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CORRELATION OF FOUR MAGNETOSTRATIGRAPHICALLY CONSTRAINED SECTIONS OF MIOCENE BHUBAN FORMATION OF SURMA BASIN IN MIZORAM, INDIA

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ABSTRACT

In the present study, four magnetostratigraphically constrained isolated sections in the Mizoram part of the Surma basin, namely, Kolasib-Rengtekawn (KR) section in Kolasib district; and Bawngkawn–Durtlang (BD); Tuirial and Sairang sections in Aizawl district of Mizoram have been successfully correlated. The youngest magnetozone of BD section i. e. C5Cn magnetozone (16.726-16.014 Ma) has also been recorded in the KR section and both the sections expose Middle Bhuban Unit of Bhuban Formation, Surma Group. Thus KR section is correlated with the upper part of BD section. Three younger magnetozones, *viz*., C4 An (9.025 - 8.699 Ma), C4Ar.1n (9.308 - 9.230 Ma) and C4Ar.2n (9.642 - 9.580 Ma) of Tuirial section have been delineated in the Sairang section and both the sections belong to Upper Bhuban Unit. Thus Sairang section is correlatable with the upper part of Tuirial section. Stratigraphically also, KR and BD sections are older than the Tuirial and Sairang sections. Similar pattern in rate of deposition has been noticed in the KR and BD sections and Turial and Sairang sections. The study thus demonstrates that magnetostratigraphy may emerge as the reliable tool for regional correlation of isolated successions of varied litho-stratigraphic units in the Surma basin. An integrated study on litho-, bio- and magnetostratigraphy along with sedimentology is needed to reconstruct the tectono-depositional history of the basin and biotic evolution in it.

Keywords: Magnetostraigraphy, Surma basin, Bhuban Formation, Mizoram, regional correlation.

INTRODUCTION

Surma succession is exposed in a large area extending southward from the centre of the Kohima syncline through Surma Valley, Tripura and Chittagong to Indo-Myanmar Range. Mizoram is considered as the depocentre for the Surma basin as thickest sedimentary succession is developed in Mizoram part of this basin. The major lithostratigraphic unit exposed in the Mizoram State is the Surma Group of Miocene age represented by Bhuban and Bokabil Formations. Lithologically, Bhuban Formation is further subdivided into Lower, Middle and Upper Bhuban Units. Main rock facies of this formation are sandstone, siltstone, shale, mudstone and their admixtures in various proportions and a few pockets of shell limestone, calcareous sandstone and intraformational conglomerate (Tiwari and Kachhara, 2003).

Previously, attempts were made to classify and correlate the Surma succession based on lithology by Evans (1932), sand/shale ratio by Holtrop and Kaizer (1970) and with heavy mineral assemblages by Sinha and Sastri (1972). In spite of the success of such attempts in broad stratigraphic correlations and in regional mapping (Dasgupta, 1982), these have limited applications in the correlations of the isolated sections of the Surma Group, both at local as well as on regional scale. Extensive palaeontological studies were performed in the Bhuban Formation comprising bivalves, gastropods, echinoids, crab, corals, foraminifers, ichnofossils and fishes (Rajkonwar *et al*., 2013; Jauhri *et al*.,. 2003; Lokho and Raju, 2007, 2011; Srivastava *et al*., 2008; Tiwari, 2001, 2006; Tiwari and Kachhara, 2000,Tiwari and Mehrotra, 2002, Tiwari and Victor, 2012; Tiwari *et al*. 1997, 2011, 2013; and Victor *et al*. 2011).These fossil assemblages have broadly indicated the changes in depositional environments throughout the stratigraphy with shallow marine, near shore, lagoonal through coastal to fluvial (Malsawma *et. al.,* 2010). Such efforts have however not yielded desirable results in terms of fine resolution biostratigraphy owing to long-ranging nature of the recorded taxa. Moreover, planktonic foraminifers and nanno-planktons – excellent biostratigraphic markers in Neogene successions elsewhere – have not yet been studied in desired details in Mizoram. Due to such limitations of lithostratigraphic and biostratigraphic tools, correlation of isolated sections of varied units of Surma succession becomes difficult and sequence stratigraphic and basin evolutionary aspects of the Surma basin in Mizoram could not be worked out. Magnetostratigraphy may play important role in addressing this issue and in reconstructing the history of basin evolution and tectonics as it has been proved successful in the Himalayan foreland basin (Appel *et al*. 1991; Burbank *et al*. 1998; Johnson *et al*. 1983; Tauxe and Opdyke, 1982). In Surma basin of Mizoram also, magntostratigraphy has yielded desirable outcome along the two sections, namely Bawngkawn-Durtlang and Tuirial sections in Aizawl (Tiwari *et al*., 2007, Malsawma *et al.*, 2010 and Badekar *et al.*, 2013). In this paper, we present the results of two new magnetostratigraphically constrained sections and correlation of these with the two previously studied sections. Out of the four sections, Kolasib-Rengtekawn and Bawngkawn-Durtlang sections fall in Middle Bhuban Unit and Tuirial and Sairang sections in the Upper Bhuban Unit of Bhuban Formation in Aizawl and Kolasib districts of Mizoram, India.

REGIONAL GEOLOGY AND DEPOSITIONAL ENVIRONMENT

The Surma basin is surrounded by three litho-tectonic regimes, viz., The Himalaya in the north, the Indo Myanmar Range (IMR) in the east and the Shillong plateau in the NW and it has received sediments from all these litho-tectonic domains. This implies that the Surma basin has received a variety of clasts composition. Information on age constraints and sediment accumulation rate may enable reconstruction of the evolutionary history of the Surma basin during Neogene vis-à-vis respective hinterlands (Badekar *et al*. 2013). Moreover, changes in rock magnetic properties observed in the sedimentary record can reflect shifts in climatic and/or tectonic regimes (Thompson and Oldfield, 1986; Verosub and Roberts, 1995).

Johnson and Alam (1991) have interpreted Bhuban Formation as prodelta and delta-front deposits of a mud-rich delta system similar to the modern Bengal delta. The sediments of Bokabil Formation represent sub-aerial to brackish environment, based on mud rocks and pollen types (Holtrop and Keizer, 1970). Alderson (1991) noted marine influence within the Bokabil Formation in eastern Sylhet Trough. On the basis of detailed facies analysis of core samples and wire line log interpretation, Alam (1995b) envisaged a micro-tidal coastal setting with extensive development of intertidal and sub-tidal environments within a proto-Surma delta embayment, for the Surma sediments in the Sylhet Trough. Similarly, on the basis of comprehensive logging of the core samples from the Sylhet Trough, Sultana and Alam (2001) have interpreted the sediment of the group as deposits of environments ranging from shallow marine to tide-dominated coastal settings within a cyclic transgressive–regressive regime.

