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Paleoenvironments and Genesis of Mixed Siliciclastic and Carbonate Sediments of the Upper Permian Chhidru Formation in the Salt Range, Pakistan

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ABSTRACT

The Upper Permian Chhidru Formation in the Salt Range displays a mixed sequence of siliciclastic and carbonate sediments. The formation is divisible into four lithofacies which in ascending order are: CF1 bioturbated shale with sandstone and limestone intercalations, CF2 sandstone-limestone with shale alternations, CF3 medium to thick-bedded sandstone and limestone, and CF4 white friable sandstone with subordinate limestone.

Various features of the Chhidru Formation are characteristic of shallow marine environments where mixed clastic and carbonate conditions of deposition prevailed. Mixing appears to have taken place both by punctuation as well as in situ mixing mechanisms. In general, these strata were deposited in shallowing upward conditions with a significant variance above facies CF3 where deepening occurred and facies CF2 was repeated before shallowing up again during the deposition of facies CF3 and CF4.

The shelf during deposition of the Chhidru Formation was frequently affected by storms and there is evidence to suggest it to be tidally influenced as well.

INTRODUCTION

The Chhidru Formation is the uppermost Permian formation exposed in the Salt Range. It makes a conformable lower contact with the dominantly carbonate Wargal Formation and the upper Paraconformable contact with the Early Triassic Mianwali Formation (Kummel and Teichert, 1970; Shah, 1977). Three sections i.e., Zaluch Nala, Nammal Gorge, and Chhidru Nala in the western Salt Range were measured (Figure 1) for sedimentological studies. The latter is the type locality of the formation. The paleontological studies of Permian-Triassic boundary sequence were discussed in detail by Kummel and Teichert (1970) and Pakistani-Japanese Research Group (1985). Stratigraphy was discussed in detail by Teichert (1966).

The Chhidru Formation displays a mixed sequence of siliciclastic and carbonate sediments. Mixed sequences are very common in the ancient geological record (e.g., Markello and Read, 1981; El-Haddad et al., 1984; Johnson and Risk, 1987) and range in age from Precambrian (Salt Range Formation and Hazara Formation) to Tertiary (Shekhan Formation and Kohat Formation) in Pakistan. Not much has been published on the mixed sequences previously considering their community. However, recently there is an upsurge in research on such strata (Rezak, 1985; Mount and Ward, 1986; Doyle and Roberts, 1988; Tanoli, 1990). There is a tremendous scope to work on mixed lithologies in the Upper Indus Basin i.e., Salt Range and Kohat and also in Hazara area of Pakistan. The present article deals with the mixed strata of the Chhidru Formation. A brief and depositional account of the formation was given by the Pakistani-Japanese Research Group (1985).

FACIES

On the basis of lithology, bioturbation, and primary sedimentary features, the Chhidru Formation is divisible into four lithofacies (Figures 2 and 3) which are: CF1 bioturbated shale with sandstone and limestone intercalations, CF2 sandstone-limestone with shale alternations, CF3 composite bedded sandstone and limestone, and CF4 white friable sandstone with hard calcareous lenses. Previously Pakistani-Japanese Research Group (1985) had also subdivided the Chhidru Formation into four similar units. The presence of brachiopods, gastropods and other marine fossils throughout the formation suggests its deposition in marine environments (Kummel and Teichert, 1970).

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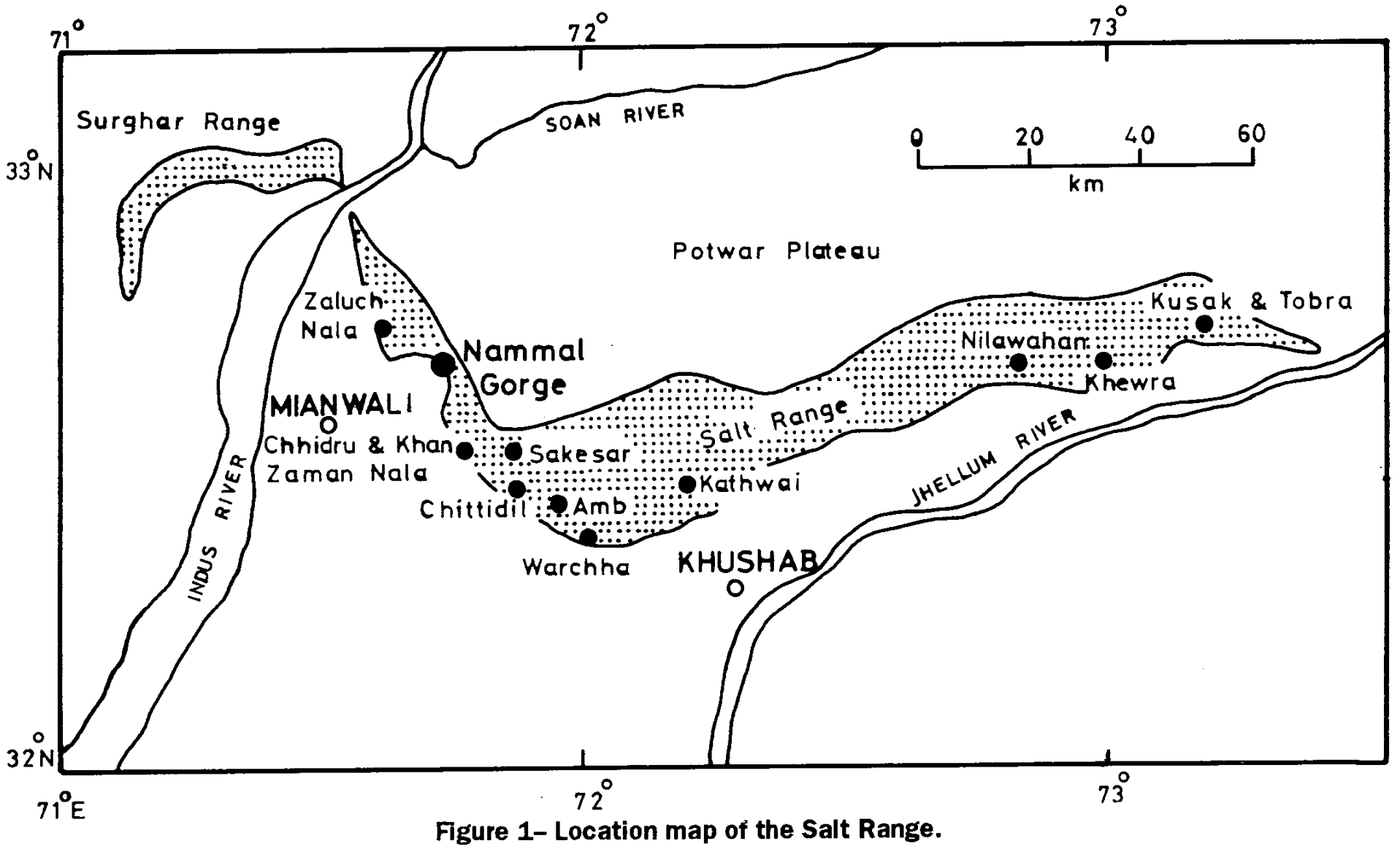


Figure 1– Location map of the Salt Range.

