Pakistan Journal of Hydrocarbon Research
Vol.7, No.1 (January 1995), P.31-52,14 Figs., 1 Table

Late Mesozoic Sedimentary Megacycle in the Rifted Haro Trough, Hazara, Pakistan and its Hydrocarbon Implications in the Northern Rim of the North West Himalayan Basin

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ABSTRACT

Late Jurassic to Late Cretaceous Haro megacycle (Chichali, Lumshiwal, and Kawagarh formations) is geographically situated between Nathiagali, Murree, and Jhelum faults. This megacycle is unconformably contained between the Middle Jurassic Samana Suk platform carbonates and the Early Tertiary carbonates. The megacycle consists of two unconformity bounded sequences: (1) above the top-Bathonian unconformity with Late Oxfordian basal belemnite bed, two coarsening up cycles, and a pelecypod coquina cycle bounded by Late-Albian unconformity; (2) middle/Late Turonian to Campanian planktonic foram wackestone-packstone, a carbonate slope breccia, and a localized Campanian/Maestrichtian low stand Jamhiri Sandstone bounded by the Basal Tertiary unconformity. The Sequence 1 clastic cycles were supplied from the east and prograded westward axially in the basin. At least two major marine transgressions are recorded in the Haro megacycle. The Cretaceous tectonics, the sedimentary facies and their relations to the bounding faults, suggest the Haro Trough was an extensional rift basin. The original basin bounding and internal normal faults have later been inverted as thrusts. Regional time shifts at the base of the Late Mesozoic megacycle and the collapse of underlying carbonate platform, suggest the rifting started in the north and gradually migrated southward in Pakistan.

The horsts bounding the Cretaceous grabens are attractive for hydrocarbon exploration. The deformed sedimentary basins in northern Pakistan should be reevaluated for identification of horsts to better target hydrocarbons exploration in the early Tertiary and the older rocks.

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INTRODUCTION

The Haro Trough is a Cretaceous depocentre in The Hazara area of northern Pakistan (Figure 1). The Haro Trough sedimentary fill is classified as the Chichali, the Lumshiwal, and the Kawagarh formations (Latif, 1992). The Haro is the main river draining this area. This trough extends towards Kohat and Samana areas in northwestern Pakistan and was separated from the Soan Trough and the northern Hazara Cretaceous basin named the Dor Depression (Latif et al., 1993) during Cretaceous.

The Hazara area in northern Pakistan is part of the northwestern Himalayan fold and thrust belt (Lillie et al.,1987). This area remained a sedimentary basin intermittently from Cambrian to Tertiary and contains many superimposed basinal sedimentary megacycles (Shah, 1977; Kemal et al., 1992). Cretaceous megacycle is well developed here and is the focus of this study. This megacycle is further defined into smaller cycles that record the tectono-sedimentary events which happened when the Indo-Pakistan subcontinent was separating from the Gondwanaland and drifting northward. The earliest collision probably took place in the Late Cretaceous (Bannert and Raza, 1992). All the major events have been recorded in these sediments, which are not well studied.

If the earliest collision took place by the Late Cretaceous (Bannert and Raza, 1992) then the sedimentary basins probably started to change with a new set up in the Early Tertiary. This new basinal set up can be better understood with improved understanding of the Cretaceous.

The Early Tertiary marine basins are major hydrocarbon producers in northern Pakistan (Khan et al., 1986). The well understood Cretaceous events will explain the Early Tertiary basins. Besides that, the Late Jurassic-Early Cretaceous black shales are considered an important source rock in southern Pakistan (Raza, 1992), where abundant hydrocarbons are produced from the Cretaceous rocks (Quadri and Shuaib, 1986). Similar Cretaceous black shales in northern Pakistan may have acted as hydrocarbon source and the Cretaceous reservoirs may contain hydrocarbons.

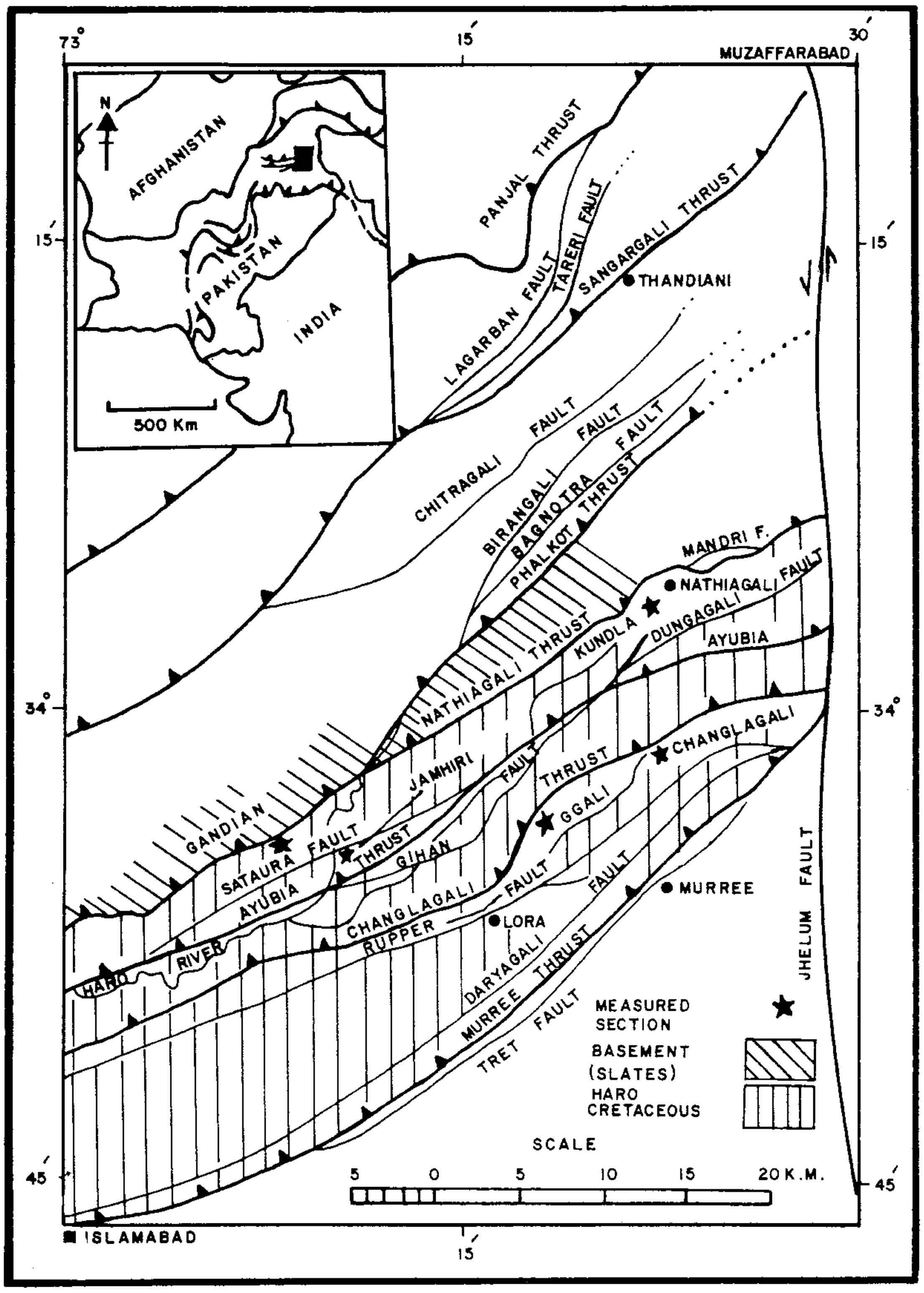

Figure 1-The map showing the Haro Trough and the locations of the studied sections.

The Hazara Cretaceous sediments were deposited in extensional stress regime. The area is an active thrust belt and the earlier extensional structures have been inverted. The earlier syndepositional normal faults are inverted as thrusts. Latif et al. (1993) suggested that sedimentary facies show major changes across the present thrusts and were influenced by them when deposited. This suggests that the earlier synsedimentary normal faults are now reversed as thrusts.

Magmatic carbonatites are now found close to thrusts in the Peshawar Basin, which were originally emplaced near the normal faults (Personnel Communication, M.N. Choudhry, 1992). This suggests that the earlier normal faults are the present day thrusts.

These extensional Cretaceous sediments are now well exposed due to uplift and erosion. Hence detailed outcrop studies have made possible to test the sedimentary models explaining the rift basin fills such as those presented by Leeder and Gwathorpe (1987).

The Cretaceous extensional events probably produced fault related hydrocarbon plays similar to those in the southern Indus Basin (Kemal et al., 1992). From an understanding of the timing and scale of the extensional events, it will be easier to look for such plays on the seismic sections.

The earlier horst blocks are now uplifting relatively also due to inversion as seen near the Shahkot, at an exposure of the basement metamorphics on the Sargodha Horst. The Recent unconsolidated sediments are considerably uplifted. Such horsts attract migrating hydrocarbons in the adjacent basins. Considerable hydrocarbons have been discovered above and on the flanks of the Jacobabad and Mari horsts in southern Pakistan (Tainsh et al., 1959; Qadri and Shuaib, 1986; Siddiqui, 1993). By outlining the Cretaceous basin fills the presently unrecognized horst blocks can be delimited and explored for stratigraphic pinchouts and fault traps.

This paper outlines an evaluation of the Cretaceous sediments of Hazara. The sedimentary facies, depositional sequences, basinal boundaries, sedimentary processes, and tectonics are discussed. A new lithostratigraphic unit is also recognized that equates with the Pab Sandstone of the Lower Indus Basin (Shah, 1977). This paper also sets a basic framework for subsequent multidisciplinary studies in the Haro Trough. Besides that it gives guidelines towards studying the nearby Cretaceous basin fills.

CRETACEOUS SYSTEM IN PAKISTAN

The Cretaceous System in Pakistan (Shah, 1977) and Zanskar (Gaetani and Garzanti, 1991) consists of siliciclastics, carbonates, and volcanic rocks (Figure 2). These rocks date from Late Jurassic to Late Cretaceous and a general similarity is apparent in all the sediments that represent broad, regional controls such as climate, tectonics, eustatic sea-level change, sediment supply, oceanic circulation and ocean water chemistry (Garzanti, 1993). The Makran area was separated from the rest of Pakistan as it lies across the Muslim Bagh-Bela Ophiolites marking a suture (Yasin et al., 1993). The Zanskar, the Haro Trough, the Kohat and the Lower Indus Basin show significant similarities to suggest their closely related evolution. In Salt and Trans Indus ranges Cretaceous basins were rather different from the rest. The Haro Trough and the Nizampur Depression differ from the Lower Indus Basin in having a Cenomanian-Turonian unconformity (Shah, 1977), that probably was a result of the local tectonic movements.

LATE MESOZOIC TECTONO-SEDIMENTARY EVENTS IN INDO-PAKISTAN

In Early to Middle Jurassic, a shallow carbonate platform developed all over the Indus Basin (the Samana Suk Formation and the Chiltan Limestone), the Hazara (Samana Suk Formation), and the Zanskar (Kioto Limestone) (Gaetani and Garzanti, 1991). The carbonates are several hundred metres thick (Shah, 1977; Jadoul et al., 1989; Kemal et. al., 1992). Such platforms developed along the other Tethyan Sea margins also (Bernoulli & Jenkyns, 1974; Bosellini, 1989).

The platform remained stable until Bathonian stage in Hazara (Shah, 1977) after which it remained exposed and then started to collapse due to extension with the separation of the Indo-Pak continent from the Gondwanaland (Garzanti, 1993). This separation started with the Late Mid-Jurassic opening of the Somali and Mozambique basins (Scotese et al., 1988).