The Miocene-Pliocene succession of Surma basin in Mizoram has been sub-divided into Surma and Tipam Groups. Surma Group is divisible into a Bhuban and Bokabil Formations. Bhuban Formation is further divisible into Lower, Middle and Upper Bhuban Units (Karunakaran, 1974; Ganju, 1975; Mandaokar, 2000 and Tiwari and Kachhara, 2003). Holtrop and Keizer (1969) made an attempt to classify and sub-divide the Surma sediments occurring below the Bangladesh Alluvial Plain by sand/shale ratio. Sinha and Sastry (1972) analysed the heavy mineral assemblages from the exposed Surma rocks in Cachar and Tripura Hills with a view to classify and sub-divide these successions. Detailed study on these aspects is however required for evolving any meaningful scheme of classification of Surma rocks. Tiwari and Kachhara (2003) proposed five biozones in the Tertiary succession of Mizoram based on mega-invertebrate fauna which can be used for regional correlation and classification. Tiwari (2002, 2006) based on molluscan fossils inferred shallow marine environment of deposition for Bhuban Formation. More recently, Uddin and Lundberg (1998) carried out detailed heavy mineral study of Surma sediments from the Bengal basin and concluded that Surma sediments had an orogenic source both from the Eastern Himalayan region and Indo-Myanmar range. Malsawma (2011) from the magnetostrtaigraphic and sedimentation results along three sections in Bhuban succession of Mizoram inferred that the basin subsidence and/or the tectonic upliftment was occurring during the late Miocene period during the evolution of the Surma basin. This resulted into thick pile of sedimentation records in this basin. It is obvious therefore from the above that the evolution of the Surma basin is not yet fully understood.

LOCATION OF THE SECTIONS

Three of the studied sections, namely, Bawngkawn –Durtlang, Tuirial and Sairang sections are in Aizawl district whereas Kolasib-Rengtekawn section is located in Kolasib district of Mizoram (Fig. 1).Bawngkawn –Durtlang and Kolasib-Rengtekawn sections belong to Middle Bhuban Unit of Bhuban Formation, Surma Group whereas Tuirial and Sairang sections constitute Upper Bhuban unit of Bhuban Formation. Bawngkawn –Durtlang and Kolasib-Rengtekawn section expose 565m and 445m rock succession belonging to Middle Bhuban unit whereas Tuirial and Sairang sections represent 1355m and 460m rock successions of Upper Bhuban Unit of Bhuban Formation.

LITHOSTRATIGRAPHY OF THE STUDIED SECTIONS

The lithostratigraphy of Bawngkawn-Durtlang (BD) and Tuirial sections has already been discussed (Tiwari *et al*., 2007, Malsawma *et al*., 2010 and Badekar *et al*., 2013). We present here the lithostratigraphy of Kolasib-Rengtekawn (KR) and Sairang sections.

Kolasib-Rengtekawn (KR) Section

This section belongs to Middle Bhuban Unit of Bhuban Formation of Surma Group. It shows alternations of fine sandstone, siltstone, shale and mudstone in the lower and middle parts whereas the upper part becomes fine to medium-grained sandstone dominating. The lower part is mainly dominated by the grey-sandstone and siltstone whereas the upper part shows intermixing of grey and yellowish brown (buff) coloured sandstone and yellowish brown (buff) sandstones at places. Overall the grain size increases from fine siltstone to medium grained sandstone with occasional coarse grained sandstone towards the top. The shales are mainly olive green to grey colour with variants of dark grey, light grey to greenish and show gradation from shaly-siltstone to silty-shale. Forty-one sedimentologic units have been delineated in the total exposed thickness of 445m in this section (Fig. 2a).

Sairang Section

This section lies in the western slope of Aizawl city (Fig.1). The 460m thick measured section comprises of shales, siltstones and fine grained sandstones of predominantly grey and Buff at places and become intermediate colored. Nineteen sedimentological units have been delineated in this section. Lower part of the section mainly exposes grey coloured sandstones where as upper part is dominated by buff colored thickly bedded multistoried sandstones. Sandstone becomes calcareous in the middle part. The proportion of sandstone increases towards the top. Cyclicity of sandstone-siltstone alternation is common in the lower part of the section. Unit 10 and 15 of this section have yielded bivalves and echinoid fossils. The shales are grey in color and show splintery characters. The silty-sandstone at times becomes compact and hard containing several calcareous pebbles as in unit 10. The sedimentary structures observed are flaser, lenticular and trough cross beddings which are persistent almost throughout the section. Worm burrows are also observed in many parts of the section(Fig 2b). A calcareous intraformational conglomeratic bed is exposed at 230m level that has yielded selachians, decapods and foraminifers (Victor *et al*., 2011).

MAGNETOSTRATIGRAPHIC RESULTS

Magnetostratigraphic results of Kolasib-Rengtekawn section and Sairang section are presented in this paper as Tiwari *et al*. (2007) and Malsawma *et al*., (2010) have already discussed magnetostratigraphy of the other two sections.

Kolasib-Rengtekawn (KR) Section

The palaeomagnetic samples collected from 25 sites from KR section are all of mudstone to fine siltstone and fine grained sandstone representing a total of 40 litho units. It is observed that the samples from individual stratigraphic horizons within the section behave differently during demagnetization, although the rock magnetic results have shown no major change in the magnetic mineral composition. Therefore we applied the complete demagnetization spectra for all the samples without adopting blanket demagnetization. For a set of sample there is major drop in intensity at 100^0C followed by relatively stable decay up to 400^0C (Fig. 4). The temperature range from 400^0 to 500^0C and 500^0 to 600^0 C have shown plateau like effects for many samples. Almost all the samples have shown a spurious acquisition after 600^0C. The ChRM directions are therefore based on the criteria of the steady decay in the intensity without any major change in vector directions and the magnetic susceptibility. This indicates