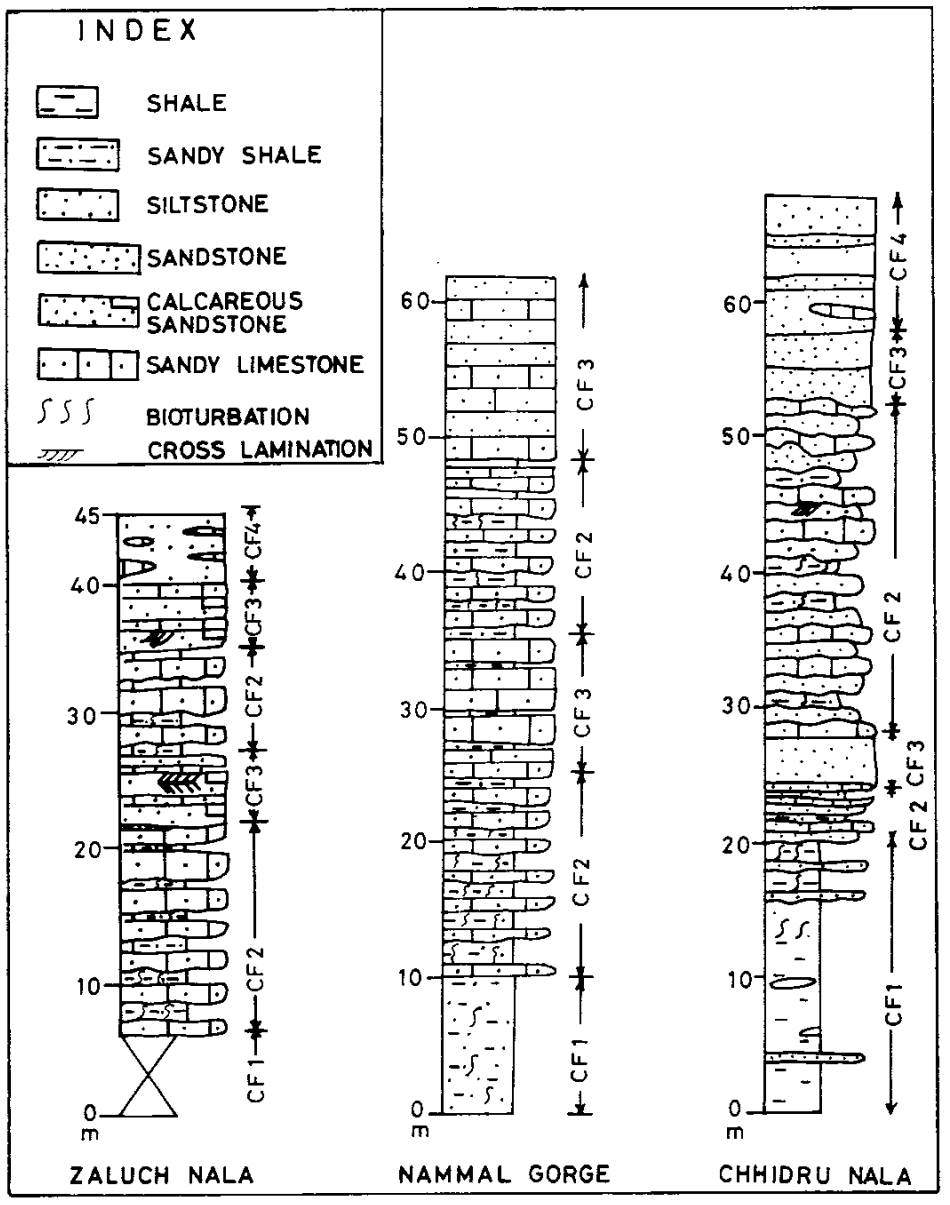


Figure 2– Lithologic columns of the Chhidru Formation with facies distribution.

Facies CF1: Bioturbated Shale with Sandstone and Limestone Intercalations

Description.– This facies makes the basal portion of the Chhidru Formation. It consists of dark grey colour bioturbated calcareous shale in the lowermost reaches. Upwards the shale becomes sandy in nature and occasional muddy calcareous sandstone and muddy limestone beds start appearing (Figure 4). These sandstone and limestone beds, where observable, are sharply based, thicken and thin laterally (Figure 4b) and may actually pinch out laterally. The muddy limestone beds are filled-up with fossil shells, mostly of brachiopods, slightly more concentration of which in the lower parts develops crude normal grading (Figure 4c). Some of the sandstone and limestone beds are also bioturbated and in some cases vertical as well as horizontal burrows were noticed. Occasionally the sandstone beds internally display horizontal lamination. Thickness of the facies ranges between 7 to 20m.

Interpretation.– The lithologic characteristics i.e., predominant shale and biogenic activity in the form of intense bioturbation suggests the deposition of facies CF1 in quiet environment. From its stratigraphic position lying conformably above the carbonate facies of the Wargal Formation and faunal content, these strata are