A striking regional time shift in the basal black shales overlying the platform carbonates is apparent (Figure 2). The base of the Spiti Shale in the Zanskar is Late Middle Jurassic (Gaetani et al., 1986), while that of the Chichali Formation in the Upper Indus Basin is Early Late Jurassic, and that of the Sembar Formation in the Sulaiman and the Kirthar areas (Lower Indus Basin) is Late Upper Jurassic to Basal Early Cretaceous (Shah, 1977; Dolan, 1990). The top of Kioto Limestone is older than the Samana Suk Limestone and that in turn is older than the Mazar Drik Formation overlying the Chiltan Limestone (Figure 2). Therefore, the Middle Jurassic carbonate platform lasted longer and the black shales came late in the southern Pakistan. It may suggest that rifting started towards the Zanskar area and progressed gradually towards the Upper Indus and then towards the Lower Indus Basin. This probably represents how the Indo-Pakistan continent broke away from the Gondwanaland. This is further supported by complete pinch out of the Chichali Formation on the margin of the Langrial Horst where the Lumshiwal Formation overlies the Samana Suk Formation with just one metre thick shale in between. This suggests that the Langrial Horst may be older in age than the Jacobabad Horst, southern Pakistan, where the Sembar Formation pinches out towards its crest (Siddiqui, 1993; Eickhoff & Alam, 1991) (Figure 3).

According to Garzanti (1993) the "volcanism and enhanced tectonic subsidence both started significantly in Zanskar later than in central Nepal" and rifting migrated westward at a rate of few tens of kilometres per million years. Hence the southward migration of rifting in Pakistan was part of the general westward migration of rifting in the Indo-Pakistan sub-continent.

In the Early Cretaceous, the South Asia experienced a domal uplift. Hence due to craton erosion, sands are widespread in all the Indo-Pakistan sedimentary basins from Berriasian to Aptian stages (Sastri et al., 1981; Alam, 1989; Acharyya and Lahiri, 1991; Garzanti, 1993). In the basal Early Cretaceous the sub- continent was separating from the Madagascar and the West Coast Fault (WCF) was formed (Katz, 1979; Norton and Sclater, 1979). Also the Jacobabad horst (Eickhoff & Alam, 1991), and probably the Sargodha horst started to rise relatively. In Early Cretaceous the Indo-Pakistan

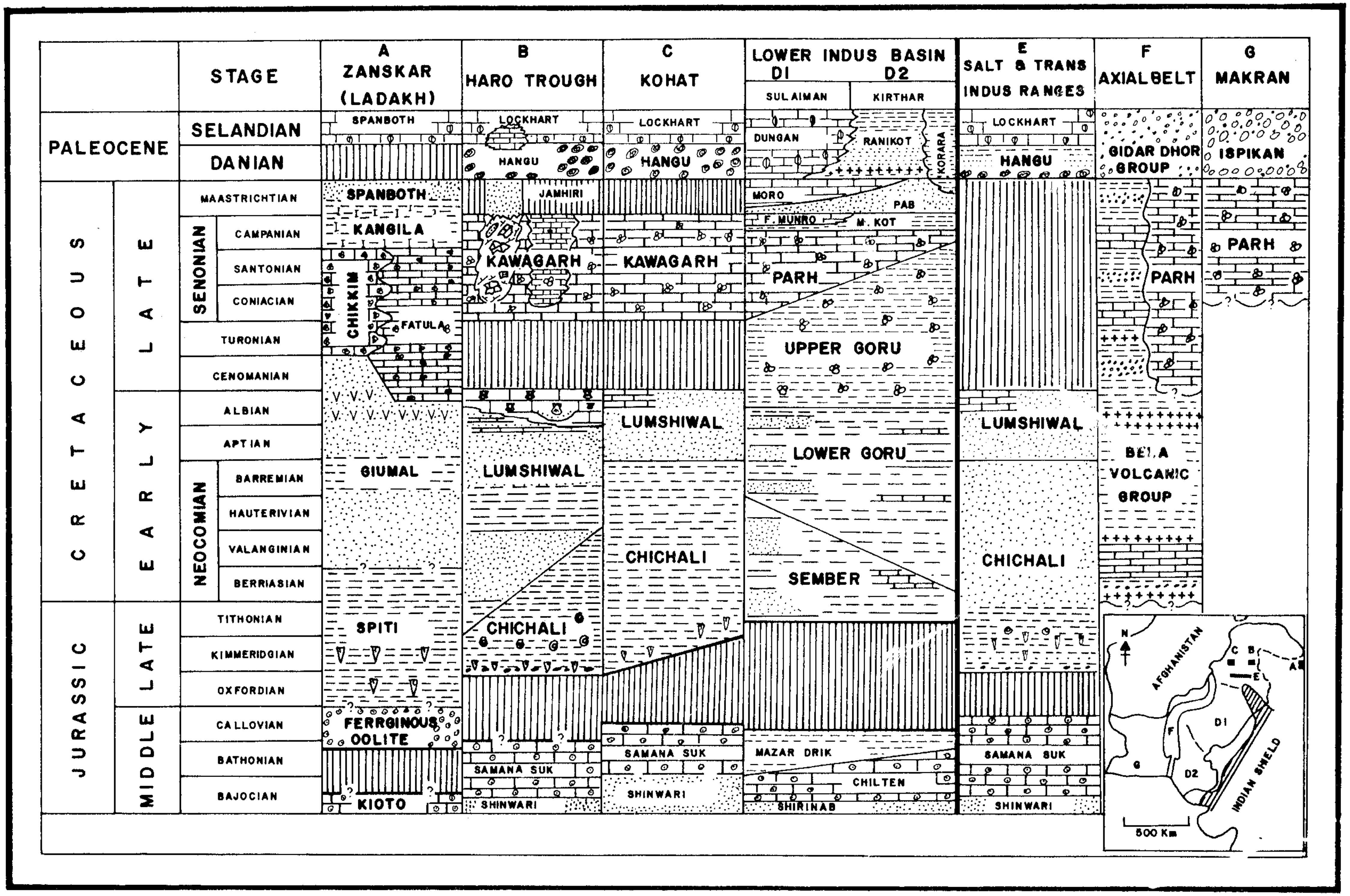

Figure 2- Regional stratigraphic chart of Jurassic/Cretaceous, showing the time shift at the base of the Haro Megacycle and the top of the Middle Jurassic carbonate platform. The data is taken from Shah (1977), Dolan (1990), Gaetani et al. (1986). Our own data is also included.

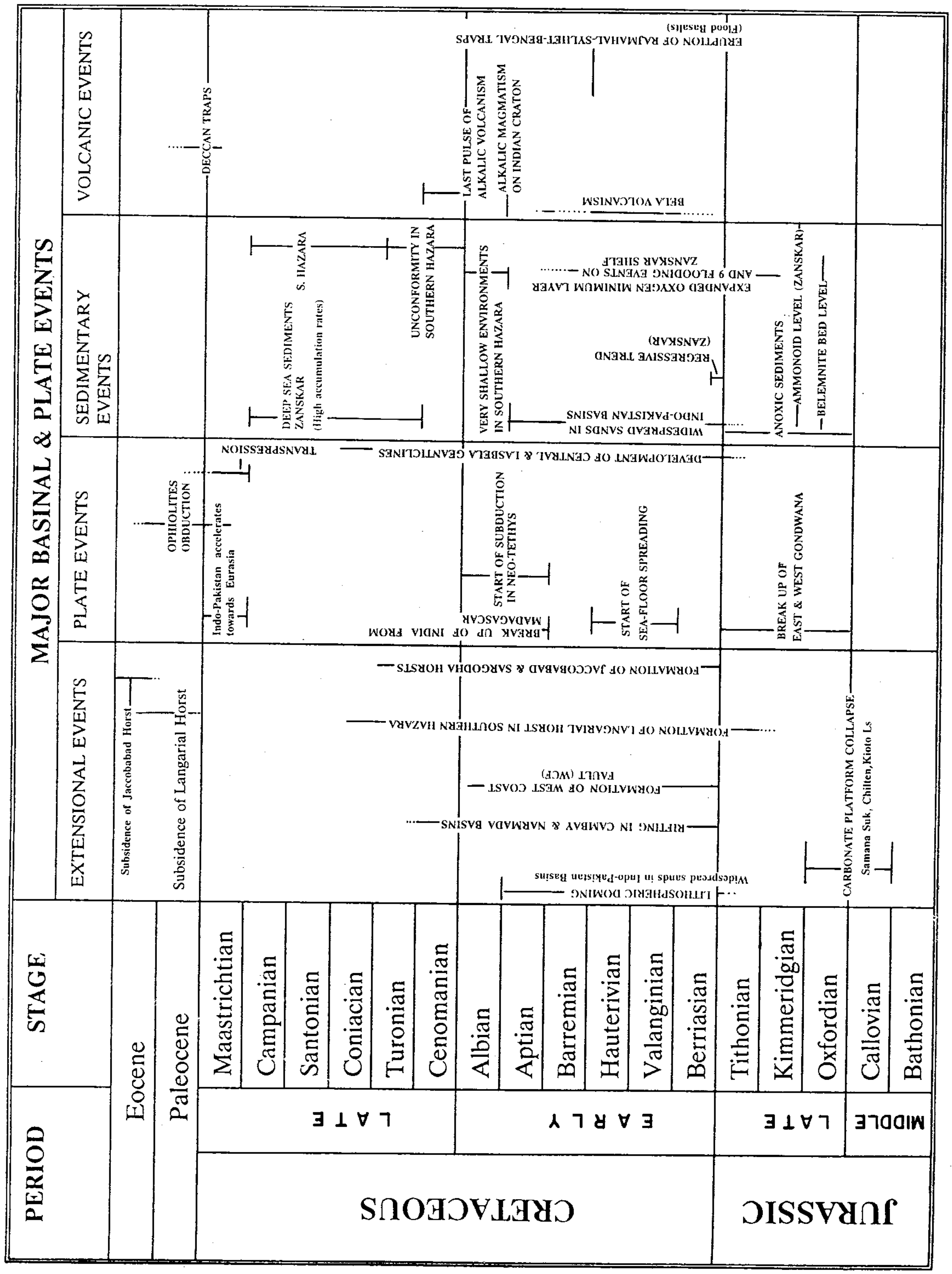

Figure 3- Major Jurassic Cretaceous events in the Indo-Pakistan basins. Data is compiled from many sources mentioned in the text.

passed over the Ninety East-Kerguelen hotspot and the Rajmahal Traps of north- east India erupted (Mahoney et al., 1983; Baksi et al., 1987) and the Bela volcanism was active in the Axial Belt (Auden, 1974; Shah, 1977) (Figures 2, 3). The Bela volcanics and their equivalents near Quetta, Early to Middle Cretaceous consist of submarine pillow basalts and conglomerates of volcanic rocks; the volcanics make some 1200 metres thickness out of a 2000 metres formation thickness and have an estimated volume of 4000 km3 (Auden, 1974). The formation of the Lasbela and the Central geanticlines also date from the Early Cretaceous (Hunting Survey Corporation, 1960). In Early Cretaceous, rifting started in the Cambay and the Narmada grabens in India (Biswas, 1987). The sea-floor spreading began in the Indian Ocean in Valanginian and the subduction of the Neo-Tethys ocean crust started in Aptian to Albian stages towards the end of Early Cretaceous. The alkalic volcanism also saw its end in the Late Albian (Garzanti, 1993).

The northern and northwestern Indo-Pakistani basins were drowned at various times in Late Cretaceous and deep water sediments are common dating from Turonian to Campanian (Gaetani and Garzanti, 1991). The Indo-Pakistan accelerated towards the Eurasia in the Late Cretaceous, Maestrichtian (Powell, 1979). Widespread ophiolites obduction also took place in Late Cretaceous to Early Tertiary on the Indo-Pakistan's northern margin (Bannert and Raza, 1992). Transgression is also said to affect the northwestern Indo-Pakistani continental margin (Kemal et al., 1992). The continent also passed over the Reunion Hot Spot and the Deccan Traps were erupted onto the Indo-Pakistan (Biswas, 1982). There is a record of such eruptions in the Lower Indus Basin as well (Auden, 1974; Shah, 1977). Probably the earliest collision of Indo-Pakistan Plate took place in the Late Cretaceous (Bannert and Raza, 1992).