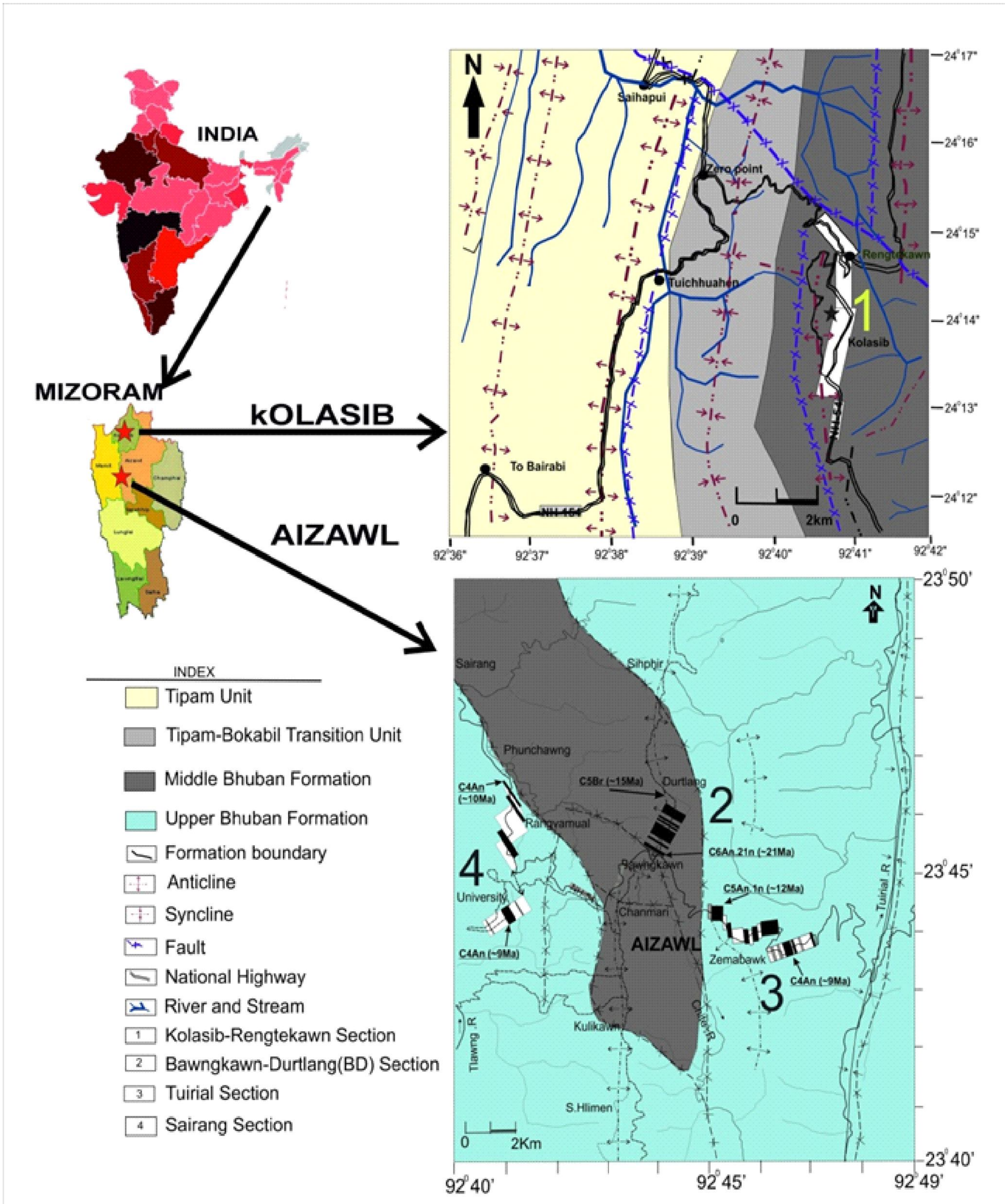


Fig.1. Location map of studied sections in Surma Basin of Mizoram.**1.** Kolasib-Rengtekawn section, **2.** Bawngkawn-Durtlang section, **3.** Tuirial section and **4.**Sairang section.

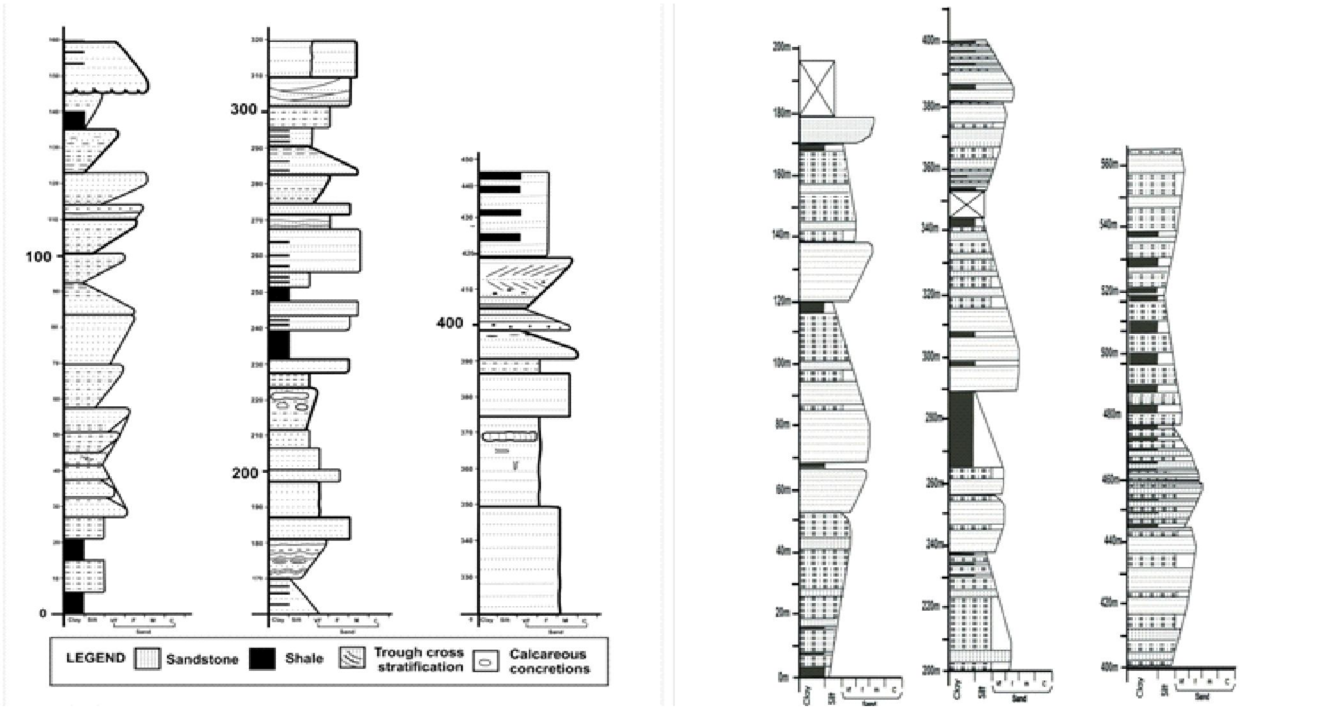


Fig. 2. Lithocolumns of studied sections **(a).** Kolasib-Rengtekawn section and **(b).** Sairang section in Mizoram

a spread of unblocking temperatures from 300^0 - 500^0C for individual samples. The major drop in intensity at 100^0C may be attributed to the presence of viscous component and/or a set of iron oxides like goethite with low Neel temperatures.

Finally, the VGP latitude of each horizon is plotted and correlated with Geomagnetic Polarity Time Scale (GPTS) of Cande and Kent (1995) based upon iterative matching of the local polarity pattern with the GPTS. A total of 3 normal and 4 reverse magneto-zones are obtained for the Kolasib–Rengtekawn section (Fig. 5). These match fairly well with the corresponding magneto-zones available on GPTS. Thus, the GPTS correlated ages of the KR section falls between 17.2 Ma (at the base) to 14.9 Ma (at the top). It estimates a total 2.3 Ma duration for the accumulation of 445 m thick sedimentary pile in this section. The details of the three normal polarity events are tabulated below.

Table. 1. Summary of the magnetic anomaly (normal) intervals (of Cande and Kent, 1995) in the local magnetic polarity of the KR section.

