CHAPTER 8: AGGRADATION HISTORY AND DEPOSITIONAL MODEL FOR UCHEDIYA SURFACE

"A disciple of the sage Bhruga, from whose name the present Broch is said to be corrupted, one day, complaining to him of the distance he had to go to wash his cloths, was told that his grievance would be at an end if, the next time he went to wash, he on his way home, dragged his clothes after him and did not look behind him. The advice was followed, and the man, on turning round to look, when he reached his own door, found that the river flowed at his feet instead of Ankaleswar"

Bombay Presidency Gazetteer (1877-1905, p.342)

8.1 Integration of Multi-proxy Records

Lower reaches of Narmada Valley preserves an assemblage of landforms belonging to broader age bracket providing an opportunity for a researcher to comprehend continental response over a range of climatic phases. The channel of River Narmada in its lower reaches, further gives a wisdom to build up step wise segmental changes, which otherwise is a multifarious. The river segment under present study is identified as a sandy segment that preserves evidence for both landform accretion and erosion. The study area is noteworthy for having Archaeological importance (Bharuch mount: Desai, 1993, a Fort wall – built during year AD 1094 to 1143, tenure of Hon. Sidh Raj Jaisinhji of Anhilwara), Historical important constructions (Golden bridge -build during British rule-Preliminary work started from 1864 followed by construction phase from December 1877 and was completed in May 1881), historical documents for human response to undergoing changes in the river channel (Bombay Presidency Gazetteer) and meteorological record (from Garudeshwar station: 1948 to 2009) (Section 1.4).

The proposed aggradation model of QS_2 for past 500 years is based on high resolution multi-proxy record generated from sandy muddy sequence representing QS_2 (Uchediya surface), meteorological records, historical documentations and observations on present channel.

The illustrative sequence of Uchediya surface (QS_2) is analysed at high resolution for sedimentology and magnetic studies supported by geochemistry and microfaunal studies on representative samples. High resolution granulometric records were further used to calculate various sedimentological parameters that capture depositional environments, palaeohydrological conditions and change in both with time. The high resolution magnetic records were further used to calculate mass specific susceptibility (χ_{lf}) and SIRM that capture relationship with mean grain size. Ferrimagnetic Mineral Concentration was fractionated from bulk sample.

The trend analysis within and across multi-proxy records provide a rationale in developing multi-proxy aggradation model. The sandy muddy intercalated Uchediya sequence is further subdivided into seven subfacies based on high resolution granulometric record (Chapter 5). Various sedimentological parameters Mean (ϕ), Sorting (σ_I), Skewness (Sk_I) and Kurtosis (K_G) were worth to distinguish 7 lithounits along distinctive depths (Section 5.4.2).

The plots of Mean (ϕ) verses FMC shows three distinct clusters (Figure 8-). Cluster -I comprises of lithounits 2, 4 and 7 dominated in muddy facies, the cluster-II comprises of lithounits 3, 5 and 6 and the cluster-III comprises of lithunits 1, 3, 5 and 6 are dominated by sandy facies. The plot further suggests lithounit 5 has association with lithounit 6 suggesting same depositional site if not similar sub facies, however lithounit 6 shows wide scatter.