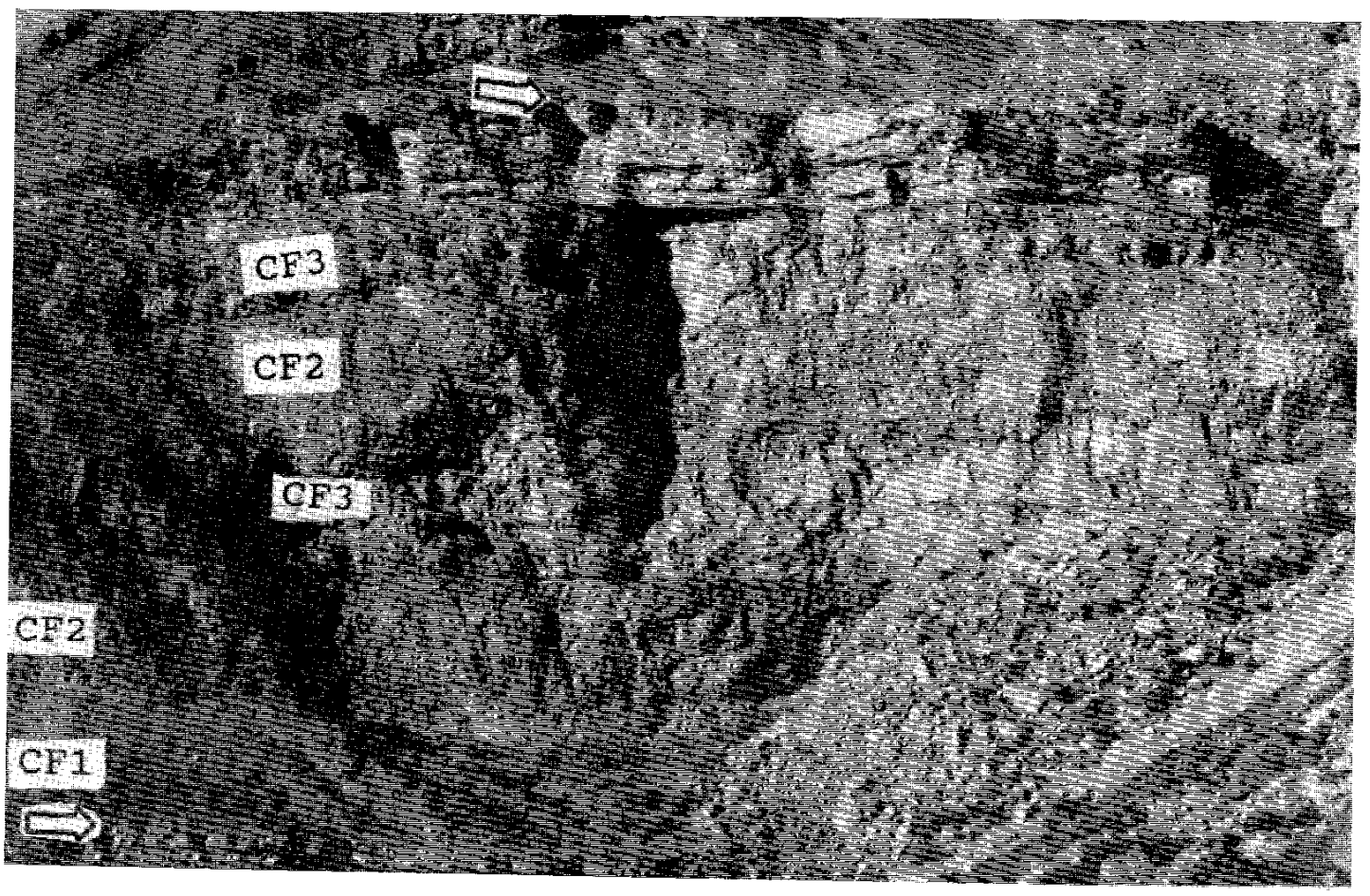


Figure 3– Field photograph from Nammal Gorge showing complete exposure of the Chhidru Formation. Both the lower contact with the Wargal Formation and upper contact with the Mianwali Formation are exposed and marked here with arrows. Note the vertical arrangement of various facies.

suggested to have been deposited in marine offshore shelf setting. Pakistani-Japanese Research Group (1985) suggested the formation of this facies at Chhidru in a restricted shelf lagoon which, according to them, was developed by a marine shoal represented by the topmost facies of the underlying Wargal Formation. Uneven sea-bed topography by the development of gentle shoals cannot be ruled out during the deposition of the Chhidru Formation. Nevertheless, uppermost nodular limestone of the underlying Wargal Formation does not appear to represent a shoal but rather a product of normal shelf sedimentation. The shale was deposited out of suspension and the faunal physical activity in relatively calm conditions produced the resultant bioturbation. The characteristics of interbedded sandstone and limestone beds such as sharp lower bedding planes, lateral thickening and thinning, concentration of fossil shells in basal portions of beds, internal horizontal lamination, suggest the deposition of these beds during more than normal energy conditions. Such energies are more typically attained during storms (Reisa, 1981; Nelson, 1982; Rice, 1984; Simonson, 1984: Tanoli and Pickerill, 1989) the associated currents of which move relatively coarser sediments in offshore environments where otherwise fine grained sedimentation takes place out of suspension (Hayes, 1967: Morton, 1981; Swift et al., 1986). The calcareous nature of shale and sandstone indicates the in situ presence of calcareous material in the ambient waters as well.

Facies CF2: Sandstone-Limestone with Shale Alternations

Description.– This facies consists of alternations of shale with calcareous sandstone and sandy and muddy limestone beds (Figure 5). The shale is sandy and calcareous and is bioturbated. The amount of shale decreases upward from 40-50% in the lower portion to about 10% in the upper portion of the facies. The sandstone and limestone beds range between 5-40cm in thickness and are generally loaded (Figure 5b). These beds are sharp based and laterally thicken and thin and in several instances pinch out over shorter distances (Figure 5b). Most of the limestone beds are filled-up with fossil shells mostly of brachiopods and in some cases normal grading is observable. In some cases the internal arrangement is as follows; basal portion made up of coarse fossil shells, in the middle portion either horizontal lamination or no structure is visible and in the upper reaches wavy lamination is present (Figure 5c). Small scale (~ 55cm thick) cross-lamination is rarely observable and in several beds upper bedding planes appear rippled. Thickness of the facies ranges between 8 to 25m.