S.N	GPTS Events	Duration(Ma)	Stratigraphic level(m)
1	C5Cn.3n	16.726 - 16.556	180 – 198
2	C5Cn.2n	16.488 - 16.327	210 – 234
3	C5Cn.1n	16.293 – 16.014	242 – 264

The datum plane for matching of the local polarity patterns with the GPTS comes from the mega-invertebrate fossils (Mazumdar, 2004) from calcareous sandstone bed at the stratigraphic level of 220m of this section. This datum plane has been assigned to early Miocene (Burdigalian) which fairly matches well with our MPTS for this section. In magnetic polarity stratigraphy this bed falls in the reversal pattern of GPTS (C5Cn.1n) of 16.293 to 16.014 Ma. The Kolasib-Rengtekawn section can therefore be correlated with the GPTS pattern existing in early Miocene period. This resulted in the identification of GPTS chrons in the section as C5Cr (~ 17.2 Ma) to C5Bn.1r (~ 14.9 Ma).

Sairang Section

Samples were collected from 24 sites from Sairang section. Overall, both the thermal and af demagnetizations have shown good results for this section. Majority of the samples have shown relatively soft secondary component removed at <25mT or <250^0C. Relatively strongsecondary component is seen only in 30-40% of the samples and is demagnetized below 50 mT or 400^0C. The alternating field demagnetization above 70 mT or the thermal demagnetization >400^0C is successful in obtaining the ChRM directions for these samples. Some of the samples

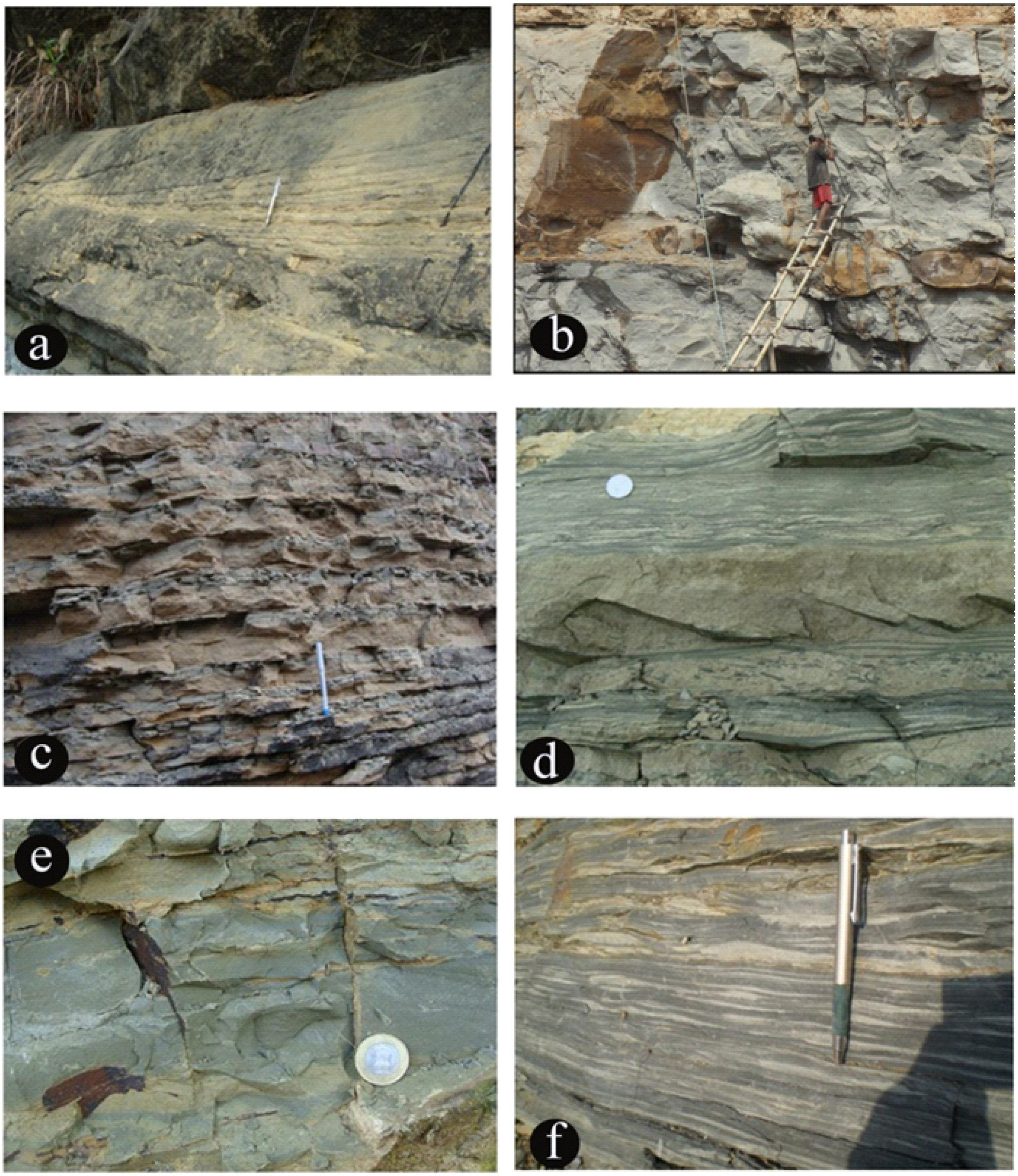


Fig.3. Field photographs. **(a)**. Tidal bundles in Buff sandstone in Tuirial section, **(b)**. Calcareous nodules in sandstone bed in KR section, **(c)**. Buff rippled sandstone in Sairang section, **(d)**. A rock unit showing flaser bedding at the bottom, cross bedded sandstone in the middle and lenticular bedding at the top in BD section, **(e).** Olive green shale at KR section in Kolasib, and **(f)**. Thinly laminated sandstone-shale alternations with parallel lamination in Tuirial section.