The close of Cretaceous was marked by widespread exposure and lateritization in the northern Indus Basin and Hazara (Shah, 1977). Sedimentation was later resumed in Early Paleocene and the Lockhart Limestone was deposited in the southern Hazara area. The basinal pattern probably changed significantly as the Paleocene sediments onlapped the long standing Langrial Horst, which subsided to accumulate significant thickness of Lockhart Limestone. A similar trend was followed by the Jacobabad Horst but it was later than the Langrial Horst as the Early Eocene Sui Main Limestone onlapped it (Tainsh et al., 1959; Iqbal et al., 1994). The Early Tertiary marine basins may be the continuation of the Cretaceous basins, being a thermal sag stage after initial extensional normal faulting. However, due to an early collision the basins started to change into a foreland stage (Latif et al., 1993).

HARO TROUGH BOUNDARIES

The Haro Trough is bounded by the Nathiagali Thrust in the north and the strike-slip Jhelum Fault in the east and it separates the basin from the Hazara Kashmir Syntaxis or the Azad Kashmir Horst. The Murree Thrust marks the southward boundary, while the Ayubia and the Changlagali thrusts lie inside the basin (Latif, 1995 ; in press). The Late Mesozoic sediments are terminated variously at these boundaries (Figure 1). The basin has a NE-SW elongation and it opens out towards Samana, the Nizampur and the Kohat areas in western Pakistan. The Pre-Cambrian Attock Slates (Shah, 1977) in the north of these basins are the extension of the Langrial Horst. The southward boundary may be marked by a concealed horst defined by the Early Eocene evaporite belt in the Kohat area.

THE HARO MEGACYCLE FACIES

The studied stratigraphic sections consisted of seven main facies with some facies having many varieties that are summarized in Table 1.

THE GRAPHIC LOGS DESCRIPTIONS

Detailed sedimentological logging was done in three sections namely: (1) the Changlagali, (2) the Kundla, and (3) the Gluccagali (Figure 1). Besides these two other places were studied that are: (1) the Jamhiri, and (2) the Gandhian (Figure 1). The index of the symbols used in logs is given in Figure 6.

The studied megacycle exposures were checked at many other places such as the Dungagali Pipeline Road, the Dungagali to Kundla roadside, the Changlagali to Khairagali roadside, the Jabbri roadside. These sections were either not complete or were structurally disturbed for detailed logging. However, the sedimentary facies were carefully observed and tentatively correlated.

Changlagali Section

This section, Lat. 33°. 39'. 48"; Long. 73°. 22'. 38", (Figure 4) starts with the lateritized surface S1 developed at the top of the Samana Suk ooidal limestone. The basal belemnite bed (A) consisting of GS1 facies, is well developed above the surface S1, followed by the two coarsening up cycles (B & C; facies

Table 1. Summary of the Haro megacycle facies.

Facies	Sub-Facies	Description
BC	Belemnites containing dark grey claystone	
DGS	Dark grey shale	
GS Glauconitic sandstone	GS1	Glaucontic sandstone with matrix supported belemnites (Figure 8)
	GS2	Yellowish green to dark green with abundant glauconite
	GS3	Grey to dark grey with subordinate glauconite
	GS4	GS41: Yellow with abundant altered glauconite
		GS42: Yellow and orange brown with pelecypod shells in growth position
	GS5	Calcareous sandstone with some glauconite to sandy limestone.
PSC Pelecypod Shell Coquina	PSC1	Grey to brownish grey bioclastic pelecypod gastropod coquina with erosional bases (Figure 11).
	PSC2	Marly with some very fine quartz sand.
	PSC3	Bioclastic grainstone showing cross lamination, plane laminations, and cross bedding
PFWP Planktonic Foram Wackestone-packstone	PFWP1	Medium to thick bedded planktonic foram wackestone/packstone
	PFWP2	Medium to thick bedded planktonic foram wackestone/packstone with significant quartz sand
	PFWP3	Cyclically thin bedded (centimetre scale) planktonic foram wackestone to packstone with marl/shale interbeds (Figure 12)
NGS Very fine grained, non-glauconitic sandstone	NGS1	Medium to dark grey, very fine grained sandstone
	NGS2	Yellowish brown to reddish brown mottled and white, very fine grained sandstone, cross and plane laminated
CB	Carbonate breccia with mudstone-wackestone and sandstone clasts up to the boulder size (Figure 13)	

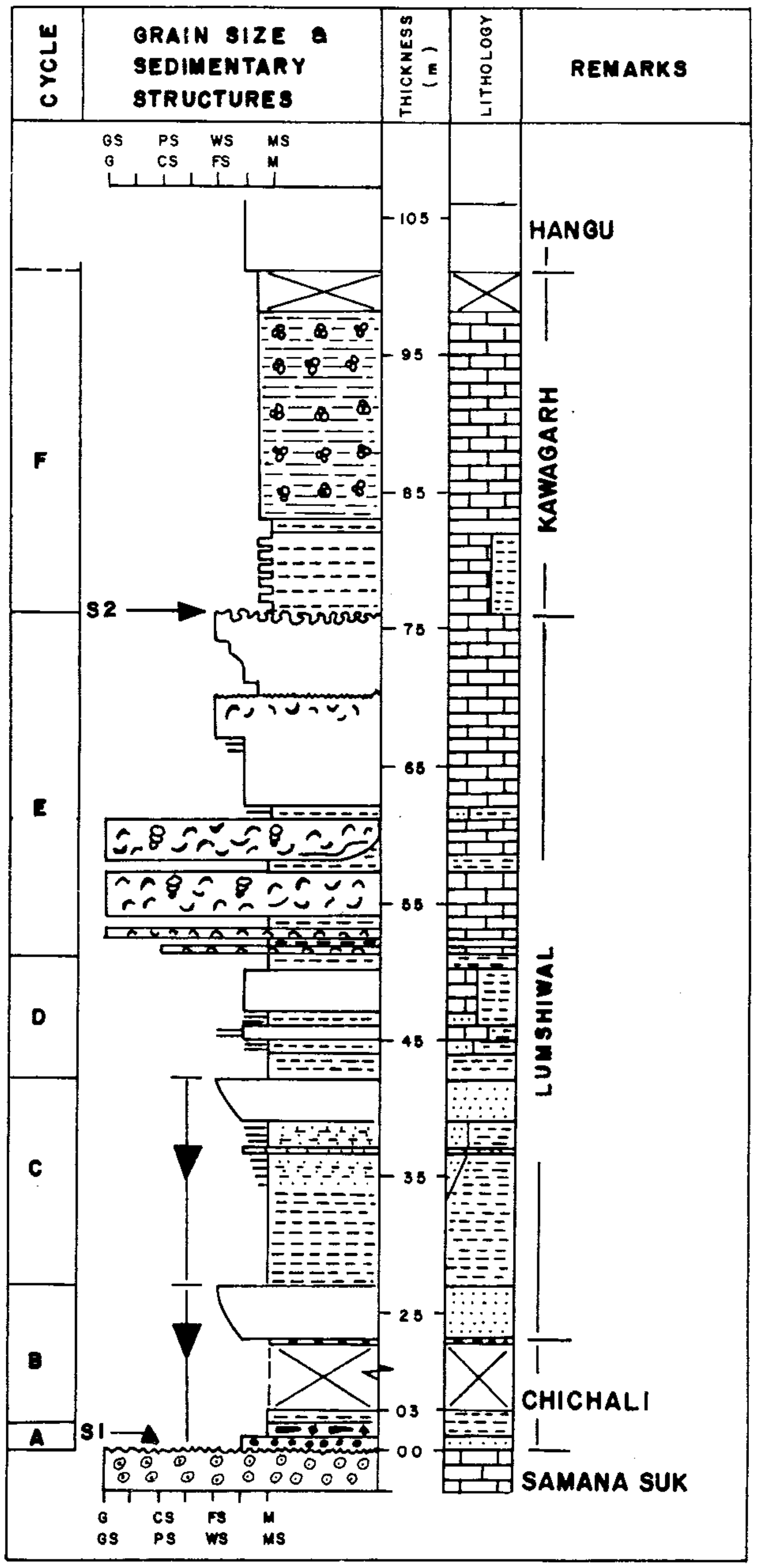

Figure 4-Graphic sedimentological log of the Changlagali section (Figure 1).

BC, DGS, GS, NGS). The coarsening up cycle (C) is followed by calcareous sandstone (D; facies GS5) that eventually changes into pelecypod shell debris coquina (E; PSC1, PSC2). The top of pelecypod coquina cycle (E) is capped by a slightly lateritized and eroded surface that marks the contact between Lumshiwal and Kawagarh formations. There are two shoaling up carbonate cycles above the pelecypod coquina. The top of the second shoaling up cycle is heavily lateritized and pitted with many pot holes, which is named as the surface S2. This is followed by many shale and limestone beds for 8 metres (facies PFWP 1 & 2) followed by a thicker shale bed, which is followed by centimetre scale bedded planktonic foram wackestone-packstone (facies PFWP3). These sediments above the surface S2 are grouped as cycle F, which is capped by the Basal Tertiary Hangu Formation, the laterites etc.

Kundla Section

This section Lat. 34°. 02'. 24"; Long. 73°. 23'. 15" (Figure 5A) starts with the Samana Suk Limestone surface S1 and the basal belemnite bed (A; facies GS1) that is followed by the coarsening up cycle (C) and the coarsening up cycle (D) consisting of facies BC, DGS, GS, and NGS. The top of cycle C is plane laminated and rather thin. There is no typical pelecypod coquina in the cycles D and E (facies PSC1, PSC2, PSC3), however, in this position facies GS41 is developed that consists of yellowish to brownish sandstone to siltstone and contains abundant and complete pelecypod shells in life positions. The surface S2 is prominently developed and consists of large pelecypod shell debris lag in a very coarse grained sandy to granule sized matrix. Above surface S2, siltstone is present for several metres followed by clay and a heavily bioturbated bed with pyrite and phosphatic nodules (Figure 5A). This bed is followed by planktonic foram wackestone-packstone.

Gluccagali Section

This section Lat. 33°. 56'. 20'; Long. 73°. 17'. 40", (Figure 5B) starts above the surface (S1) with the Basal Belemnite Bed (A; facies GS1), the first (B) and the second (C) coarsening up cycles consisting of facies BC, DGS, GS, NGS. The sandy part of these coarsening up cycles is richer in glauconite as compared to the other measured sections. The thickness of the cycle (C) is relatively more than other sections. The cycle (C) is followed by relatively thicker pelecypod coquina cycle (DE; facies PSC). This coquina sandwiches a cross-bedded and plane laminated limestone that may correspond to the channeled level in the DE cycle at the Changlagali Section (Figure 6). Above the pelecypod coquina (DE) there are three shoaling up carbonate cycles capped by a lateritized unconformity surface (S2). Above this (S2) planktonic foram wackestone-packstone follows (facies PFWP).

Jamhiri Section

This section Lat. 33°. 54'. 40"; Long. 73°. 10'. 10", (Figure 7A) is very different from rest of the sections as different lithology is developed here. The base of this section starts with a carbonate breccia (G; facies CB), whose upper surface is deeply eroded and dissected. This is followed by medium to thick bedded, grey to dark grey, very fine grained and highly calcareous Jamhiri Sandstone and marble (H; facies NGS2). The top of this sandstone is whitish, yellowish, reddish mottled suggesting an early stage of soil formation. The top of the sandstone is cross laminated with current ripple form- sets. The reddish mottled sand represents the Hangu Formation, laterites/haematite horizon (S3). This sandstone is followed by planktonic foram wackestone-packstone (facies PFWP) that is named as the Lassan Limestone, which is Middle Paleocene in age. The Lassan limestone is followed by a sharp surface above which Lockhart Limestone is present. The Lassan limestone is significantly different from the Lockhart Limestone and may be made a member of the Lockhart Limestone.

Gandhian Section

This section Lat. 33°. 54'. 35"; Long. 73°. 05'. 55", (Figure 7B) is well preserved and structurally the least disturbed Cretaceous section here. The surface S1 developed in the Samana Suk ooidal and cross bedded grainstone, is followed by a metre thick yellowish green shale bed and then glauconitic sandstone (facies GS). The cycles A to E are all represented as glauconitic sandstone, which is followed by medium to thick bedded, planktonic foram wackestone-packstone (facies PFWP) cycle (F). The cycle F is capped by ooidal/pisoidal laterite/haematite (S3).

THE SEDIMENTARY MEGACYCLE

Based on the field graphic logs, the Haro sedimentary megacycle is naturally divisible into two sequences that are bounded by unconformities.