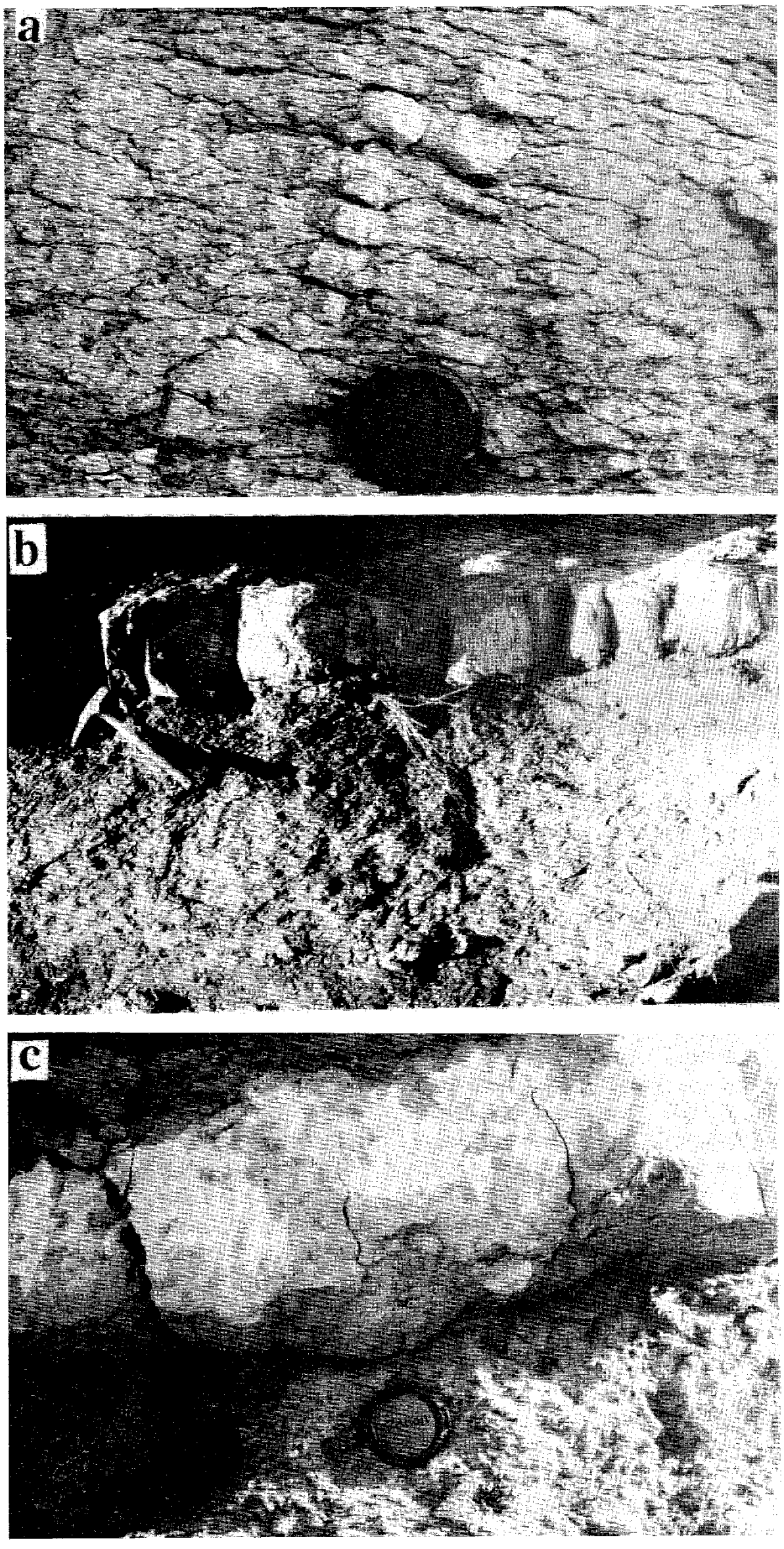


Figure 4– Description on page 69.