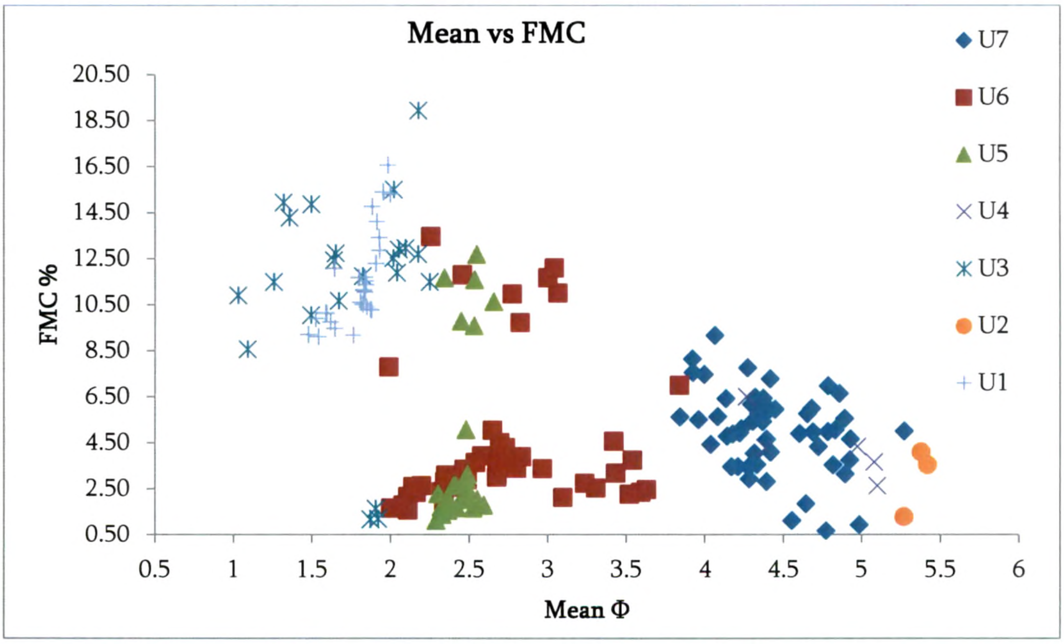
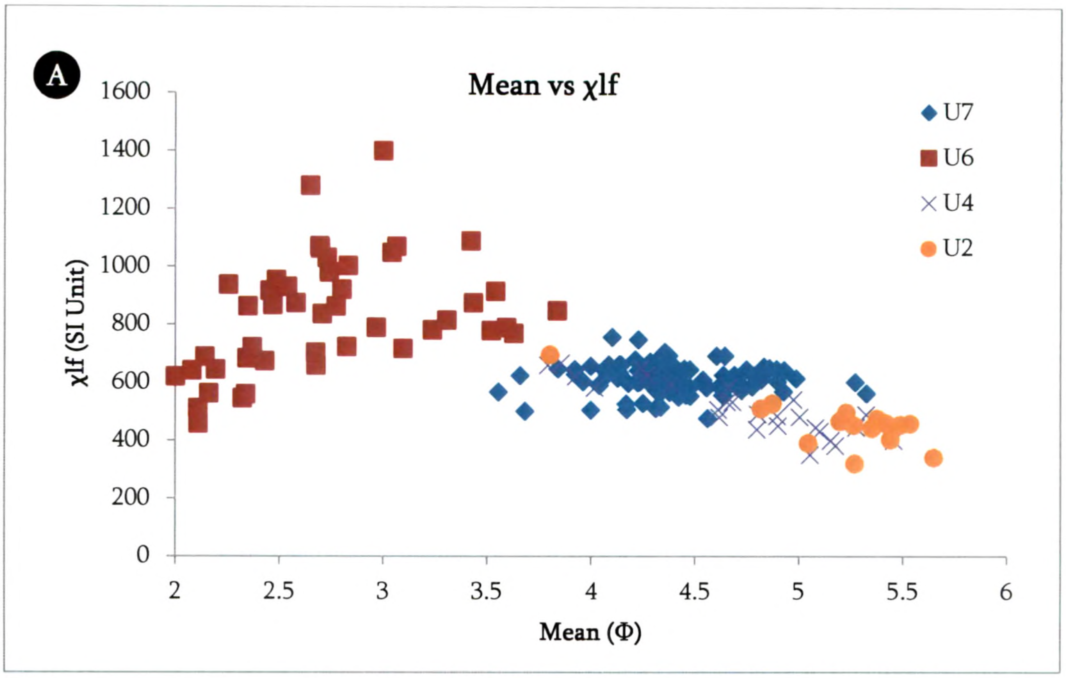


Figure 8-: Bivarient plot of Mean grain Size verses Ferrimagnetic mineral weight percentage



