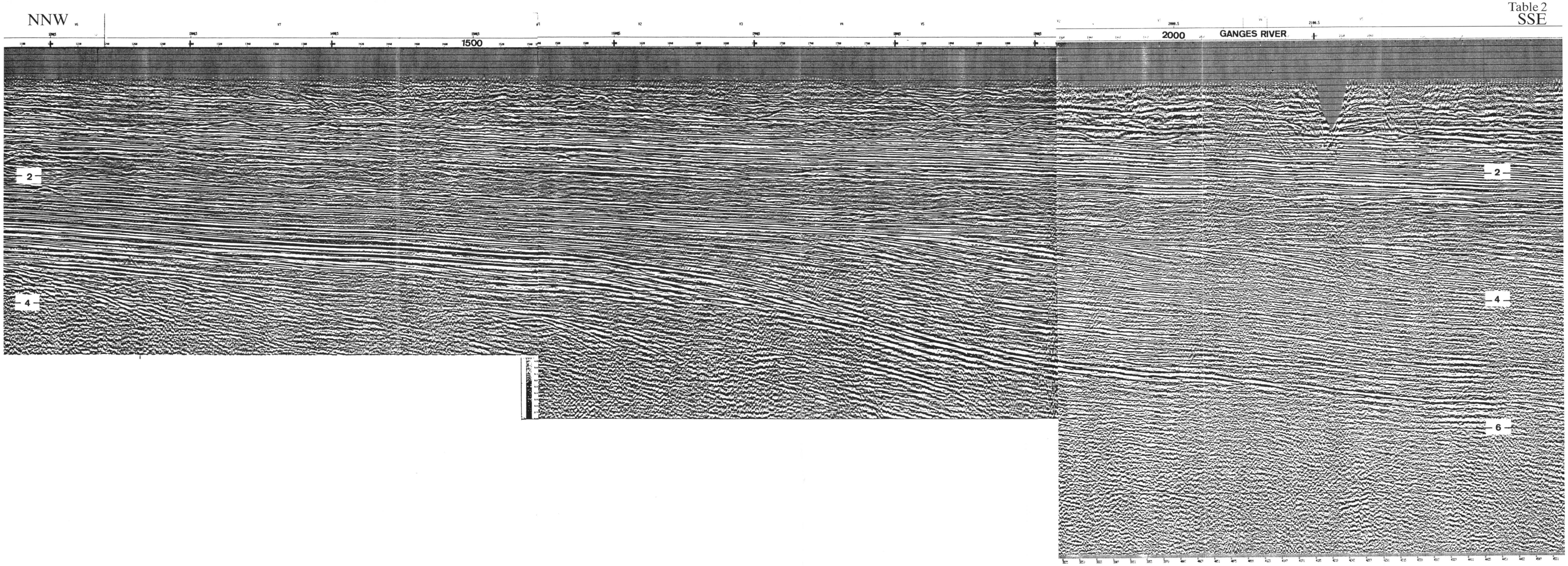


Table 3