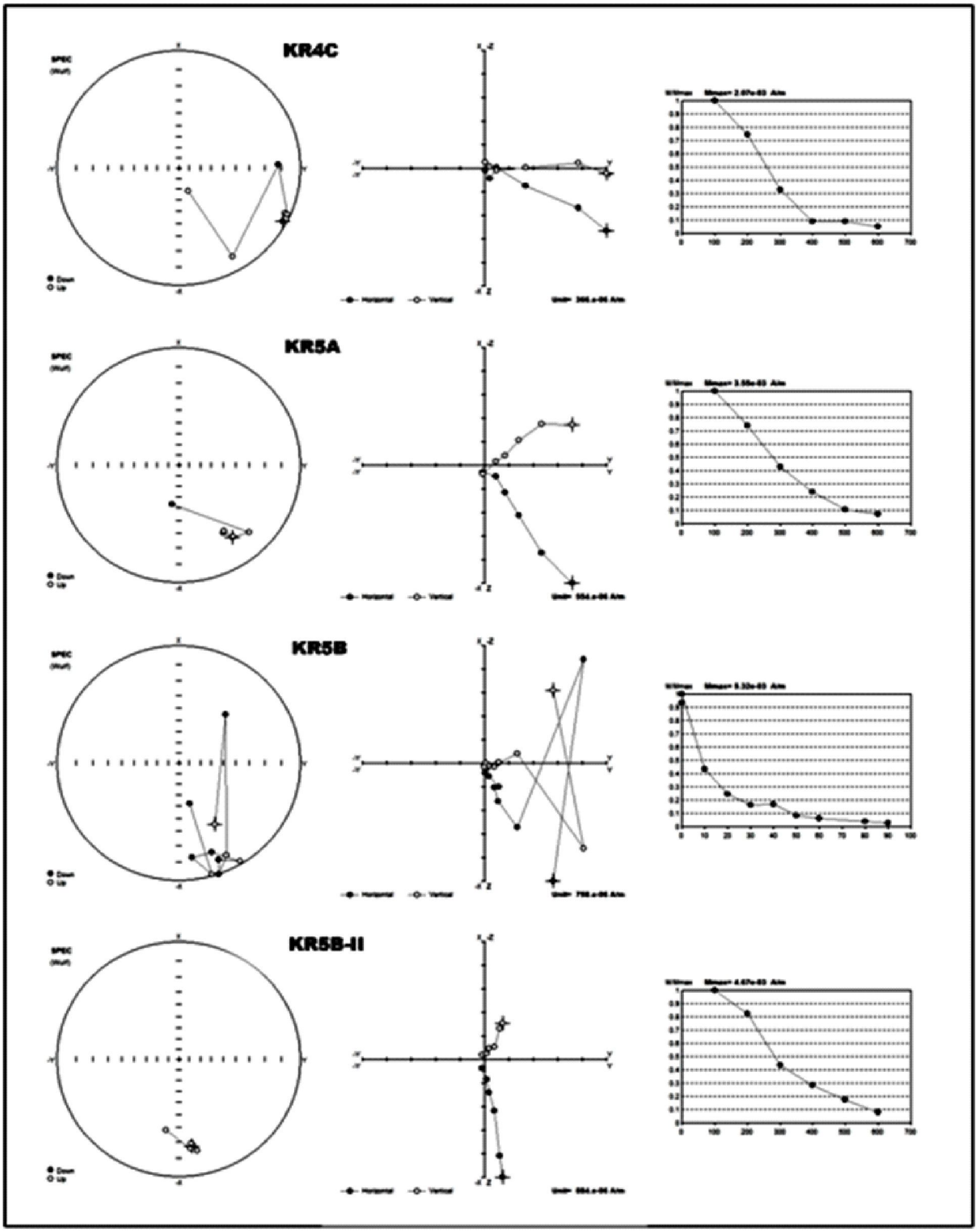


Fig.4. Zijderveld plots and the corresponding intensity decay curves of the representatives samples depicting the vector behaviour during demagnetization of Kolasib-Rengtekawn section.

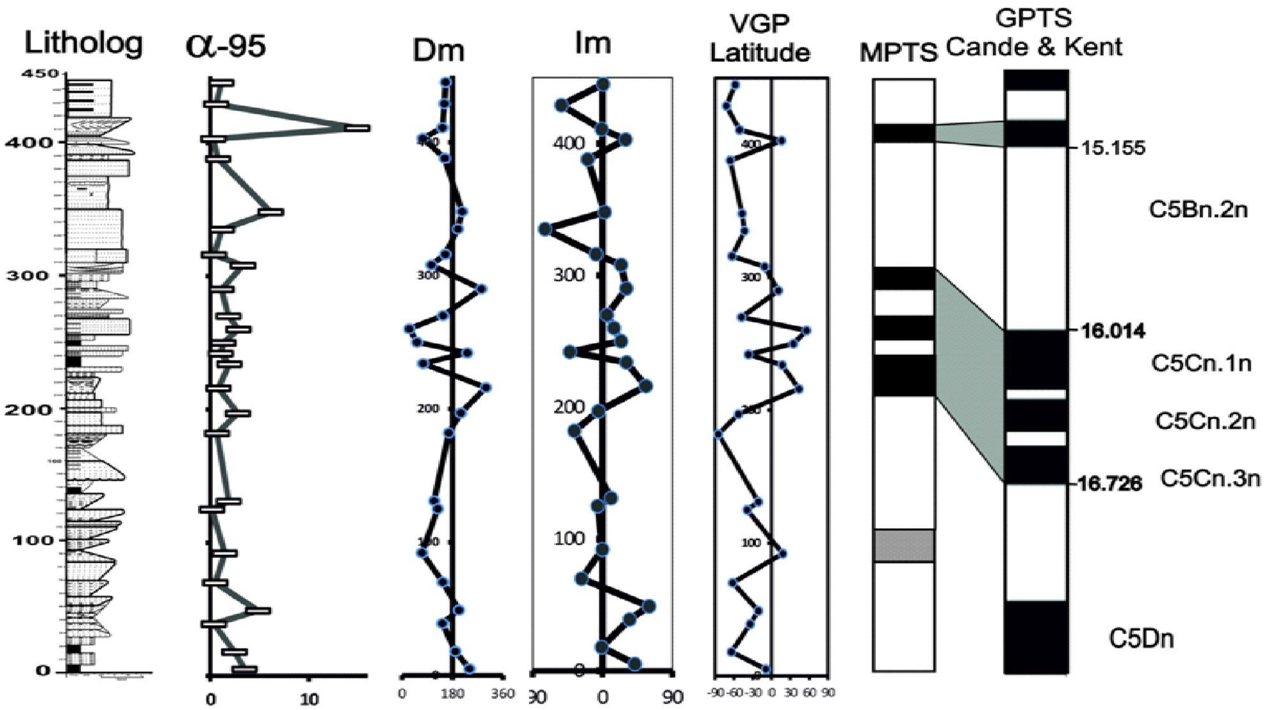


Fig.5. VGP latitudes and magnetic polarity correlation to GPTS (Cande and Kent, 1995) for the Kolasib-Rengtekawn Section, Kolasib.

have shown increase in susceptibilities during 700^{0}C due to incessant heating in the complete spectrum of the thermal demagnetization. The present analysis shows that single or double steps of heating in the range 500^{0}C-600^{0}C with holding times below 25 minutes can give reliable vectors of ChRM nature by cleaning the secondary components. So also the steps 80-90 mT in the af demagnetization can safely reveal the ChRM directions for these samples. The mean directions after tilt correction improve clustering and satisfactory antipodality (within 5%) for the mean normal and reversal. Finally, the VGP latitude for each horizon was plotted against the measured litho-column to reconstruct the local magnetic reversal pattern (Fig. 6).

The positive and negative values for the VGP latitude indicate respective normal and reverse polarity for the recorded geomagnetic fields. These magnetic reversals have been correlated with Geomagnetic Polarity Time Scale (GPTS) of Cande and Kent (1995) based upon matching of the local polarity pattern with the GPTS. The Sairang section contains fossiliferous bed at 230m bearing selachians, decapods and foraminifera which belong to late Miocene age (Victor *et al.*, 2009; 2011). In magnetic polarity this bed falls in the reversal pattern of GPTS (C4Ar.2r; 9.580 - 9.308 Ma). This formed the basis for the correlation MPTS with the GPTS. Rai *et al.*(2014) also recovered a nanno fossil assemblage of early Late Miocene age from this fossiliferous horizon. A total of 4 normal magneto-zones have been obtained for the Sairang section (Fig.7, Table 2). Thus, the GPTS correlated ages of the Sairang section falls between ~9.8 Ma to ~8.3 Ma. It estimates a total of ~1.5 Ma duration for the accumulation of 460m thick sedimentary pile in this section.