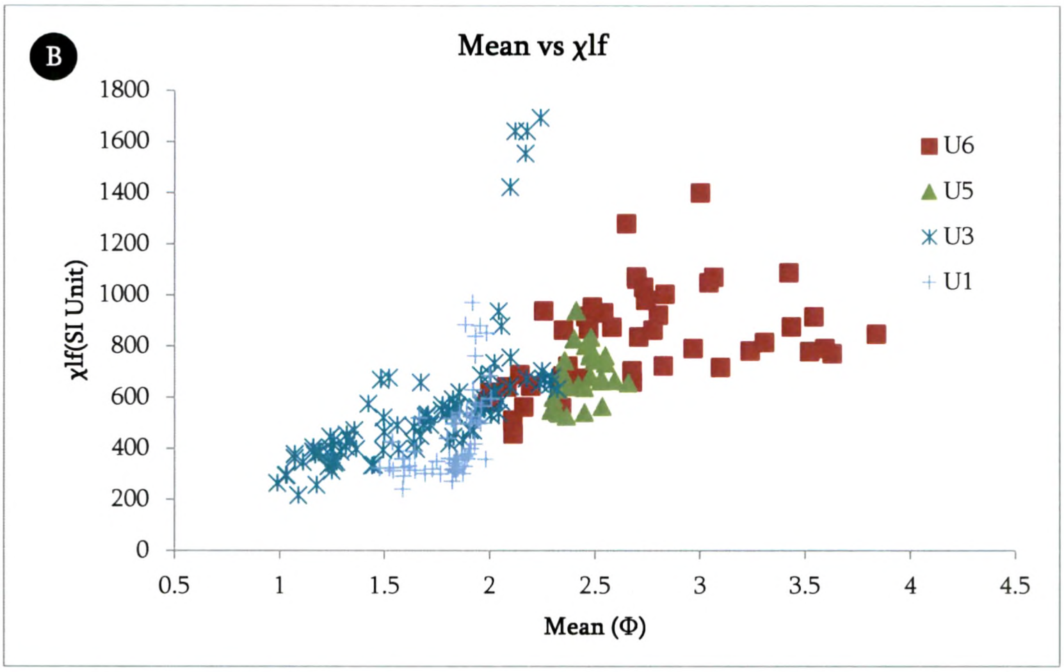


Figure 8-: Bivarient plots of Mean grains size verses χ_{lf}

The plots of Mean (ϕ) vs magnetic susceptibility (χ_{lf}) shows two clear trends within sandy and muddy facies. The values of χ_{lf} increases with decrease in grain size within lithounits 2, 4 and 7 dominated by muddy facies (Figure 8-A), whereas the values of χ_{lf} increases with increase in grain size within the lithounits 1,3 and 5 dominating in sandy facies (Figure 8-B) . However the lithounit 6 that comprises all the sediment subfacies other than St_{MS+CS} follows a scatter. The lithounit 6 therefore indicate major transition phase during aggradation of QS_1.

The plots of FMC vs SIRM show two distinct trends within muddy facies and sandy facies (Figure 8-). The values of SIRM increases with increase in FMC along lithounits 1,3,5, and 6 that dominates sandy facies, suggest that SIRM are associated with grain size of FMC and magnetic saturation attained by magnetic minerals is attained over a long period of time within sandy facies. The values of SIRM flatten with increase in FMC in the muddy facies where magnetic saturation is attaining in short time within finer facies.