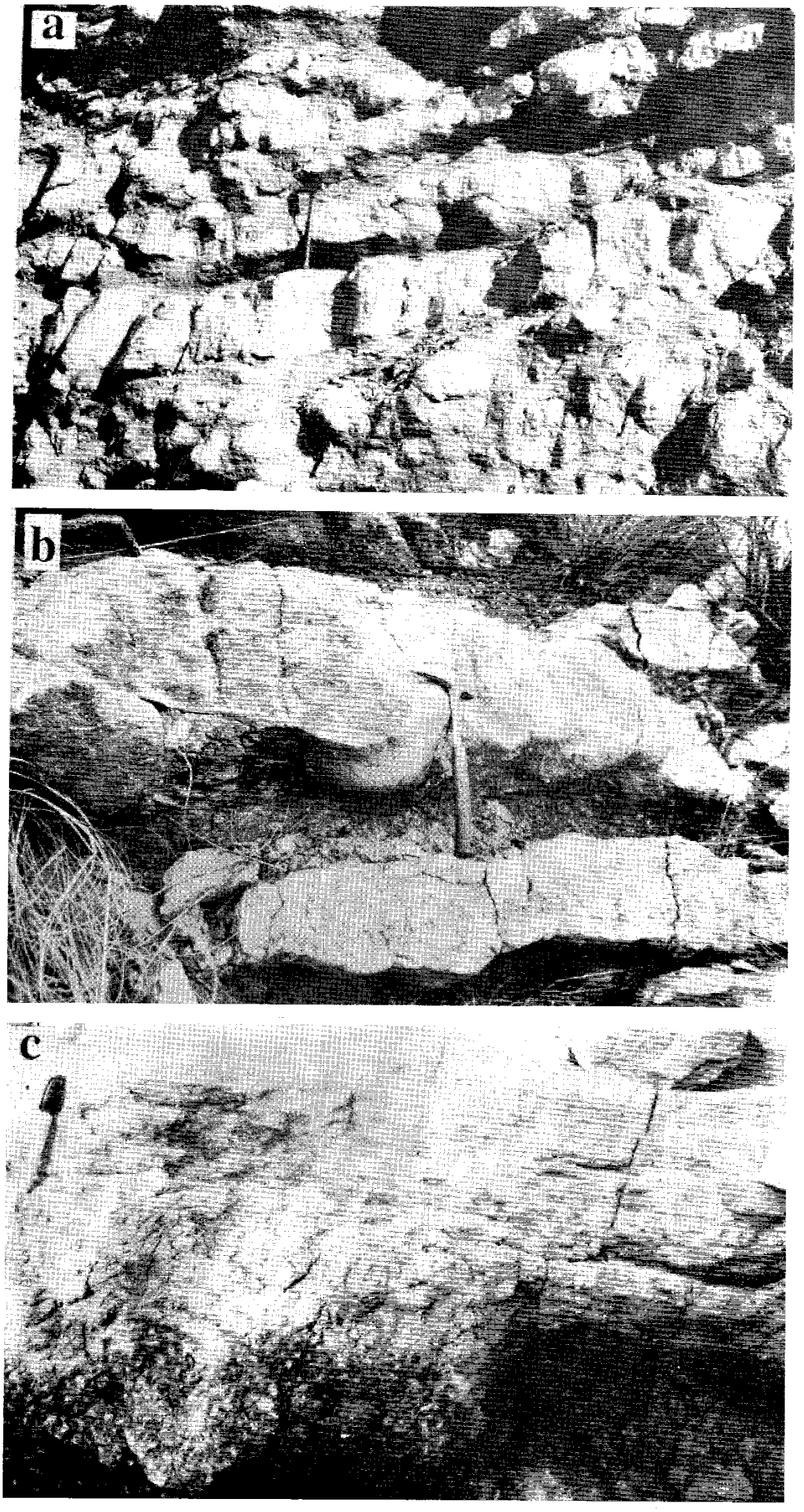
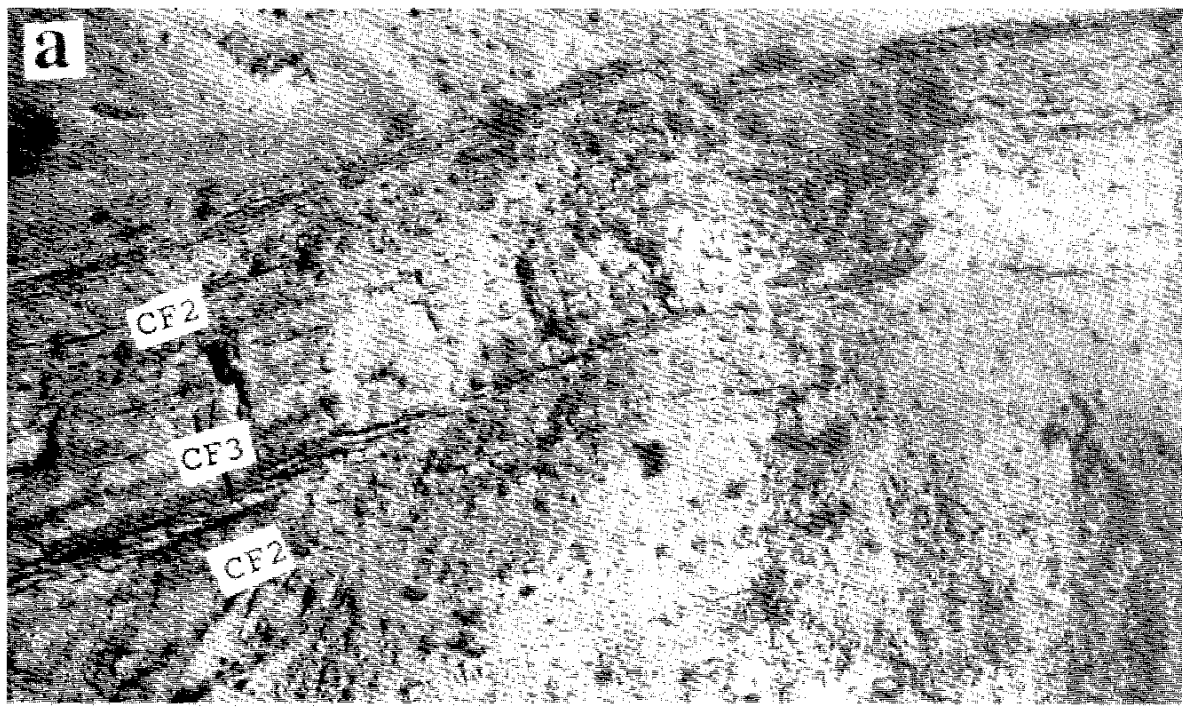
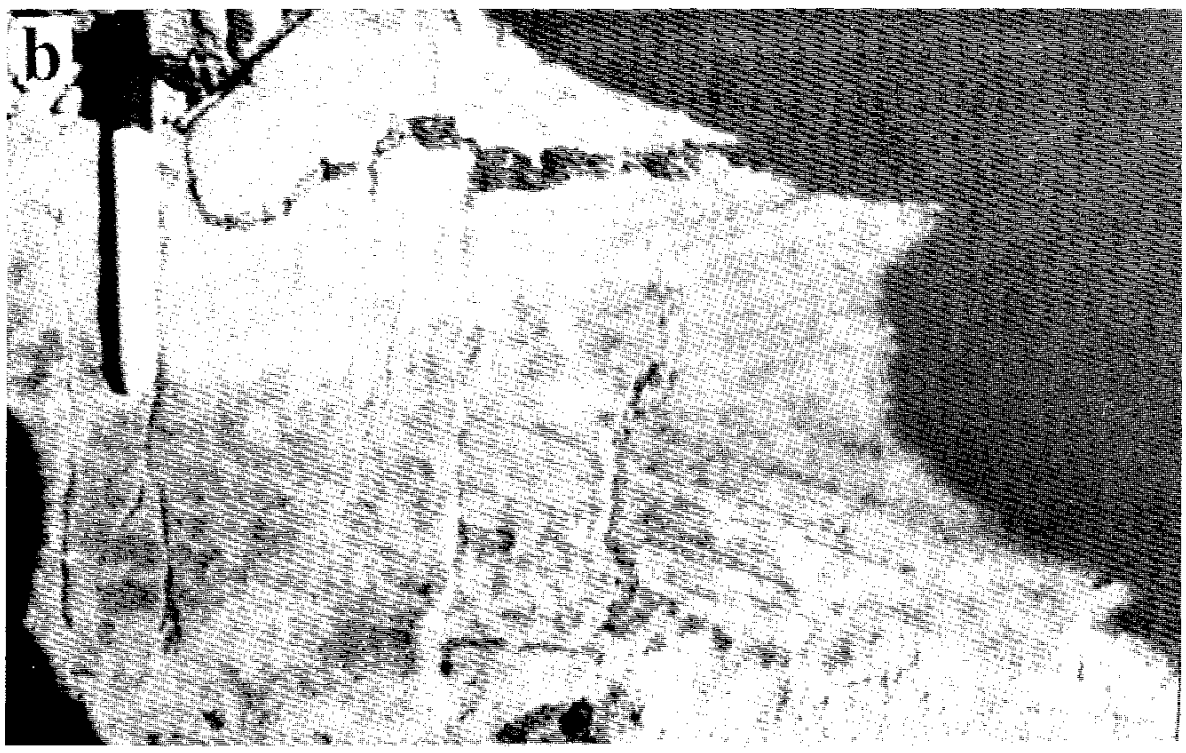


Figure 5– Description on page 69.