Sequence 1

This sequence spans a time from Late Oxfordian to Albian and is bounded by top Middle Jurassic unconformity below and the top Albian unconformity above. It is further divided into the following surfaces and cycles.

Top Middle Jurassic (Bathonian) lateritized surface (S1). The deposition of the Middle Jurassic Samana Suk platform carbonates stopped in the Bathonian stage (Shah, 1977) when the platform was exposed. It remained exposed for the Callovian and Oxfordian stages (Shah, 1977), and the top Samana Suk lateritized surface (Figure 8A) was formed due to soil development. The Samana Suk carbonate platform was very shallow with abundant cross bedded ooidal grainstones. Below the discussed lateritized surface, ooidal grainstone facies were seen at almost every studied locality. The lateritized surface was no where more than 0.2 metre thick and it was more commonly less than that. At the Gluccagali section this lateritized surface showed flat pebble conglomerate (Figure 8A).

The widespread occurrence of this surface all over the Haro Trough suggests that all the southern Hazara was exposed to subaerial processes; with Haro Trough absent.

Basal belemnite bed (A). This section lies above the top-Middle Jurassic lateritized surface and is no more than one metre thick any where in the Haro Trough. The basal bed consists of glauconitic, phosphatic sand with abundant matrix supported belemnites (Figure 8B). Most of the sedimentary material is authigenic with little or no input from outside the basin. The deposition of this basal belemnite bed started in Late Oxfordian to basal Kimmeridgian stage and probably continued upto the middle Kimmeridgian. The sediment starvation was probably due to a relative high stand of sea-level or due to lack or absence of a clastic source or due to both. This bed marks the beginning of the Late Jurassic to Late Cretaceous sedimentary sequence and it suggests the beginning of the Haro Trough. As a lateritized exposure surface formed in very shallow marine ooidal grainstones, it is directly overlain by this belemnite bed, therefore suggesting a significant relative sea-level rise. This sea-level rise may be partly due to a rise in eustatic sea-level but more probably due to the extensional collapse of the Middle Jurassic carbonate platform. This appears to be formation of the Haro Trough. Due to slow deposition and the platform collapse the Haro Trough became significantly deep and phosphate nodules were abundantly formed due to slow deposition.

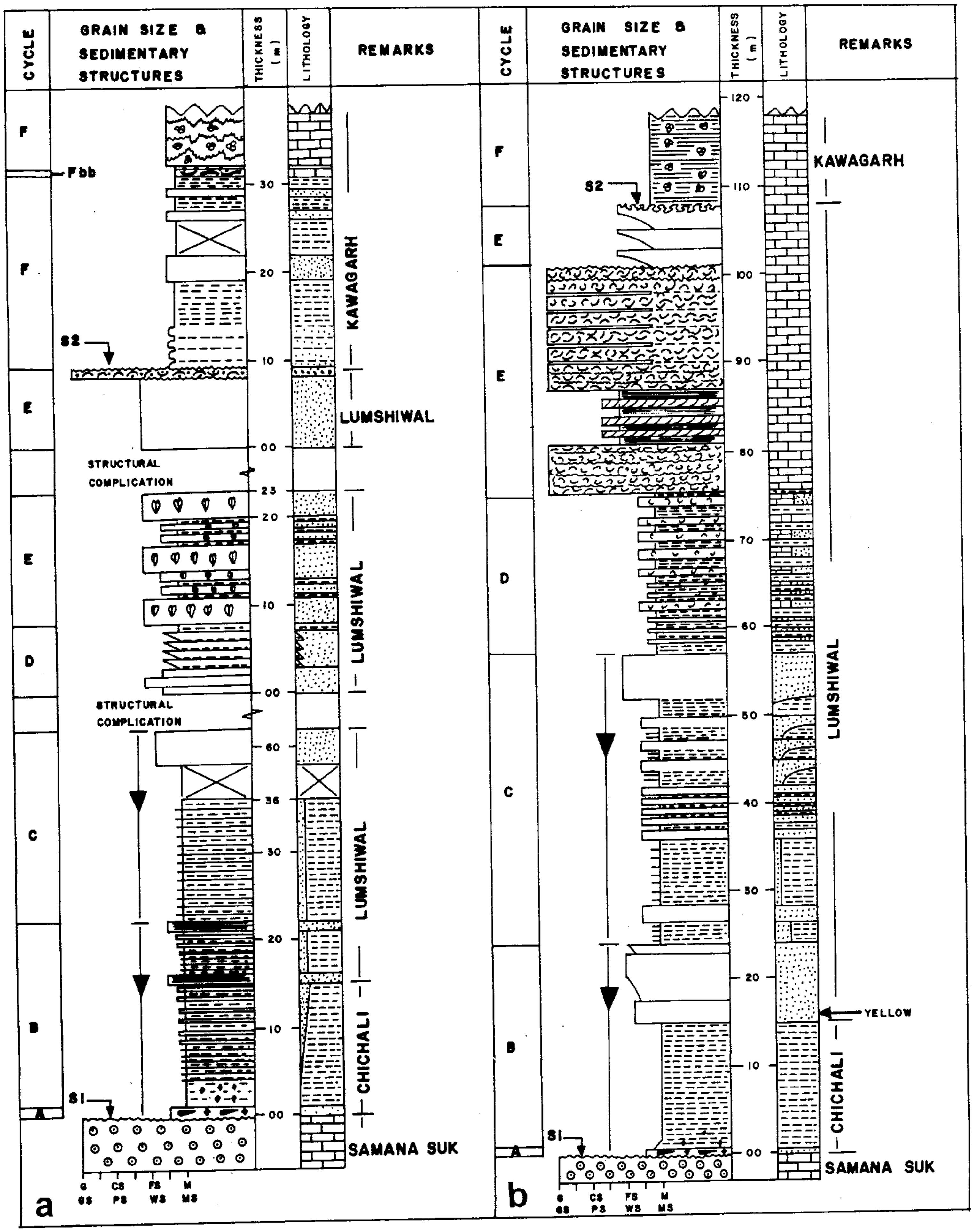

Figure 5-Graphic sedimentological log of (a): the Kundla section (Figure 1) and (b): the Gluccagali section (Figure 1).

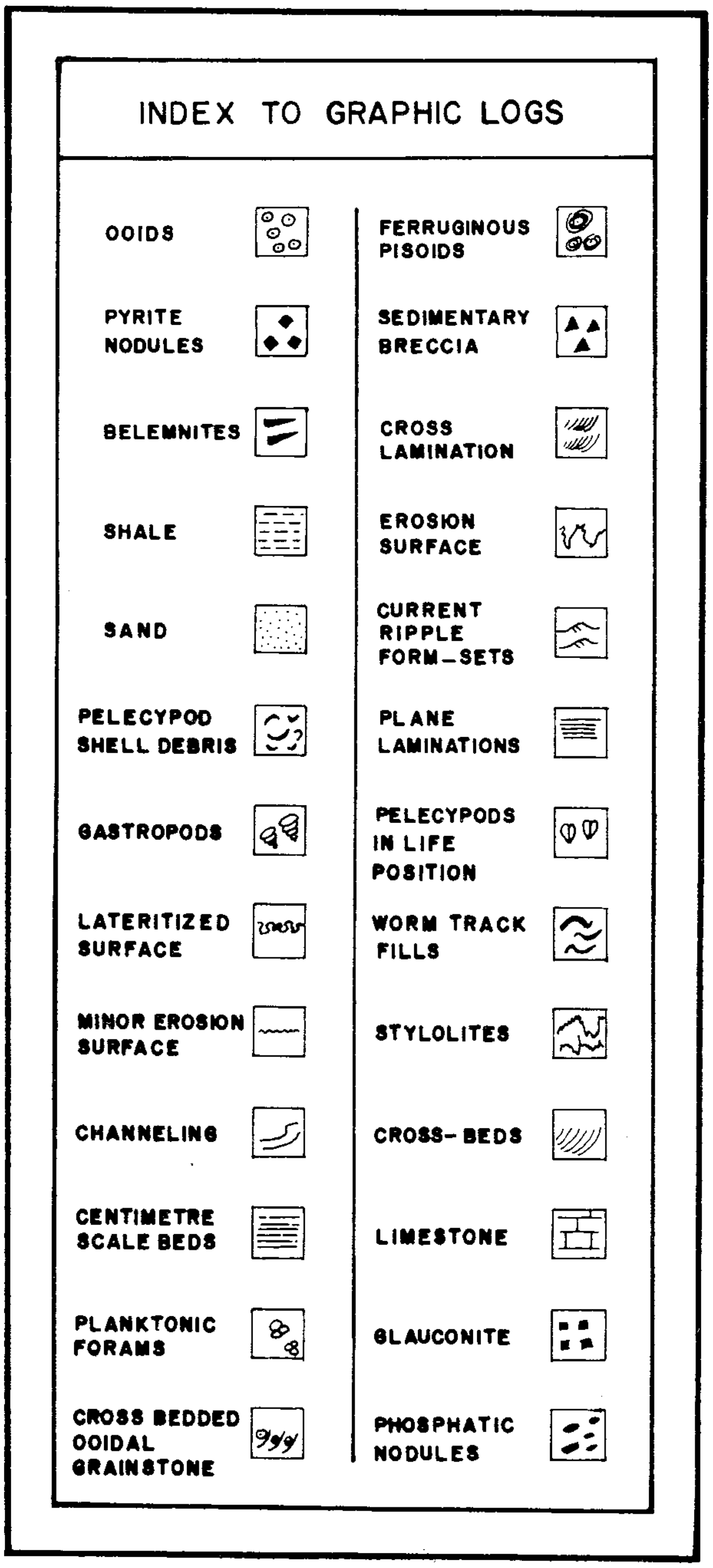

Figure 6- The index of the symbols used in graphic logs (Figures 9, 10 and 11).

First coarsening up cycle (B) *.*_This cycle is present in most of the sections except in the trough marginal successions. This cycle consists of a basal dark grey clay shale that is transitionally overlain by a very fine to fine grained sand unit. In the prevalent stratigraphic scheme the lower dark grey shale is named as the Chichali Formation while the beginning of the sand is taken as the start of the Lumshiwal Formation. However, the lower clay shale and the capping sand are depositionally part of the same system and cycle and constitute a conformable coarsening up megacycle. The lower clay shale pinches out onto the basin margins where the first sand unit directly overlies the basal condensed section or a very thinned out clay shale. The clay shale is fossiliferous but it is difficult to locate complete fossils due to very high compaction. This basal clay shale may contain many internal condensed sections below the first sand. Near Gluccagali section at Thoba, many weathered out ammonoids were seen lying on one surface in the basal clay unit (Figure 9). Such fossil enrichment points out the presence of condensed sections in this clay shale. The age of the basal sequence is Late Oxfordian to Basal Kimmeridgian but the boundary of the sand is time transgressive towards west. Based on the ammonoid fauna these sediments are considered older in the extreme east of the basin and become younger westwards while in a north-south direction there appears no time shift (Marks and Ahmad, 1962). This time shift may be explained through an eastward clastic source supplying sediment into the basin and a gradual westerly progradation of the sedimentary cycle (Figure 10). This first coarsening up cycle suggests a continuous or intermittent relative rise of the sea-level followed by a relative stabilization when the sands prograded westwards. In the Gluccagali section there are beds of glauconitic sandstone in which the original glauconite is completely altered into a yellowish clayey material, which may suggest brief exposure of these sands. These sands may have been in intertidal settings for brief periods when the glauconite was altered, which is commonly considered as highly susceptible to sub-aerial oxidation (Berner, 1981).

Second coarsening up cycle (C)._The first coarsening up megacycle is overlain by a dark grey shale that eventually coarsens up to a widespread glauconitic sand in the basin. This second cycle marks another period of relative sea-level rise and creation of more accommodation space. Firstly, the previous sand unit was drowned due to rising relative sea-level so that the second dark grey clay shale onlapped the first sand. Then later with a stabilization of relative sea-level in the basin the westward progradation of the second sand started.