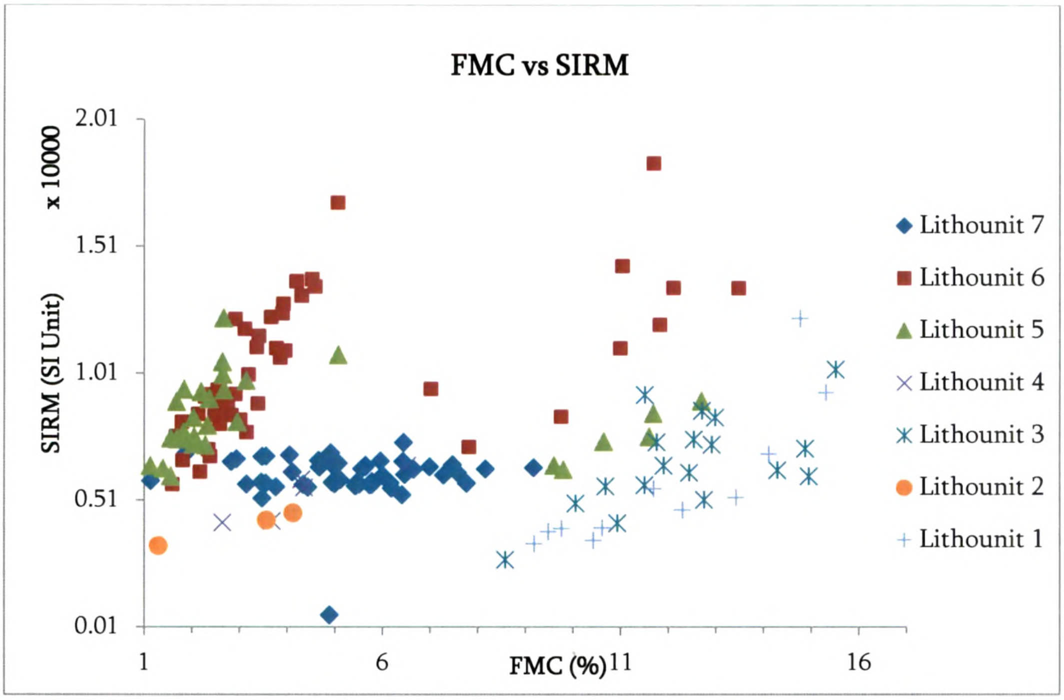


Figure 8-: Bivarient plot of Ferrimannetic mineral concentration and SIRM

The plots of Magnetic Susceptibility (χ_{lf}) vs Fe_2O_3 + TiO_2 (Figure 8-) show a linear trend, where, χ_{lf} increases with Fe_2O_3 + TiO_2, suggesting titanomagnetite as a major mineral for increase in χ_{lf}. The plots of Magnetic Susceptibility (χ_{lf}) vs CaO + Na_2O (Figure 8-) follows that same imprint with a difference made by decrease in CaO + Na_2O of lithounit 7. The higher values of Fe_2O_3 + TiO_2 for lithounit 7 suggest role of diagenesis in lithounit 7 that caps the sequence.