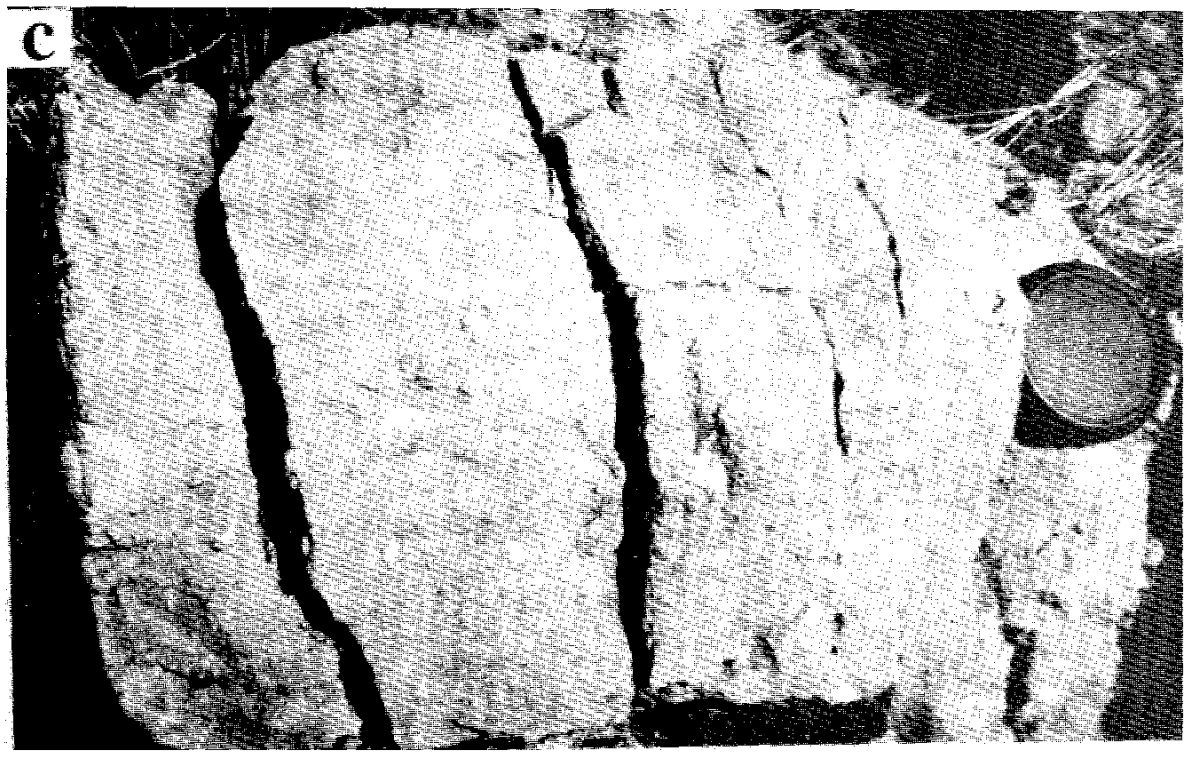


Figure 6– Description on page 69.

Figure 4– Facies CF1: (a) Bioturbated calcareous shale with a muddy limestone bed; (b) Muddy and sandy limestone bed in bioturbated shale with sharp lower bedding plane and laterally uneven in thickness; (c) close-up of a muddy limestone bed interbedded in the bioturbated shale.

Figure 5– Facies CF2: (a) Interbedded shale and sandy-muddy limestone and calcaeous sandstone beds. Note the lateral unevenness in thickness of these beds; (b) close-up of a portion of (a) showing more clearly the nature of bedding planes and lateral pinching of limestone/sandstone beds. The lower bedding planes are loaded; (c) Close-up of a sandy limestone bed showing internal graded arrangement. In the basal portion fossil shells are concentrated and near the top wavy lamination is visible.

Figure 6– Facies CF3: (a) Outcrop photograph at Chhidru Nala showing facies CF3 which is proceeded and preceded by facies CF2; (b) Herringbone cross-lamination in a sandstone bed at Zaluch Nala; (c) Bioclastic limestone bed showing well sorted zones of fossil shells with densely packed fabric.