Clastic-carbonate transition zone (D)._The second coarsening up megacycle is directly and conformably followed by changing depositional conditions from a clastic, authigenic dominated to a carbonate dominated environment. This may have happened due to decrease of clastic supply and very shallow environmental conditions leading to higher carbonate productivity. The clastic carbonate transition zone is present in most of the studied sections. The sediments become

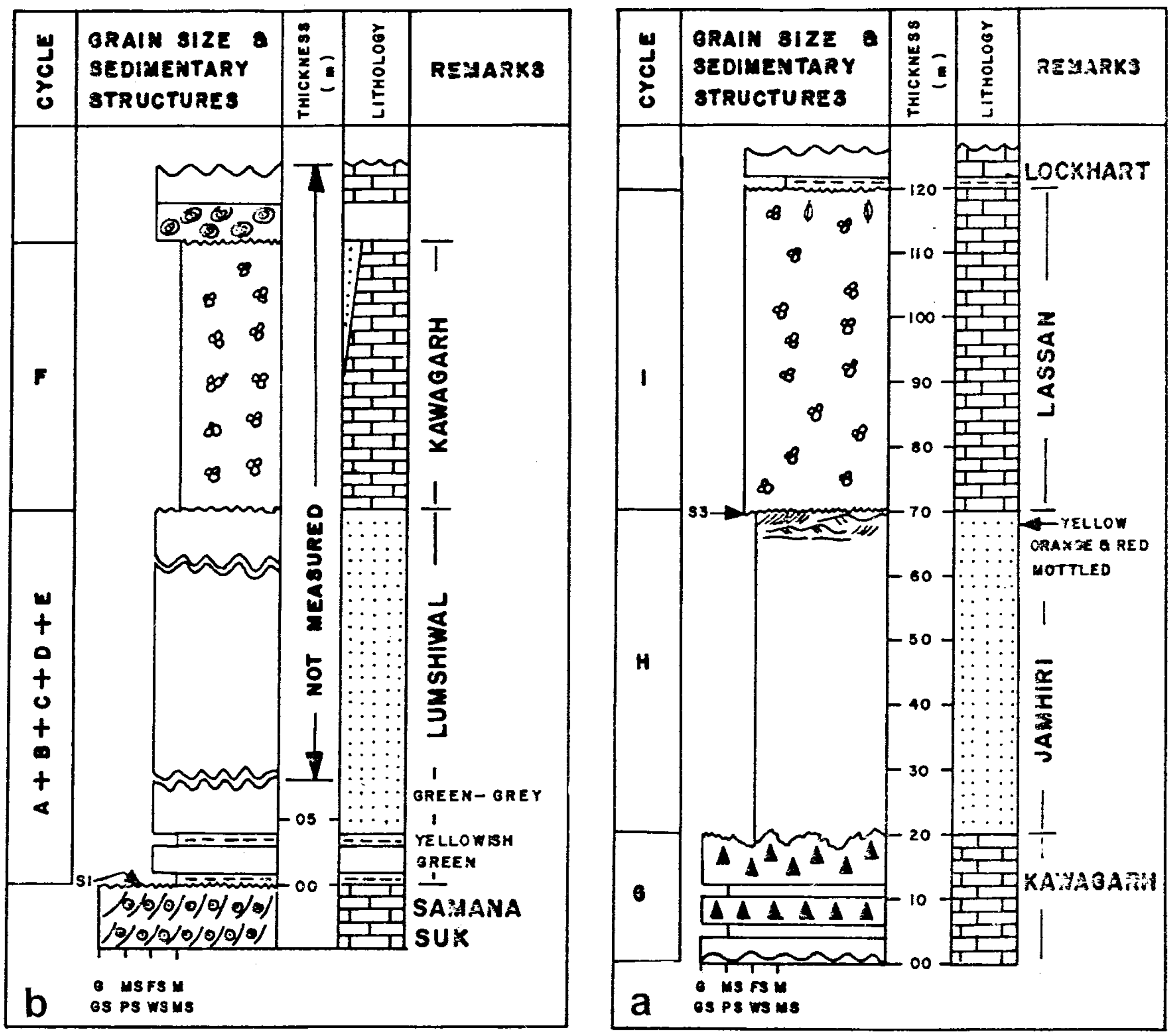

Figure 7A-Graphic sedimentological log of (a): the Jamhiri section (Figure 1) and (b): the Gandhian section (Figure 1).

progressively richer and richer in the carbonate upwards and the glauconite content decreases gradually. There are calcareous sands with glauconite grains changing to calcareous sands without glauconite and ultimately changing into sandy limestones. There are intermittent shale beds between these sandy and calcareous units.

Pelecypod coquina cycle (E). This cycle conformably overlies the second coarsening up megacycle through the clastic-carbonate transition zone. This cycle consists of coquina limestone made entirely of the pelecypod shell debris with some gastropods (Figure 11). The shell debris is framework supported and cemented by carbonate. This cycle is apparently very shallow marine deposit and is found in considerable part of the southern half of the Haro Trough. There are internal erosion surfaces and medium scale channelling that were upto a metre or more deep. There are cross bedded and plane laminated limestones present in the coquina cycle that were formed under the influence of high energy water currents. This coquina cycle may be inferred as Albian based on Shah (1977). It appears that the coquina was derived from the pelecypods living in the sands due to erosion and

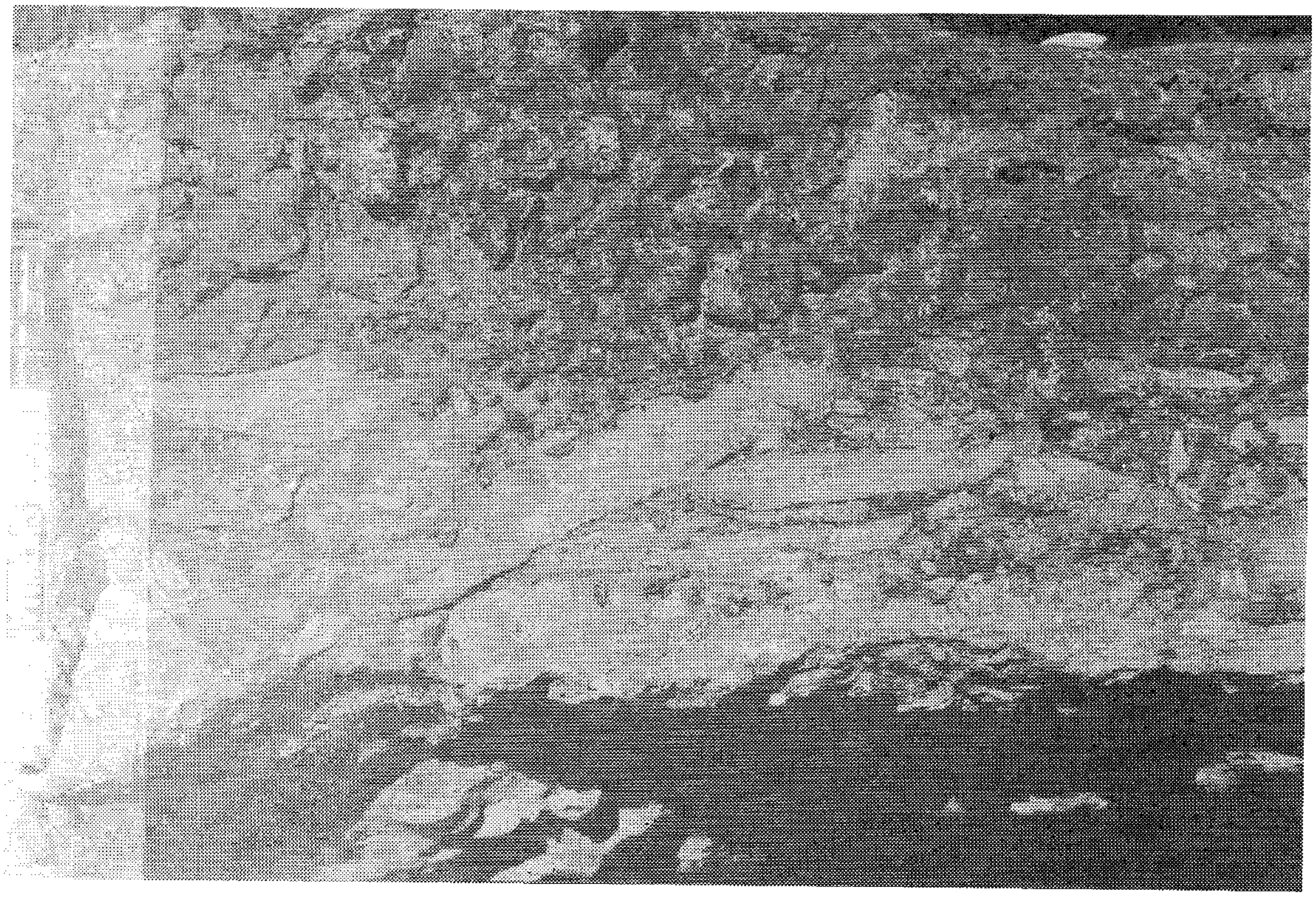

Figure 8A-The base of the Haro megacycle in the Gluccagali section that shows eroded platy clasts of the Samana Suk limestone and the overlying glauconitic sandstone with matrix supported belemnites.

concentrated as coquina under the influence of water currents. This reworking and concentration of pelecypod shells may be due to storm induced erosion and currents. In the Kundla section in the east of the basin this coquina was not seen but it correlates to a clastic sand unit with in situ pelecypod shells in life position with both valves intact. Probably, these pelecypods lived in a sand facies like that seen at Kundla Section and were reworked by storms and concentrated as a coquina.

Top pelecypod coquina unconformity (S2). This surface is developed above the coquina beds and it is best exposed at the Changlagali Section. It is present as a heavily lateritized surface with pot holes signifying a major period of erosion and exposure. There are two other surfaces very close below this one; the one immediately below is lateritized to a lesser extent and the one further below is barely lateritized. Those surfaces below the major ones probably represent minor periods of exposure and erosion before the major period of exposure. The upper two of these surfaces are traceable at the Gluccagali Section at a comparable facies position. Only one surface is traceable at the Kundla Section, where it is represented near the very top of the sandy succession as an erosional lag deposit of pelecypod shells. This major lateritization surface appears to be widespread in the southern part of the Haro Trough.

This surface marks the post-Albian unconformity and separates the Lumshiwal Formation from the Kawagarh Formation deeper water carbonate beds. This surface is an important sequence boundary, which separates the Chichali-Lumshiwal cycles from the Kawagarh cycles. This surface also separates the Early and Late Cretaceous. The basin was exposed in Late Albian and remained so while being lateritized until Late Turonian. The basal beds of Kawagarh Formation have been dated as Late Turonian.