Table. 2. Summary of the magnetic anomaly (normal) intervals (of Cande and Kent, 1995) in the local magnetic polarity of the Sairang section.

S.N	GPTS Events	Duration (Ma)	Stratigraphic level (m)
1.	Top of C5.1n	9.740	14
2.	C4Ar.2n	9.580 - 9.642(0.062)	28 – 44
3.	C4Ar.1n	9.230 – 9.308(0.078)	152 – 191
4.	C4.An	8.699 – 9.025(0.326)	309 – 349

SEDIMENT ACCUMULATION RATE

Sediments accumulation rates in cm/ka for the KR section have been estimated from the duration of the events (3 normal and 4 reverse) that are obtained after successful correlation. The average sediment accumulation rate for this section is ~ 21.52 cm/Ka. Overall the SAR is higher at the lower part of the section

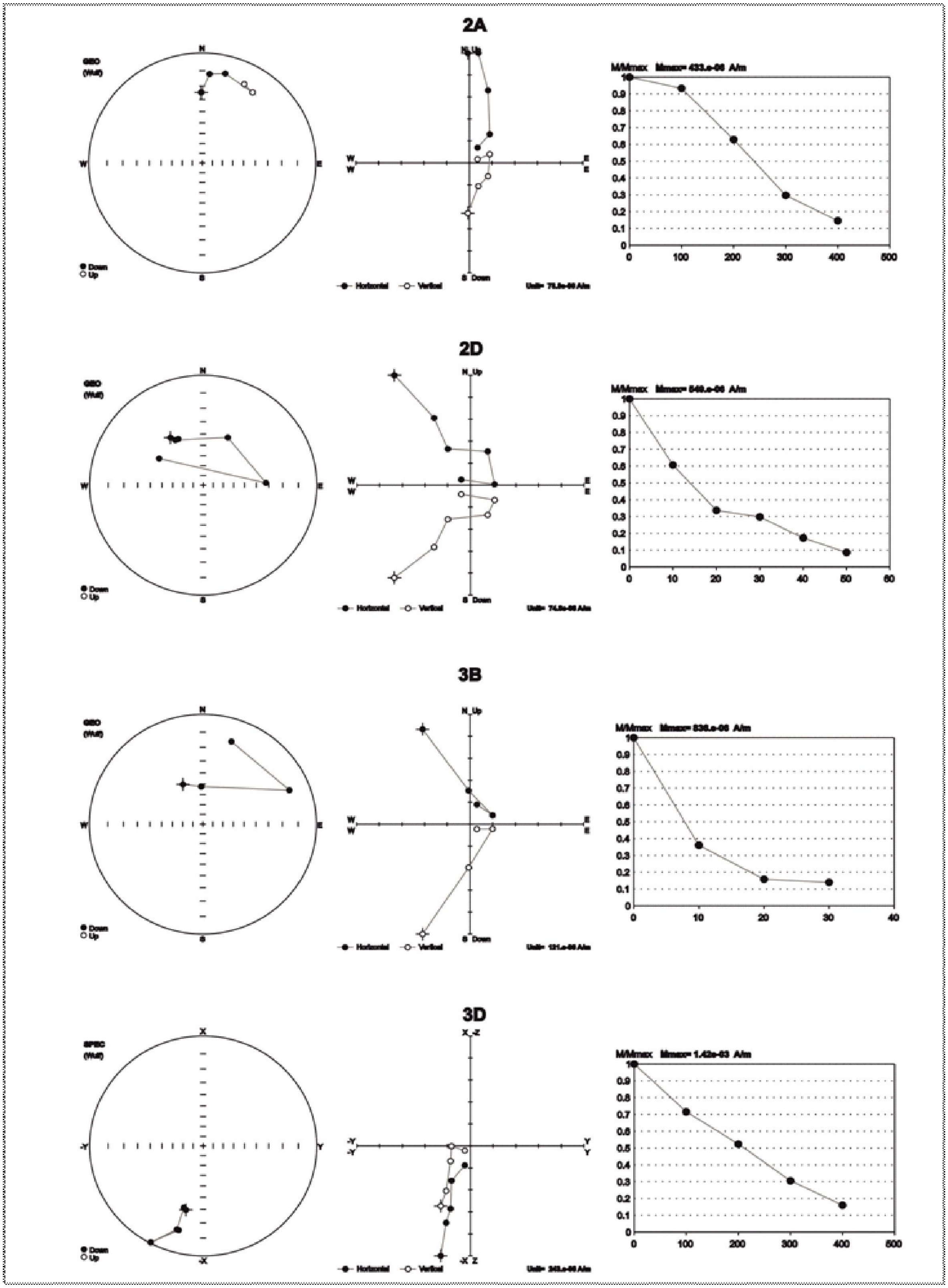


Fig.6. Zijderveld plots and the corresponding intensity decay curves of the representative samples depicting the vector behaviour during demagnetization of Sairang section.