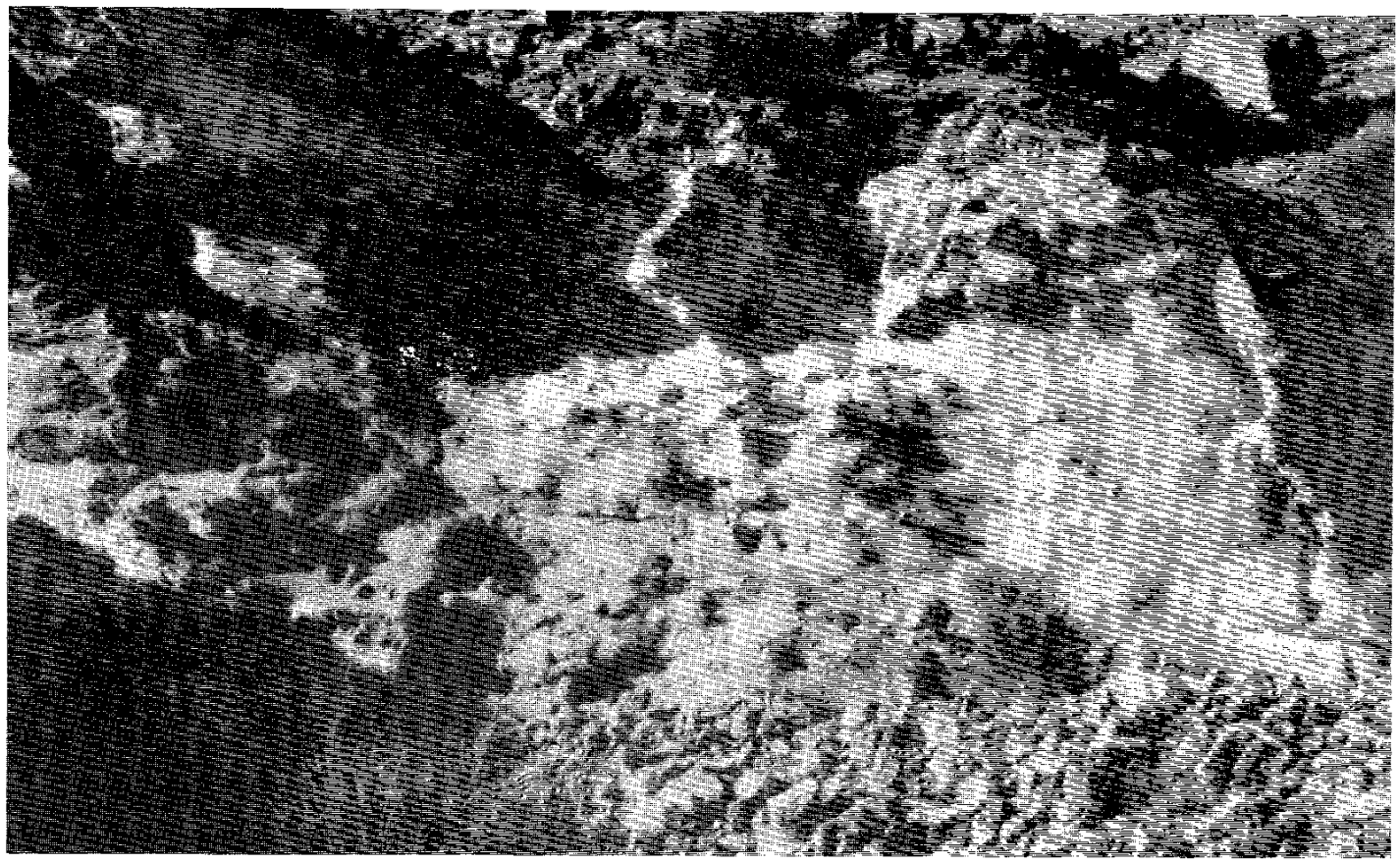


Figure 7– White friable sandstone of facies CF4 at Nammal Gorge.

Interpretation.– The increased amount of sandstone and limestone relative to bioturbated shale in this facies suggests its formation landward of facies CF1 in shallow marine environments. The deposition of the facies occurred in offshore transition to middle shoreface settings, dominantly in lower shoreface environments. The bed characteristics like lateral pinching, thickening and thinning, sharp bedding planes, internal graded arrangement are indicative of the role of higher than normal energy conditions (Kumar and Sanders, 1976; Nelson, 1982). These beds were deposited during waning currents. The interbedded shales were introduced during normal energy conditions which were churn down by the organisms to produced bioturbation. The loading of the sandstone and limestone beds resulted due to density contrasts with the interbedded shales (Anketell et al., 1970). The sedimentation rate would have been fast which suggests that at least partial shale deposition was associated with storm related processes (Swift et al., 1986) due to which water got entrapped in the shale beds. Deposition of the overlying beds exerted vertical load as a result of which the shale beds behaved plastically giving loaded appearance to the overlying limestone/sandstone beds. The sediments under fast rates of sedimentation generally escape bioturbation. The bioturbation of shales in this facies therefore suggests an enormous organic life which flourished in the Late Permian sea.

Facies CF3: Composite Bedded Sandstone and Limestone

Description.– This facies is dominantly composed of calcareous sandstone and limestone beds. Generally

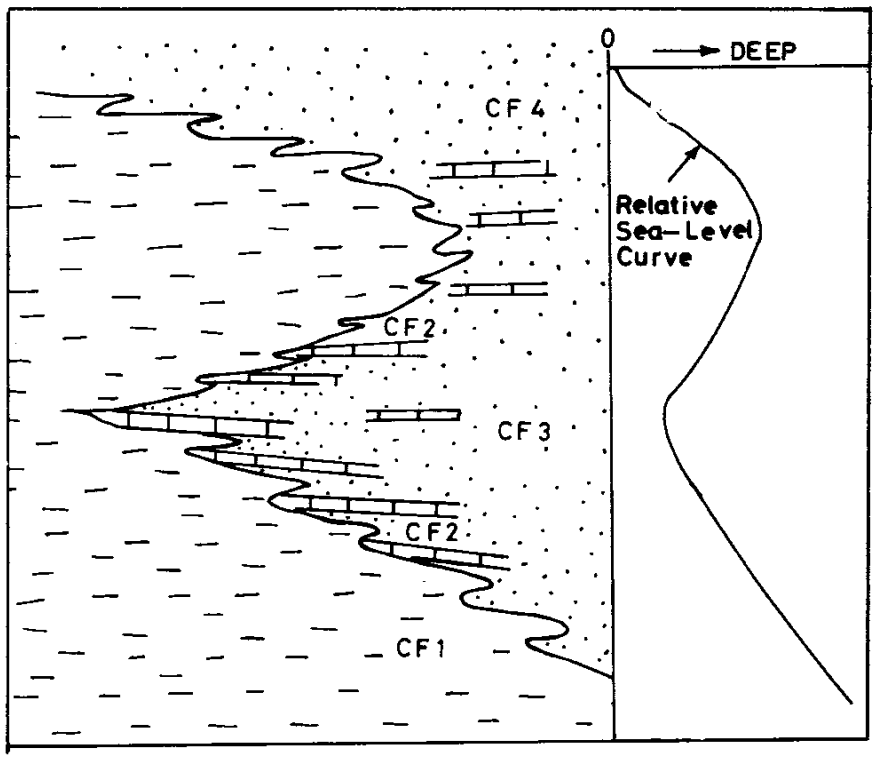


Figure 8– Relative sea stand during deposition of various phases of the Chhidru Formation.

the beds are medium to thick-bedded and range from 15 to 70cm or rarely more in thickness. In lower portions, and where this facies is proceeded by facies CF2 in the upper portions as well, these beds are separated by thin occasionally up to 6cm thick mostly bioturbated and cleaved siltstone or silty shale beds. In middle of the facies, sandstone and/or limestone beds are amalgamated (Figure 6a). Several of the beds appear to pinch out laterally. Where visible due to suitable weathering, these beds exhibit cross-lamination which was bi-directional in several cases. Herringbone cross-laminate were also observed in a few cases (Figure 6b). Most of the limestone beds of the 2nd repetition of facies CF3 at Nammal Gorge are literally filled-up with fossil shells dominantly of gastropods (Figure 6c). Generally, these shells do not specifically show graded arrangements but are scattered all through the beds. Thickness of the facies ranges between 5 to 15m.