Sequence 2

This sequence starts above the top Albian unconformity and ends at the Basal Tertiary unconformity. The basal sediments of this sequence are Middle/Late Turonian and the top is Campanian-Maestrichtian (?) in age (Latif 1970). Similar sediments at the Giah Section are dated as Upper Turonian to Campanian in age (Chaudhry et al., 1992), which are

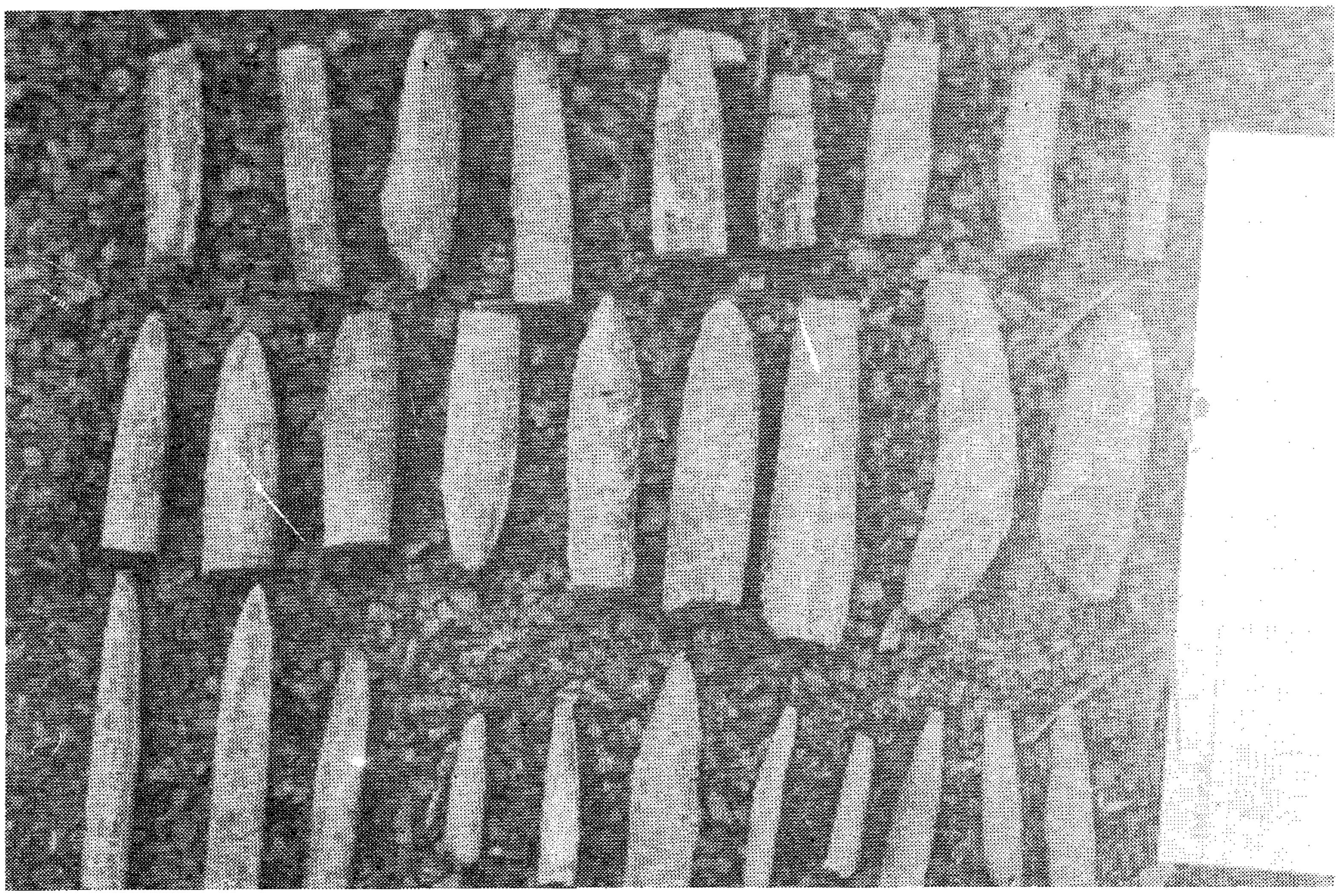

Figure 8B- Belemnites collected from the basal belemnite bed of the Haro megacycle.

located northward of the Haro Trough in the Dor Depression (Latif et al., 1992). This is further divided into the following surfaces and cycles.

Basal dolomitic bed (F_{db}). _This basal dolomitic bed is yellowish grey in colour and is widespread in the eastern part of the basin where it can be used as a marker. It is best developed and exposed on the Dungagali Pipeline Road section near Dungagali where it marks the start of the Kawagarh Formation. It is also present at the Kundla Section.

It marks the beginning of shallow deposition after the Late Albian unconformity.

The Bioturbated bed (F_{bb}). _An intensely bioturbated thin bed is present at the Kundla Section (Figure 12A) with abundant worm track fillings. These track fillings are present at the base of the first carbonate bed. There are centimetre sized pyritic nodules, phosphatized pellets and nodules and fish scales. This bed is present above the pelecypod lag surface representing the Late Albian unconformity (S2) in the Kundla Section. There is a 20 metres thick clastic succession consisting of siltstone, mudstone, and claystone above the unconformity (S2) up to this bioturbated bed.

This surface marks rapid drowning of the basin in Late Turonian to Coniacian. Abundant bioturbation, phosphatization, large pyrite nodules on this surface and the planktonic foram mudstone to wackestone above suggests very slow deposition in deeper water environments.

Planktonic foram wackestone-packstone cycle (F). _This cycle represents the proper Kawagarh Formation. The basal boundary of this cycle is the Late Albian unconformity surface. The sediments just above this unconformity are Middle/Late Turonian in age. At the Changlagali section the sediments just above the unconformity yielded the planktonic forams *Marginotruncana renzi, Marginotruncana sigali, Marginotruncana coronata, Marginotruncana pseudolinneiana*. Being below the dated level of Coniacian in this section (Latif, 1970), the base of this cycle is dated as Middle/Late Turonian. There are mainly two facies developed in this cycle. One is the planktonic foram wackestone-packstone, which contains less clay material and is bedded at the scale of a metre or more

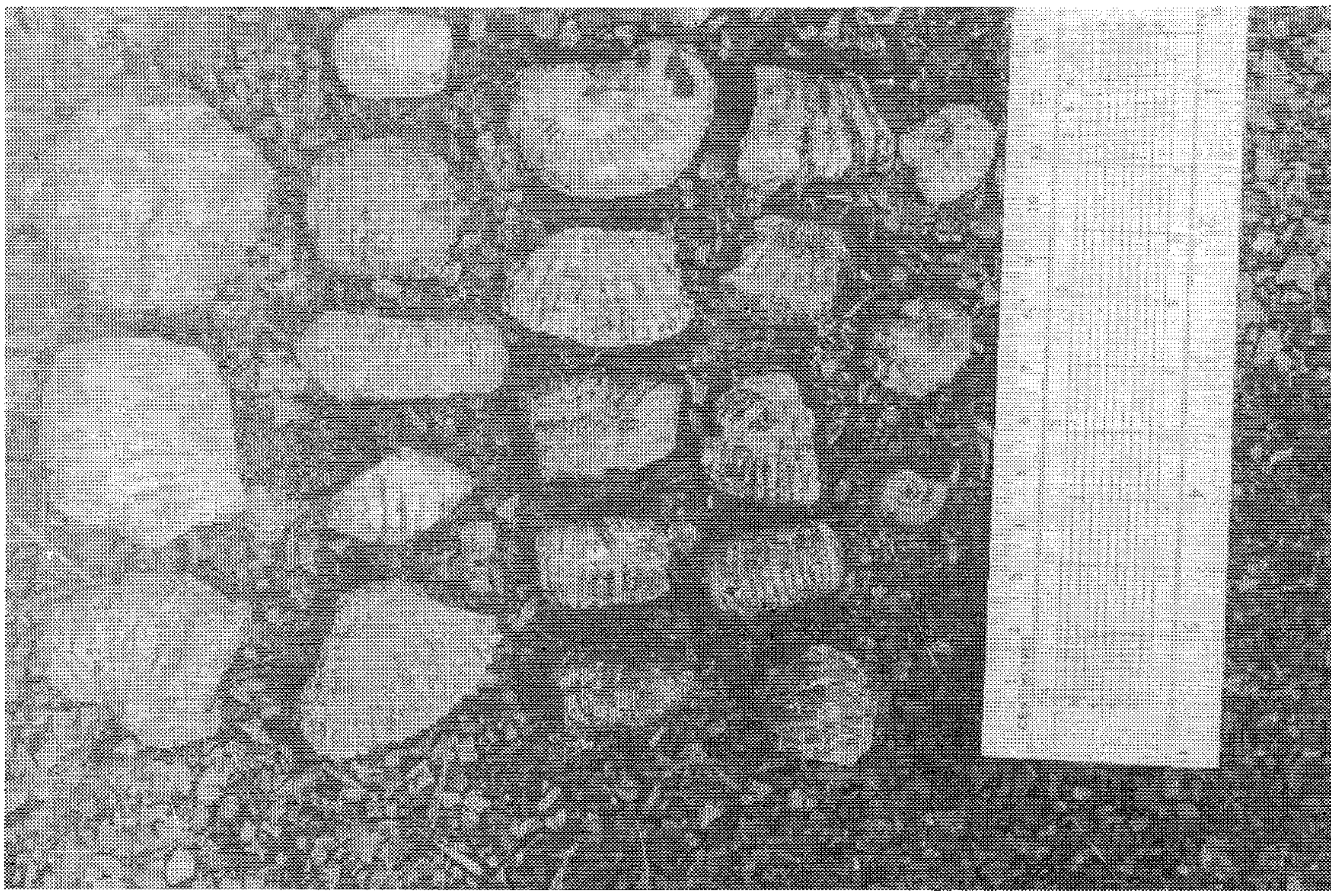

Figure 9- Various ammonites recovered from the coarsening up cycle B at the Thoba near the Gluccagali section.

(facies PFWP1). The other facies is marly with significant clay material and it is cyclically bedded at a centimetre scale (facies PFWP3)(Figure 12B). The marly facies is considered of deeper water deposit. This facies is best developed at the Changlagali and Kohalagali sections.

Carbonate breccia cycle (G). A carbonate breccia (facies CB) is well exposed in the northern Haro Trough near Jamhiri village. This breccia consists of granules to boulders of carbonate wackestone and sandstone in a carbonate matrix (Figure 13).

This breccia is a lateral equivalent of the planktonic foram wackestone-packstone cycle. It showed *Heterohelix sp.*, *Globotruncana sp.* and a deep slope environment green algae Oligostegnia (*Pithonell ovalis*) in the breccia matrix. These microfossils suggest a Santonian-Campanian age, Latif 1970, and a deep water carbonate slope environment.

The low stand Jamhiri Sandstone cycle (H). This sandstone is named as the Jamhiri Sandstone (Figure 14) and it postdates the planktonic foram wackestone-packstone cycle as it overlies its time equivalent carbonate breccia cycle. Its base is erosive and cuts across the top of the carbonate breccia cycle. It is apparently massive except the top 2 metres or so. This sand appears to have been derived from the erosion of the slates of the Hazara Group present in the north of the Haro Trough. The sand is medium to dark grey and highly calcareous. The bottom part of the Jamhiri Sandstone is highly calcareous and have recrystallized almost as marble. The top 2 metres of this sand are cross bedded, cross laminated, show ripple form-sets and mottled into yellowish, white, brownish, and reddish colours. The top of this sandstone is unconformable as the sedimentary structures suggest a shallow current dominated environment and the colour mottling suggests exposure and early stages of soil formation.

Jamhiri Sandstone top surface (S3). This surface is colour mottled suggesting exposure and early stages of soil formation. This surface is overlain by a planktonic foram wackestone-packstone, the Lassan limestone, that is apparently very similar to the Kawagarh Formation carbonates but is Middle Paleocene in age. This limestone is named after the village Lassan situated near the village Jamhiri. The Lassan limestone is rich in