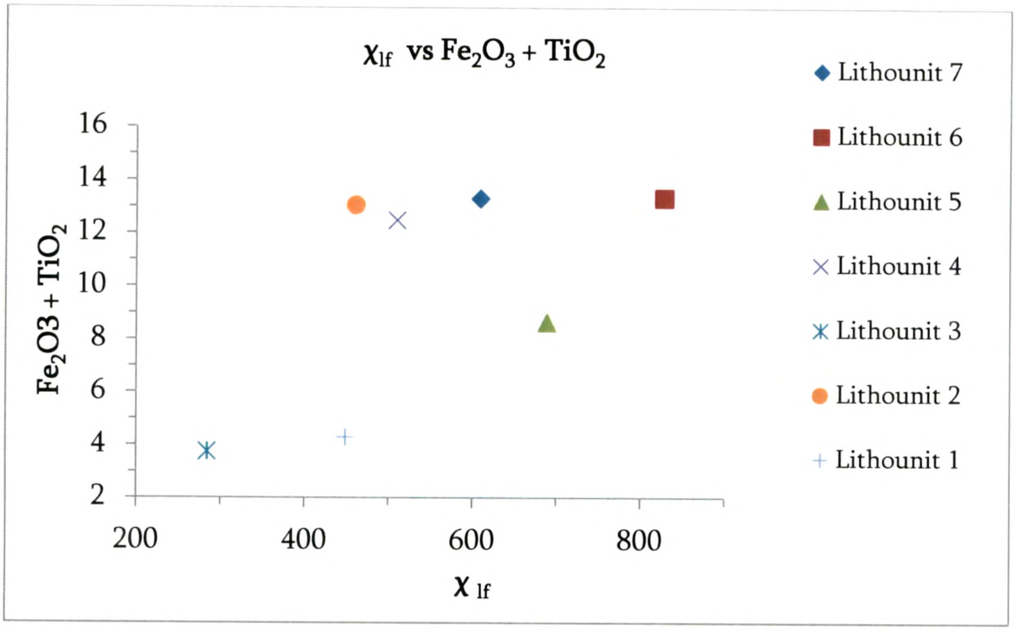


Figure 8-: Bivarient plots of χ_{lf} vs Fe_2O_3 + TiO_2

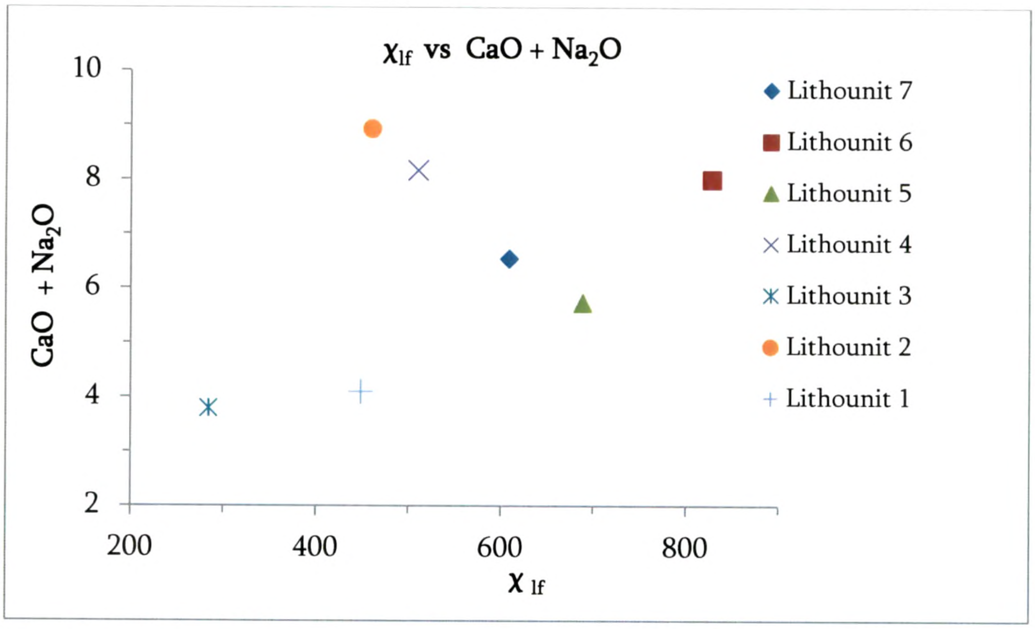


Figure 8-: Bivarient plots of χlf vs CaO + Na_2O

8.2 Depositional Environment

Each lithounit is distinguished by subfacies, magnetic character, FMC and major element geochemistry. The two muddy lithounits viz., lithounit 2 and lithounit 4 were examined for microfaunal studies (Chapter-6). The multi-proxy records generated further assist to derive at depositional environments viz., 1. Channel deposits 2. Channel margin Deposits (CD), 3. Transitional Deposits (TrD), 4. Over bank Deposits (OBD), and 5. Catastrophic Monsoonal Storm with Coastal Upwelling Deposits (CMS_CU).

8.2.1 Channel Deposit

The Channel Deposit (CD) is characterized by sandy facies having an overall average mean grain size range between 1.68Φ and 1.81Φ. The sandy facies are further classified into three subfacies viz., Sm_{FS+MS} subfacies, $St_{MS+FS+CS}$ subfacies and St_{MS+CS} showing well to moderately well sorting. The sandy subfacies aggrades in couplets namely, $St_{MS+FS+CS}$ subfacies and Sm_{FS+MS} subfacies (thin couplets) and $St_{MS+FS+CS}$ subfacies and St_{MS+CS} subfaices (30 cm to 60 cm thick couplet). The overall average values of FMC and χlf of the sandy facies are 11.5 wt % (high) and 448 to 563 SI respectively. At Uchediya sequence CD is well exposed along the base (114 cm thick: lithounit1) and between 152 cm and 342 cm (190 cm thick: lithounit 3). These sediment characteristics single out sandy facies as rapidly aggraded facies under high energy condition within channel. The occasional occurrence of basalt pebbles within the sandy facies further suggests sediment source in immediate upstream within the sandy channel. The suite analysis (Figure 5-) suggests that both lithounits 1 and 3 were deposited at a lower level along the channel. The sandy deposits are therefore depicted as rapid aggradation, resultant rapid sand movement within the channel during adjustment of thalweg line. Similar activities are observed within present Narmada channel at about decadal scale.