Interpretation.– The composite and amalgamated bedding with little or no intervening shale in this facies is suggestive of high energy conditions in which the shale could not be settled due to continuous agitation (Howard and Reineck, 1981). This facies, therefore, was deposited landward of the site of deposition of facies CF1 and CF2 in shallow subtidal upper shoreface environments. During deposition of these strata one of the energy sources was tidal currents. Channelized beds may have been deposited in channels cut by occasional strong tidal currents in shallow subtidal areas. The tidal effect was not observed in strata of facies CF1 and CF2 which most probably never developed in those units due to their distance from the shore and therefore, a low to medium tidal range is suggested during deposition of the Chhidru Formation. The limestone beds literally made up of fossils indicate the abundance of organic life. Formation of bands of more or less equal size shells or shell fragments (Figure 6c) are due to the activity of currents. The upper repetition of facies CF3 at Nammal Gorge, however, displays non-sequential distribution of fossils throughout the beds which were either deposited in situ without much reworking or were the result of very strong currents. If the first possibility is true then deposition of such strata most probably took place in locally developed barred areas within the shelf where energy levels were reduced to minimal and for the time being clastic input was considerably reduced. In the 2nd case, the strong storm related currents in shallow shoreface waters dumped their load without much sorting due to sudden decrease in energy levels. This again has to do with floor topography which appears to have been quite uneven at Nammal during deposition of these strata.

Facies CF4: White Friable Sandstone with Calcareous Lenses

Description.– The facies is composed of dominantly white sandstone which is friable and is composite bedded (Figure 7). Interbedded with the sandstone are hard calcareous lenses and beds. No intervening shale is present. At the bedding planes horizontal as well as vertical burrows are present. Thickness of the facies is upto 7m. Teichert (1966) and Kummel and Teichert (1970) named it 'white sandstone unit' and described its thickness as variable and ranging from less than a metre to 5m. Pakistani-Japanese Research Group (1985) measured this facies from 0 to 3m in thickness.

Interpretation.– The maturity and absence of intervening shale in this facies suggest its deposition further landward of facies CF3 in upper shoreface to foreshore environments. These characteristics result by continuous winnowing due to intense wave and current action. The less resistant minerals breakdown and as a consequence almost pure quartz sand results (Folk, 1974). In such highly agitated environments no sedimentation out of suspension takes place (Howard and Reineck, 1981). Therefore, composite beds without intervening shale are the depositional product. Lensoid limestone beds were deposited possibly by the enhanced longshore currents during stormy events. The lateral variation in thickness of this facies is suggested due to the subaerial erosion by Kummel and Teichert (1970) and by the Pakistani-Japanese Research Group (1985), since a considerable time gap exists between this and the overlying Mianwali Formation.

DEPOSITIONAL SYNTHESIS

The Zaluch Group which comprises the Amb Formation, Wargal Formation, and the Chhidru Formation in ascending order displays a variety of lithologies and sedimentary record from Early Permian to Late Permian, within these formations. Generally the basal Amb Formation consists of mixed facies, the Wargal Formation dominantly carbonate facies and the uppermost Chhidru Formation mixed clastic and carbonate facies with sandstone at the top. The Amb Formation appears to have been deposited in shallow water with the upper part in transitional setting. The upper contact of the formation is an unconformity and shows subaerial exposure before deposition of the overlying Wargal Formation. The Wargal Formation was deposited during Late Permian in a platform type setting. The Chhidru Formation displays mixed facies deposited in an offshore in the basal part to upper shoreface-foreshore settings in the upper part. The sedimentary record for the Early Permian to Late Permian, therefore, suggests generally a regression of the sea during deposition of the Amb Formation followed by a transgression which developed a broad platform on which Wargal Formation was deposited and again a regression in Late Permian during deposition of the Chhidru Formation.

Within the Chhidru Formation basal facies CF1 was deposited in an offshore environments. Facies CF2 in an offshore to lower shoreface environment and facies CF3 in middle to upper shoreface and topmost facies CF4 in upper shoreface to foreshore environments. The stratigraphic columns (Figure 2) clearly show two cycles; basal one starting with facies CF1 and ending at facies CF3 and the overlying 2nd cycle starting with facies CF2 through facies CF3 to facies CF4 at the top. There is an overall regression during which the Chhidru Formation was deposited. However, within this generalized regression above the 1st cycle deepening occurred before shallowing-up again towards the termination of the Chhidru Formation (Figure 8). Whether this deepening was the result of a transgression or localized subsidence due to tectonic or some other reasons is unclear.

The stratigraphic thickness from Zaluch Nala in the northwest to the Chhidru Nala (Figure 2) in the southeast increases, as also noted by Teichert (1966) i.e. ~60m at Zaluch, ~65m at Nammal and ~85m Chhidru, suggesting that the basin was deepening and subsidence rate was higher towards southeast and/or the southeastern region was more close to the source. The presence of herringbone cross-stratification in facies CF3 at Zaluch Nala is also suggestive of a more broader shelf in the northwest where tidal activity was thus enhanced.

Mixed siliciclastic and carbonate nature of the lithology of the Chhidru Formation is a result of at least two different mechanisms; by background in situ mixing and by punctuated mixing (cf. Mount, 1984). The in situ mixing has been proposed due to the mixed nature of the fine-grained background sedimentation such as the calcareous shales as well as of coarser sediments which are dominantly of mixed nature such as calcareous sandstone and sandy limestone and due to the presence of scattered large fossil shells without preferred concentration horizons in some of the limestone beds. The punctuated mixing mechanism is a result of storm or high energy currents activity which transported different nature sediments (e.g., carbonates) from nearby environments and deposited them in a setting where sedimentation was of different nature (e.g., clastics). This would result in a sedimentary sequence with a mixed nature of sediments (Mount, 1984). The punctuated mixing was also going on alongwith the in situ mixing in the Chhidru Formation as is evident from the current activity which resulted in normally graded beds with more fossil shell concentrations at the base and eroded lower bedding planes.

CONCLUSIONS

1) The deposition of the Chhidru Formation took place in shelf environments ranging from offshore to upper shoreface or foreshore settings. The facies CF1 was deposited in outer shelf offshore, facies CF2 shoreward of facies CF1 in offshore and lower shoreface, facies CF3 in mid to upper shoreface, and facies CF4 in upper shoreface or foreshore environments.

2) The vertical arrangement of facies suggests an initial shallowing-up of the basin followed by a deepening phase and finally shallowing-up again towards the top of the formation.

3) Both the thickness as well as siliciclastic content of the Chhidru Formation increase from northeast to southwest i.e. from Zaluch Nala to the Chhidru Nala suggesting perhaps relatively faster subsidence of the southwestern region and at the same time proximity to the source.

4) The stratigraphic position bedding characteristics and the background sedimentation of the Chhidru Formation, suggest that the mixed siliciclastic-carbonate succession of the Chhidru Formation developed both by "in situ mixing" as well as by "punctuated mixing" mechanisms.

5) The shelf during deposition of the Chhidru Formation was mixed wave, tide and storm-dominated.

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