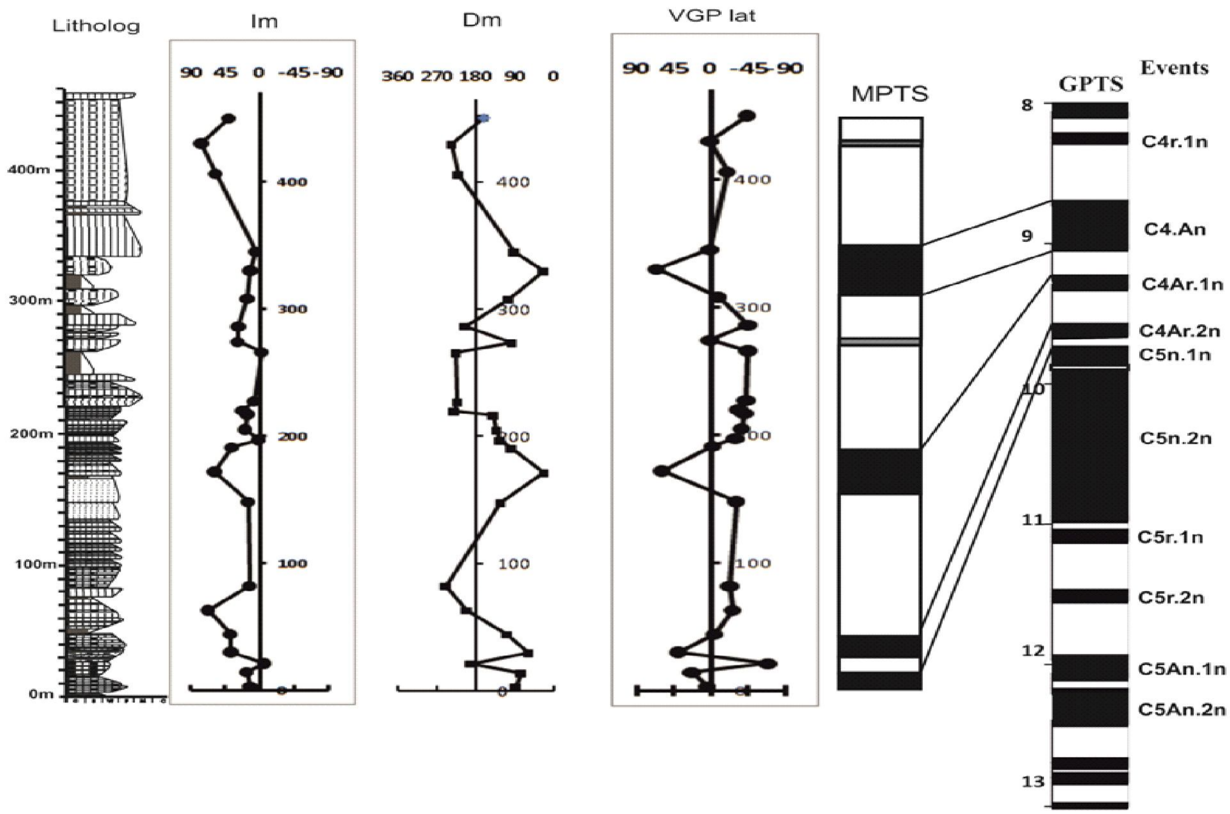
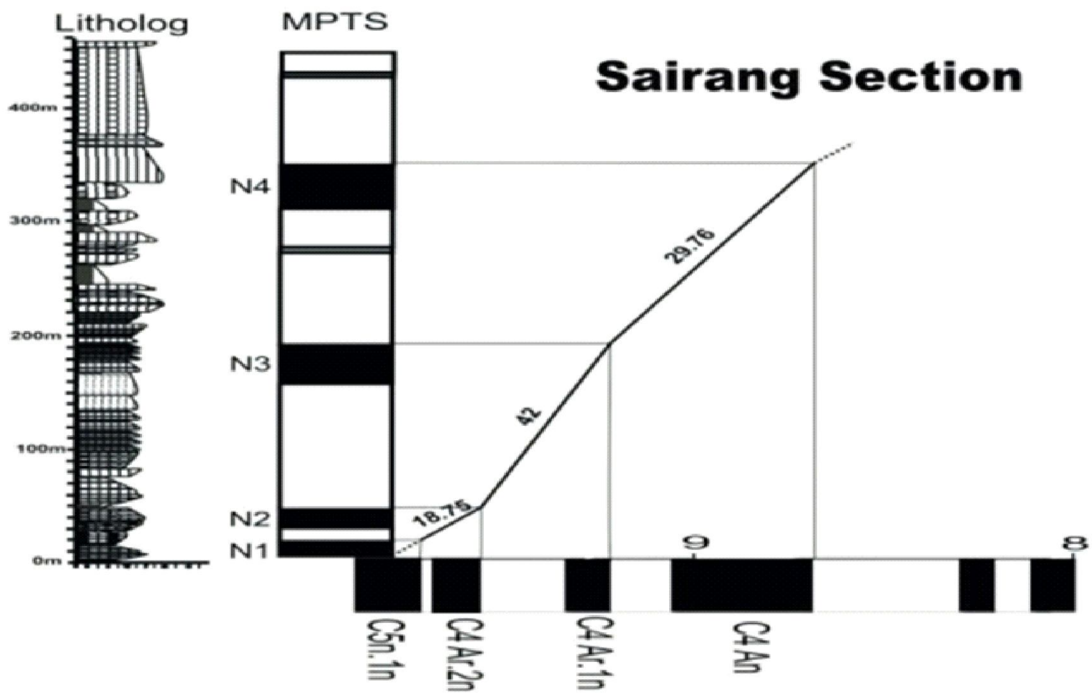


Fig.7. VGP latitudes and magnetic polarity correlation to GPTS (Cande and Kent, 1995) for the Sairang Section, Aizawl.

with a spike of 36.64 cm/ka at <16.7 Ma. There is a drop in SAR (11.18 cm/ka) around 16.2 Ma that gradually reaches to 14.68 cm/ka at around 15.5 Ma (Fig. 8). The SAR for the Sairang section shows variation in the rate of sedimentation from 18 to 42 cm/ka. In the lower part it shows a value of 18.75 cm/ka at around 9.6 Ma and suddenly rises to 42 cm/ka at around ~9.4 Ma and then drops to 29.76 cm/ka. These abrupt changes in SAR demonstrate the changes in facies from the intertidal dominant sequence to massive sand bodies suggesting a major change in depositional environments from shallow marine to pro-delta facies. This facies change is clearly visible in the field also in this section.

CORRELATION

Four magnetostratigraphically constrained isolated sections of Bhuban Formation in the Surma basin of Mizoram, namely, Kolasib-Rengtekawn sections in Kolasib district; and Bawngkawn–Durtlang; Tuirial and Sairang sections in Aizawl district are taken in to account for regional correlation (Fig 9). Out of the above, the first two belong to Middle Bhuban Unit and the last two to the Upper Bhuban Unit of Bhuban Formation, Surma Group. Three normal magneto-zones have been obtained in the Kolasib–Rengtekawn section (Fig. 5, Table 1).These are C5Cn3n (16.726-16.556), C5Cn.2n (16.488-16.327) and C5Cn.1n (16.293-16.014). The GPTS correlated ages of the KR section falls between ~17.2 Ma (at the base) to ~14.9 Ma (at the top). Thus a total 2.3 Ma duration is estimated for the accumulation of 445 m thick sedimentary pile in this section. Seven normal magentozones have been obtained for BD section; GPTS correlated age is ~21.77-~15.16 Ma and ~6.6 Ma was required for deposition of 560m sediment in this section (Tiwari *et al*, 2007). The youngest normal magnetozones of BD section i. e. C5Cn magnetozone (16.726-16.014 Ma) has also been delineated in the KR section. Thus KR section may be correlated with the upper part of BD section. Rate of sedimentation also matches fairly well in both the sections. Four normal magneto-zones have been obtained for the Sairang section (Fig.7, Table 2). The GPTS correlated ages of the Sairang section falls between ~9.8 Ma to ~8.3 Ma. It estimates a total of ~1.5 Ma duration for the accumulation of 460m thick sedimentary pile in this section. Seven normal magnetozones have been obtained for the Tuirial section