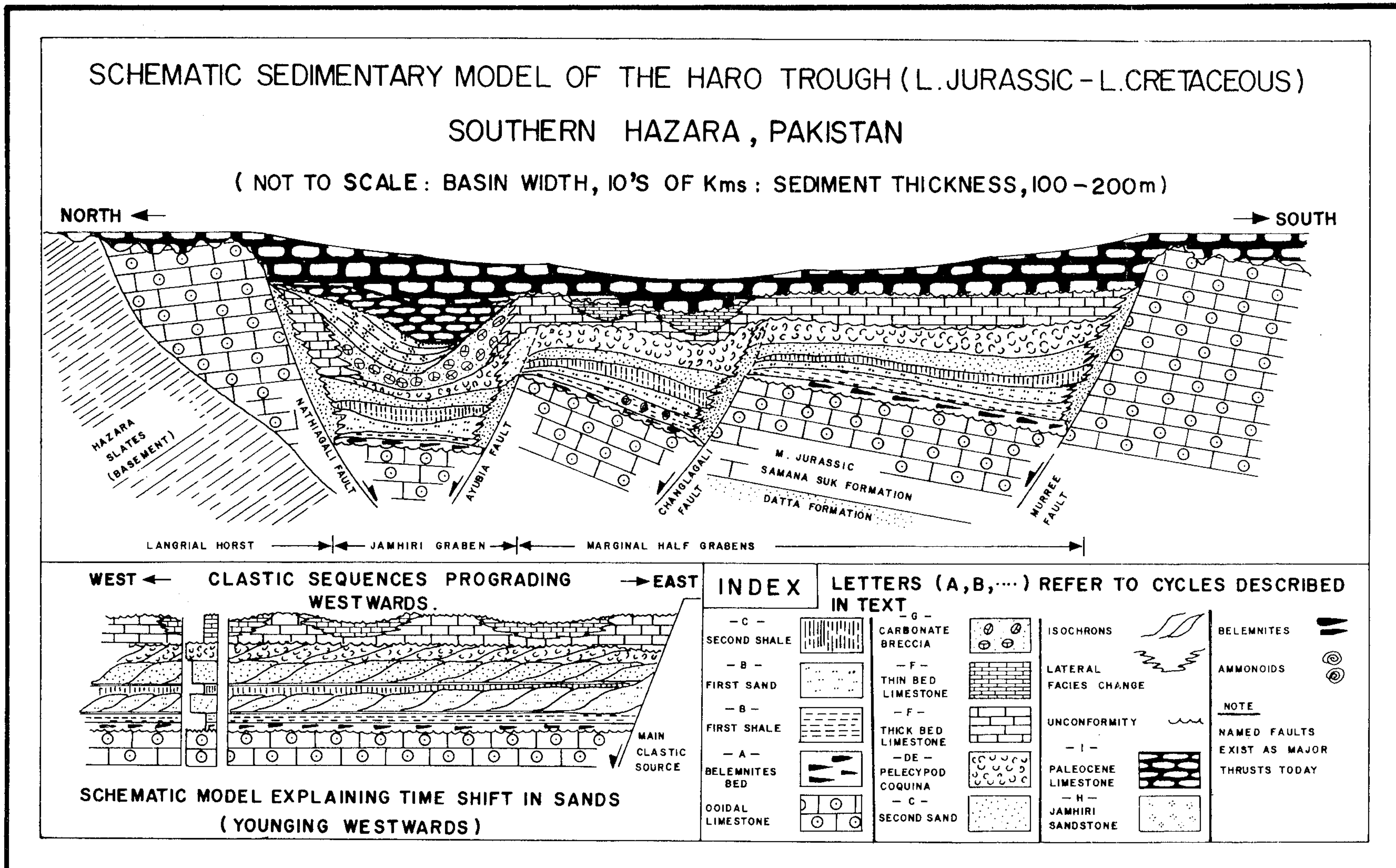

Figure 10- The basinal sedimentary model of the Haro Trough in approximately NS orientation (Figure 1).

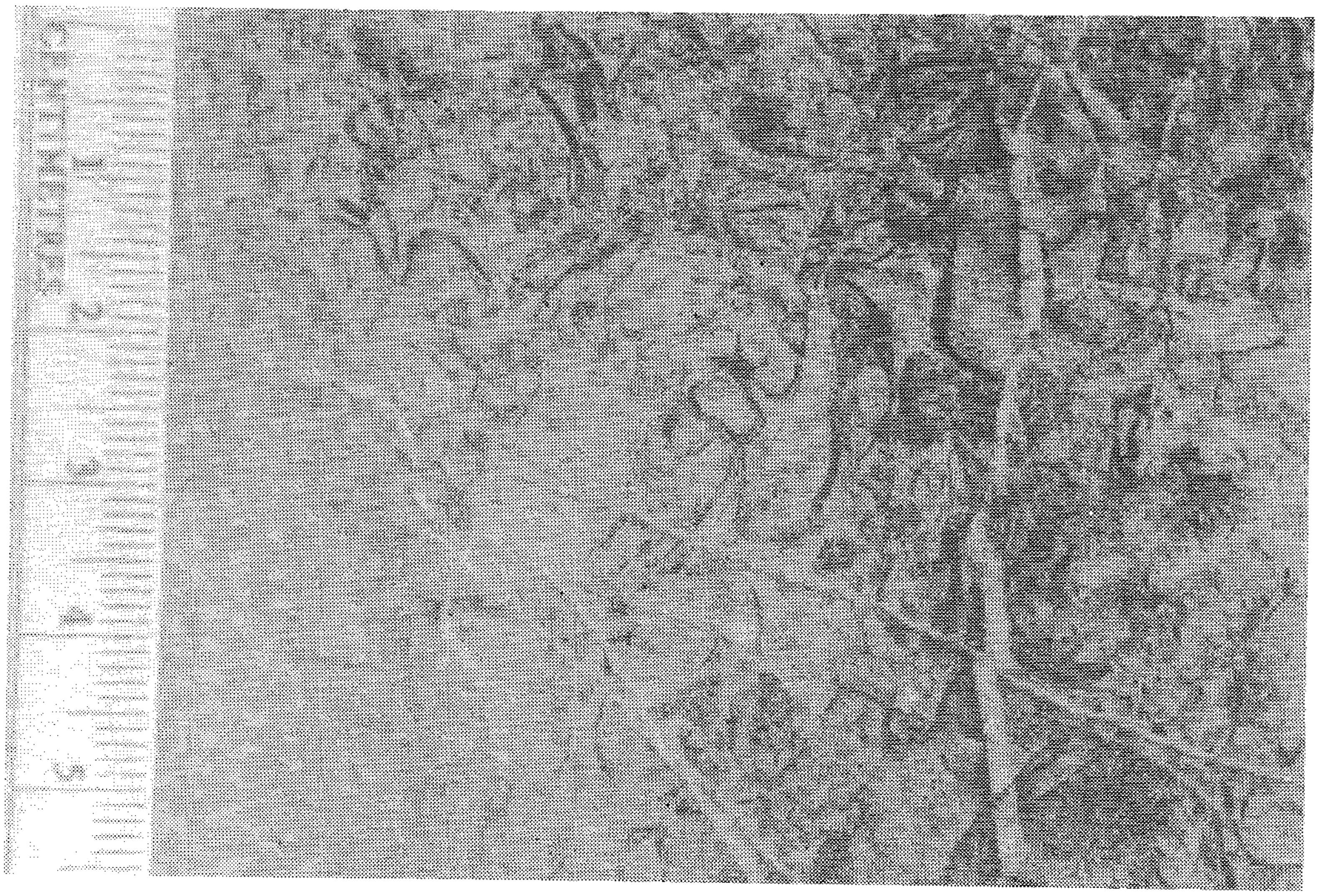

Figure 11-Pelecypod shell coquina (PSC) in the Haro megacycle.

planktonic forams and the benthic forams only appear near the top of the unit. Among the planktonic forams Planorotalites pusilla pusilla, Planorotalites cf. chapmani, Morozonella angulata, and among the benthic forams Miscellanea miscella, Discocyclina sp., Lockhartia prehaimei were found. Hence the top-Jamhiri surface (S3) marks the base of the Tertiary sediments and is equivalent of the Hangu Formation elsewhere in the trough. Further work is suggested to work out the regional setting of the Lassan Limestone.

THE BASINAL MODEL

The sedimentary fill of the trough correlates in the stratigraphic sequences and their constituting sedimentary cycles (Figure 10), all over the Haro Trough. The basal Belemnite Bed, the first and the second coarsening up cycles are present all over the trough except the trough margin successions such as that at the Gandhian (Figure 7B) where the dark grey shale of these cycles is missing and only sandstone is present. The pelecypod coquina is also widespread in the trough fill along with its top unconformity.

The Kawagarh Formation carbonate cycles also correlate well but there are lateral facies changes. The Jamhiri Sandstone and The Lassan Limestone are only present in the Jamhiri Graben. The Lassan Limestone is Middle Paleocene in age but resembles the Cretaceous carbonates. This limestone is rich in planktonic forams in contrast to the Middle to Late Paleocene Lockhart Limestone in the area, which is seen to overlie the Lassan limestone. The Lassan Limestone is a deeper water facies equivalent to the basal part of the Lockhart Limestone. Its presence is significant as it has developed in the Jamhiri Graben, which was a relatively deeper part of the Haro Trough. It also suggests that the Jamhiri Graben was not filled until Middle Paleocene and it maintained deeper water environments due to the displaced waters being the nucleous of the depocentre.

The Haro Trough is divided into a northward Langrial Horst beyond the Nathiagali Fault, the Jamhiri Graben between the Nathiagali and the Ayubia faults, and southward a system of marginal half grabens. The two

Figure 12A-The extensively bioturbated bed at the base of the planktonic foram wackestone- packstone cycle at the Kundla section

main inferred half grabens are defined by the Changlagali and the Murree thrusts (Figure 10).

The main basin margin and internal faults were probably formed in Late Jurassic as extensional normal faults, which remained active for a major part of the Cretaceous. In Early Tertiary the basin passed through a sag stage with the deposition of the Lassan and Lockhart limestones.

The source of the clastic sediments was located eastward of the Haro Trough (Marks and Ahmad, 1962). These clastic sediments were transported axially along these grabens and half grabens. Considerable part of these sediments is authigenic and the clastics supply was very small. These clastic sediments prograded westward axially along these grabens and half grabens.

CONCLUSIONS

1. The Haro Trough was formed due to extensional collapse of the Middle Jurassic carbonate platform in Late Jurassic to Late Cretaceous times. That happened when the Indo-Pakistan was separating from the Gondwanaland and the Madagascar.

2. The extension progressed from north to south in Pakistan and the Langrial Horst in the north is older in age than the Jacobabad Horst in southern Pakistan.

3. The base of the Late Jurassic to Late Cretaceous sedimentary megacycle gets younger southward in Pakistan.

4. The Haro Trough was a system of several half grabens and at least one main graben, the Jamhiri Graben, bounded by normal faults.

5. The earlier synsedimentary normal faults are now reversed as thrust faults.

6. The Late Jurassic to Late Cretaceous sedimentary package in the Haro Trough consists of two sequences classified into several cycles, which are:

a. Sequence 1

i. Top-Bathonian unconformity (S1)
ii. . A basal belemnite bed (A)
iii. . A first coarsening up megacycle (B)
iv. . A second coarsening up megacycle (C)
v. Pelecypod coquina cycle (D,E)
vi. Top Albian unconformity (S2)

b. Sequence 2

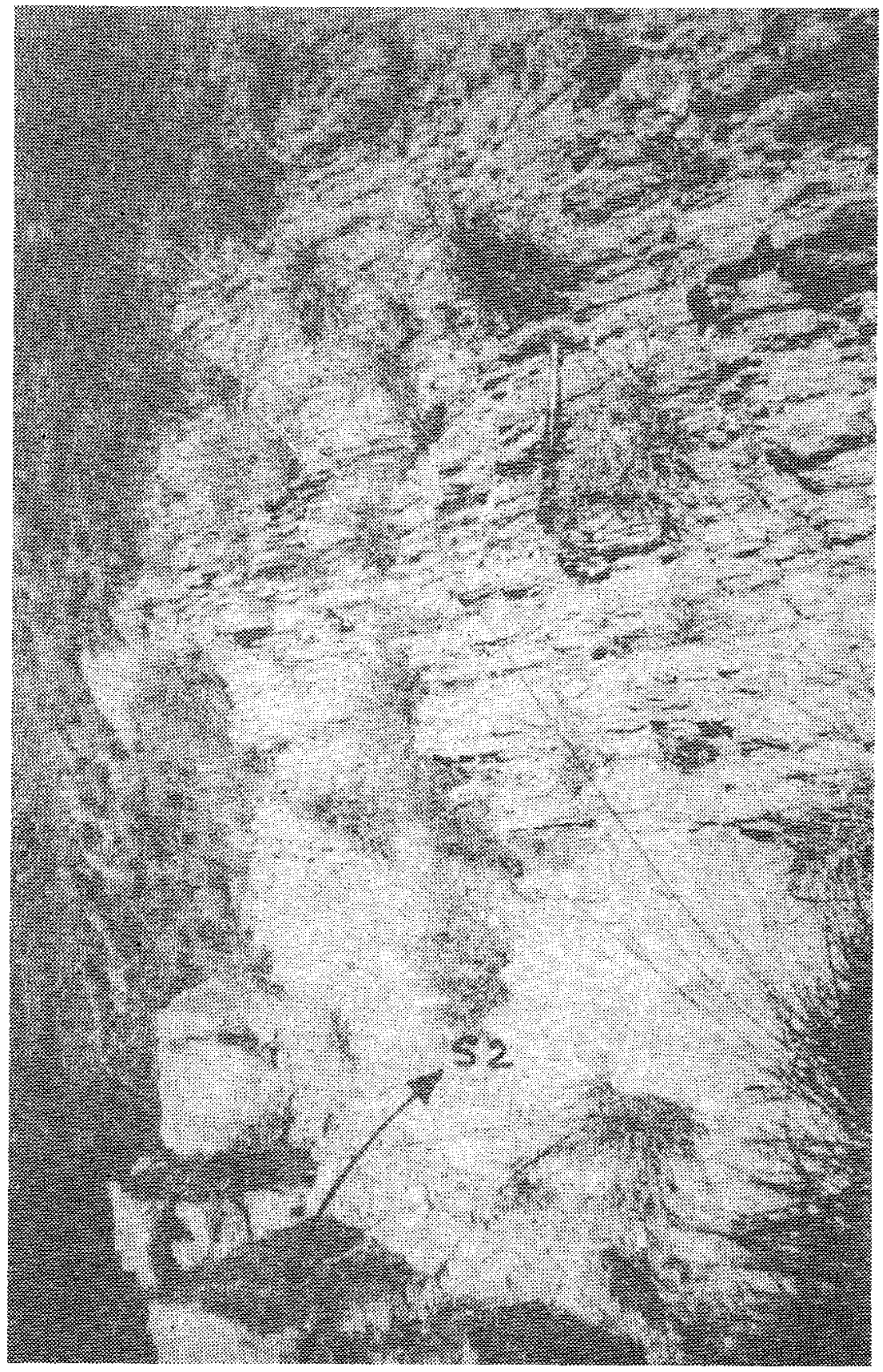

Figure 12B-Thin bedded, planktonic foram wackestone -packstone (PFWP) facies at the Gluccagali section. The surface S2 is visible towards the bottom.

i. Top Albian unconformity (S2)
ii. Basal dolomitic bed (Fdb)
iii. Basal Late Turonian bioturbated bed (Fbb)
iv. Late Turonian to Campanian planktonic foram wackestone-packstone (F)
v. Carbonate breccia cycle (G)
vi. Campanian-Maestrichtian low stand sand (Jamhiri sandstone) (H)
vii. Basal Tertiary unconformity (S3)

7. There is a time shift in the Lumshiwal sandstone that becomes younger westwards, that means the sediment source was in the east and the sands gradually prograded westwards in time.

8. The dominant sediment transport was directed axially westward in these grabens, and half grabens .

9. These sediments record at least two major transgressions in this trough.

10. The Jamhiri Sandstone may extend into Maestrichtian stage and is a likely equivalent of the Pab Sandstone in the Sulaiman and Kirthar basins.

11. Towards the end of the Cretaceous the Haro Trough was exposed to subaerial weathering resulting in lateritic/haematitic soils.

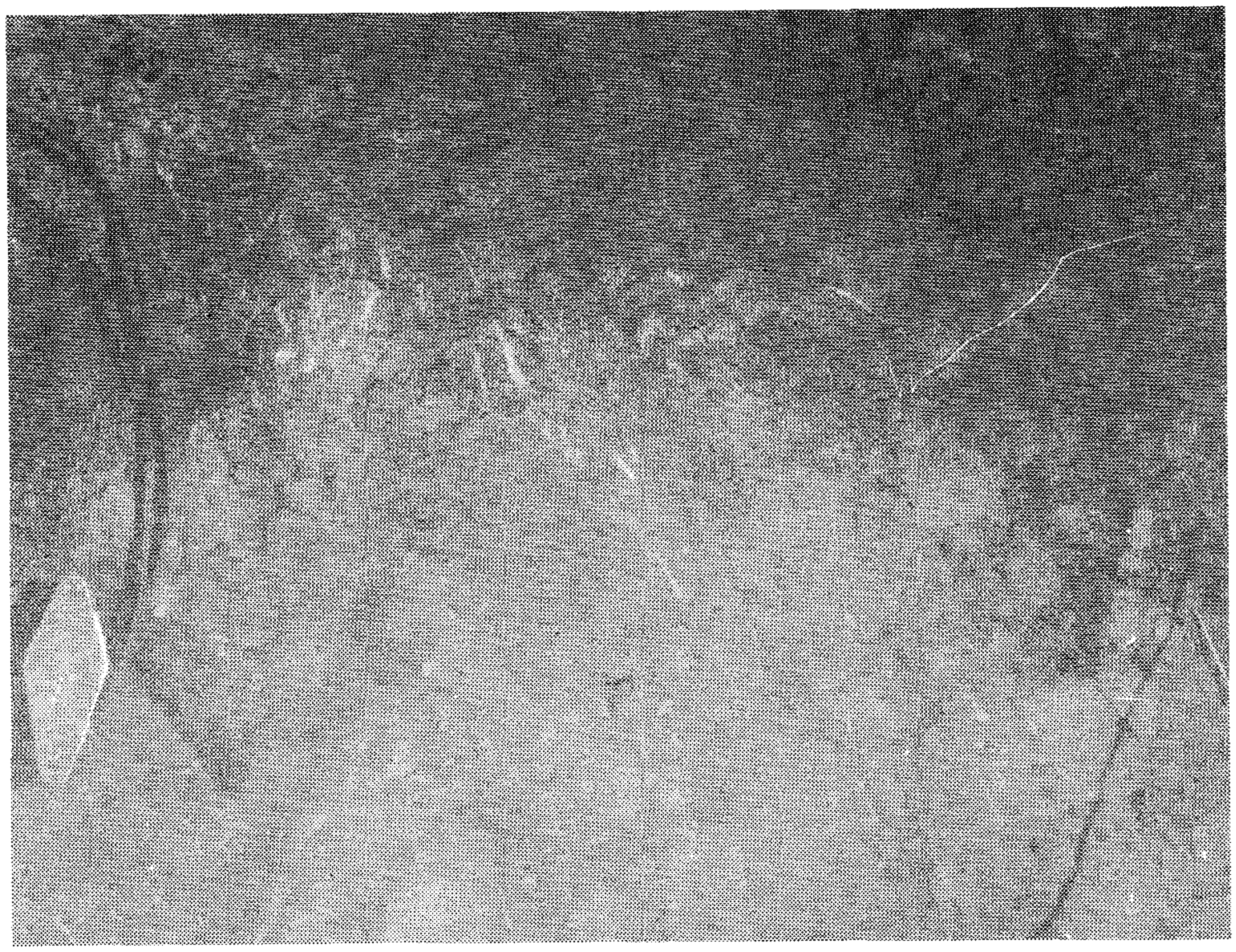

Figure 13-The Carbonate Breccia (CB) facies at the Jamhiri section. The facies contains a pelagic algae Oligostegnia in matrix and was deposited in deep slope environment.

12. The Haro Trough is closely related to the northern Kohat and Nizampur depressions in northwestern Pakistan. The Attock Slates are exposed in the north of these basins, which may be the extension of the Langrial Horst. The Early Eocene evaporite belt in the Kohat probably outlines the southward bounding horst of these basins.

HYDROCARBON IMPLICATIONS

1. The Late Jurassic to Late Cretaceous extensional events may have led to normal fault block hydrocarbon plays, which are explored in the Kirthar and Sulaiman basins (Southern Indus Basin) but have not been recognized in The N.W. Himalayan Basin (Northern Indus Basin) to date. It is suggested that such plays may be searched now.

2. The Cretaceous sediments contain important source rocks hence their lateral extensions may be better predicted referring to extensional basin models.

3. The Cretaceous basinal set up was modified in Early Tertiary due to a change in the tectonic stress regime, however, still the early Tertiary sedimentation adopted to existing basinal set up. Hence the Cretaceous basins help to explain the Early Tertiary oil producing basins and their regional facies distribution.

4. The Cretaceous horst blocks may have attracted hydrocarbons migrating out of the basins. These horsts have a long history of vertical movement both ways. The Langrial Horst was relatively uplifted in Cretaceous but subsided in Paleocene. The Jaccobabad Horst was uplifted relatively in Cretaceous but subsided in Early Eocene. These horsts, presently are uplifting relatively such as The Sargodha Horst.

5. New unrecognized horsts can be identified by delimiting the Cretaceous sediments, whose tops and flanks may be explored for hydrocarbons.

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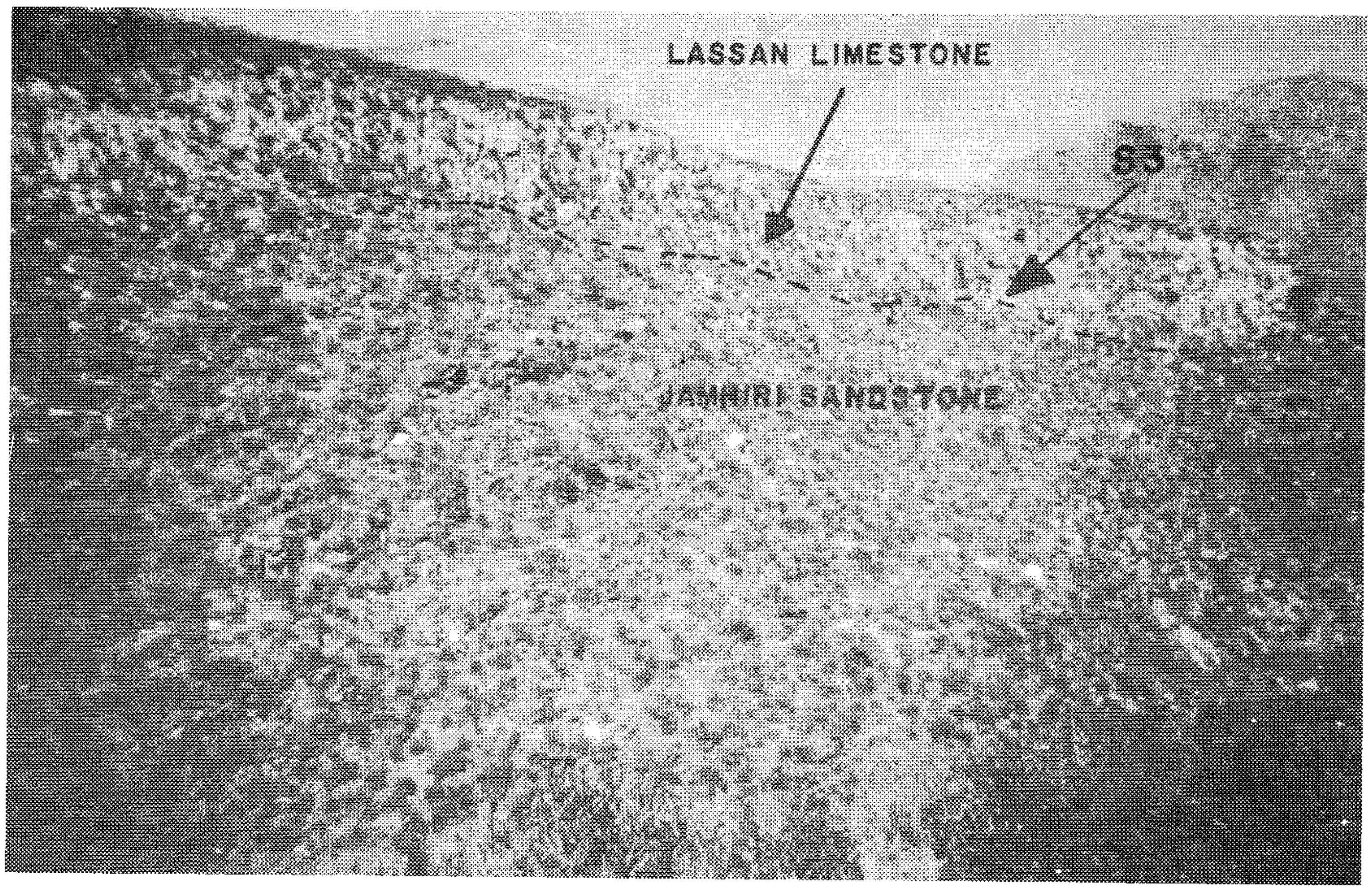

Figure 14-Photograph showing the Jamhiri sandstone in outcrop at the Jamhiri section. The light tone Lassan limestone is overlying the Jamhiri sandstone.

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