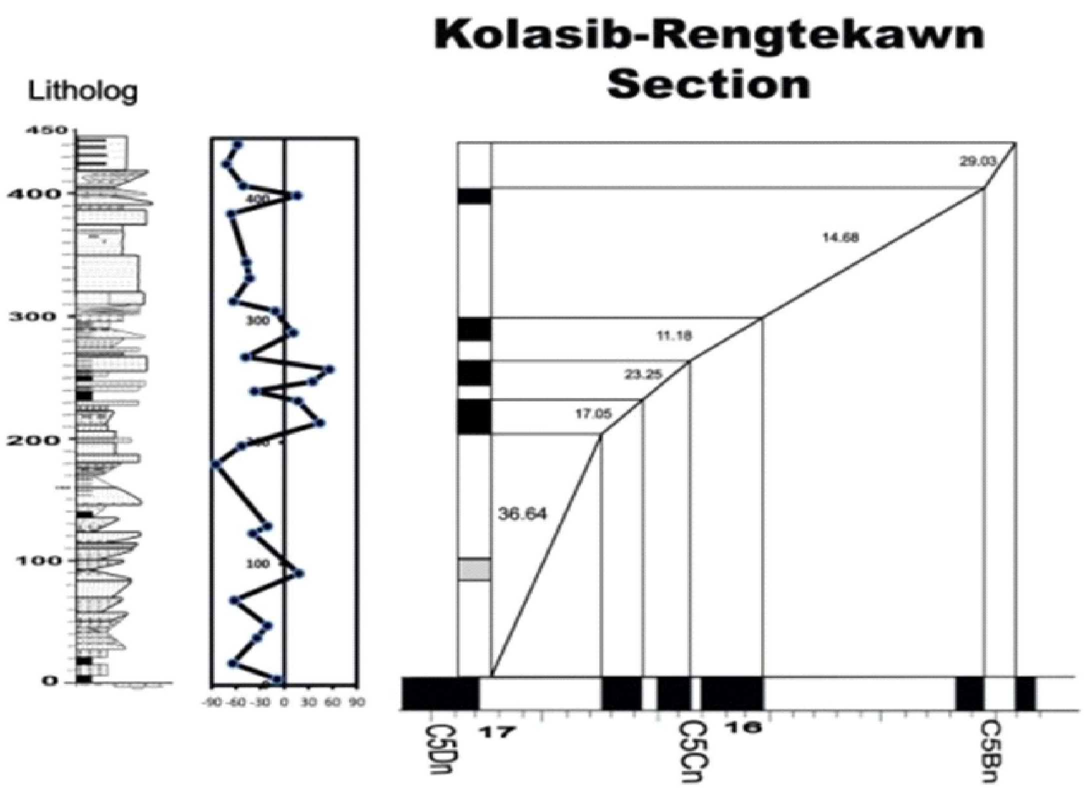


Fig. 8. Estimated rate of sedimentation in the Kolasib-Regtekawn Section (Upper Bhuban Unit) and Kolasib-Rengtekawn Section (Middle Bhuban Unit), Bhuban Formation, Surma Group. Numbers shown in the curve are rates in cm/ka.

with GPTS correlated ages between ~12.5 Ma (at the base) to ~8 Ma (at the top). Thus 4.5 Ma was needed to deposit 460 m thick succession in this section (Malsawma *et al.*, 2011). Three younger magnetozones, namely, C4 An (9.025 - 8.699 Ma), C4Ar.1n (9.308 - 9.230 Ma) and C4Ar.2n (9.642 - 9.580 Ma) of Tuirial section have also been delineated in the Sairang section. As such Sairang section is correlatable with the upper part of the Tuirial section. This implies that KR and BD sections are magnetostratigraphically older than the Tuirial and Sairang sections which holds true lithostratigraphically also. Rate of sedimentation is also matching well in both the sections. Besides, similar increase in rate of sedimentation has been noticed in the Tuirial and Sairang sections representing facies change from the turbidite dominant sequence to massive sand bodies suggesting a major change in depositional environments from shallow marine to pro-delta facies. Thus, magnetostratigraphy may emerge as the reliable tool for correlation of isolated successions of varied stratigraphic units of Tertiary period in the Surma basin.

CONCLUSIONS

Four magnetostratigraphically constrained isolated sections have been successfully correlated in this study. This shows the potential of magnetostratigraphy in stratigraphic classification and regional correlation of Miocene succession of the Surma basin. Surma succession is poor in foraminifers and nanno-planktons and biostratigraphic attempts based on mega-biota have not contributed significantly to resolve the stratigraphic and correlation issues that are confronted in the sedimentary succession of Surma basin. As such high resolution stratigraphy of the Surma basin is yet to be worked out. The data generated through previous studies on these aspects are too meagre to arrive at any tenable conclusion. A detailed work on basin-wide reconstruction of lithofacies and their relation to Himalayan tectono-climatic aspects are warranted. Also an integrated study of litho-, bio- and magneto-stratigraphy along with sedimentology is suggested in order to reconstruct the tectono-depositional history of the basin and biotic evolution in it.

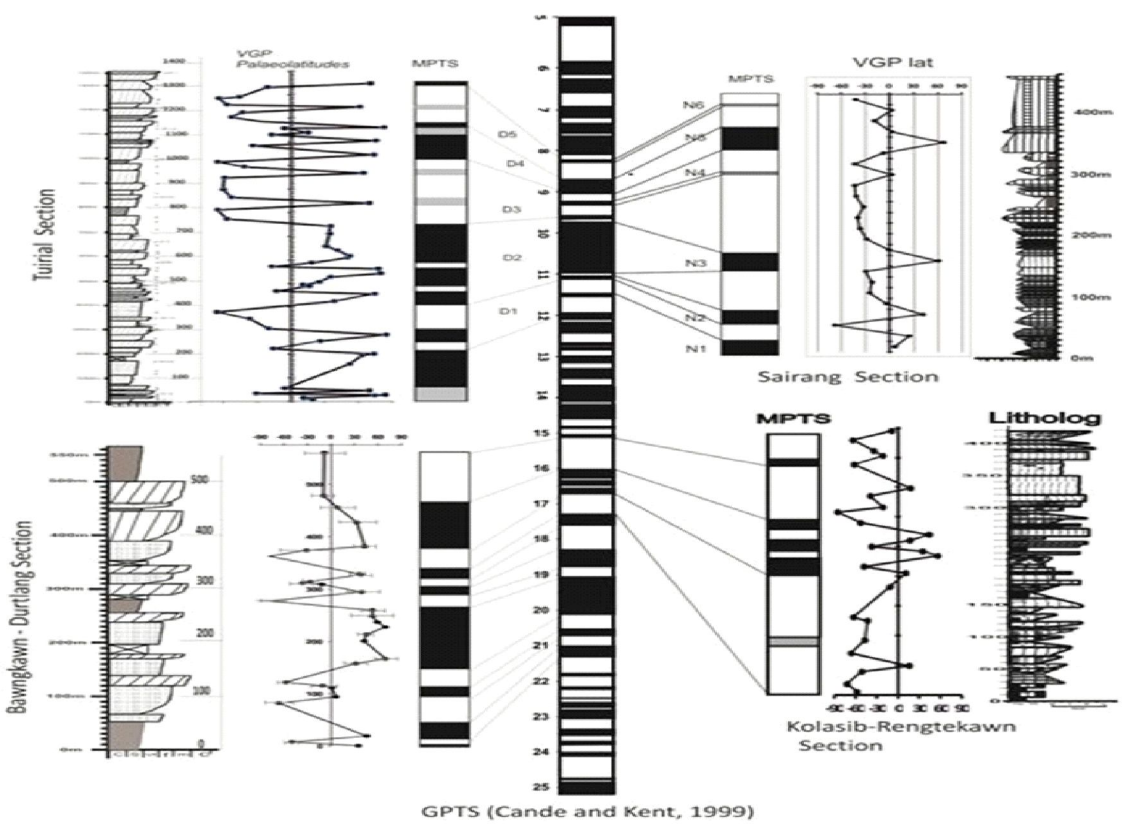


Fig.9. Regional correlation of the four studied sections in the Surma Basin of Mizoram with Global Polarity Time Scale.

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