8.2.2 Channel Margin Deposits

The Channel Margin Deposit (CMD) is also characterized by sandy facies having an overall average mean grain size of 2.44 Φ. The sandy facies are well sorted and classified as Sl_{FS+VFS} subfacies. The Sl_{FS+VFS} subfacies aggrades as a single unit. The overall average FMC and χ_{lf} of the sandy facies are 3.9 wt % and 689 SI respectively. Lower variation in magnetic characteristics suggests shift in the source from CD to relative distal portion within active channel. At Uchediya sequence, CMD is exposed between 418 cm and 492 cm (74 cm thick; lithounit 5). The sediment characteristic and suite analysis (Figure 5-5 and 5-6) indicates that the Sl_{FS+VFS} subfacies aggraded in phases under relatively calm conditions away from the thalweg line along channel margins resulting a laminated sequence. The aggradation of these facies takes place under bank full conditions.

8.2.3 Transitional Deposits

The Transitional Deposits (TrD) are characterized by sandy facies having an overall average mean grain size of 2.72 Φ. The sandy facies are further classified into five subfacies $Fm_{SILT+VFS}$ subfacies, $Fm_{SILT+VFS+FS}$ subfacies, Sl_{FS+VFS} subfacies, Sm_{FS+MS} subfacies, and $St_{MS+FS+CS}$ subfacies showing moderate sorting. The sandy subfacies aggrades in intercalations of subfacies inconsistently. The overall thickness of subfacies varies from 6 cm to 12 cm attaining minimum 2 cm and maximum 20 cm in thickness. The overall average FMC and χlf of the sandy facies is 4.54 wt % and 828 SI respectively. At Uchediya sequence TrD is well exposed between 494 cm and 600 cm (106 cm thick: lithounit 6). In consistency in couplets of subfacies and their thickness suggest short events of variable energy condition during the aggradation. The suite analysis suggests overall deposition is at lower level showing variability. The aggradation of such assemblage of subfacies would occur above eroding channel margins during shift of the thalweg line towards the channel margin.

8.2.4 Overbank Deposit

The Overbank Deposits (OBD) is characterized by silty facies having an overall average mean grain size of 4.39 Φ. The silty facies are further classified into two subfacies namely, $Fm_{SILT+VFS}$ subfacies and $FmSILT_{+VFS+FS}$ subfacies, showing poor sorting. The silty subfacies aggrades in intercalations. The overall thickness of subfacies varies from 2 cm to 8 cm attaining minimum 2 cm and maximum 36 cm in thickness. Average ferrimagnetic mineral percentage and Xlf of the silty facies are 5.05 wt % and 609 SI respectively. At Uchediya sequence, OBD is well exposed between 602 cm and 802 cm (200 cm thick: lithounit 7). Consistency of subfacies couplets with variable thickness suggests repeated occurrence of short as well moderate events under influence of flood condition. The suite analysis suggests deposition occurred at higher elevation. The sediments aggrade when water flows over the channel margin. Such a process records overall growth in channel banks. These deposits preserve historical flooding events.

8.2.5 Catastrophic Monsoonal Storm with Coastal Upwelling Deposits

The Catastrophic Monsoonal Storm with Coastal Upwelling Deposits (CMS_CU) are characterized by silty facies having an overall average mean grain size of 5.28 -4.72 Φ. The silty facies are further classified into two subfacies namely, $Fm_{SILT+VFS}$ (T) subfacies and $Fm_{SILT+VFS+FS}$ subfacies, showing poor sorting. The silty subfacies aggrade both as single facies ($Fm_{SILT+VFS}$ (T) subfacies: 30 cm thickness) as well as with intercalation of $Fm_{SILT+VFS+FS}$ subfacies (2 cm to 4cm thickness) within $Fm_{SILT+VFS}$ (T) subfacies. Overall, the average ferrimagnetic mineral percentage and X_{lf} of the silty facies ranges from 3 to 4.30 wt % and 444 to 510 SI respectively. At Uchediya sequence, CMS_CU deposit is exposed at two levels between 116 cm and 150 cm (single $Fm_{SILT+VFS}$ (T) subfacies: 34 cm thick: lithounit 2) and 344 cm and 416 cm (intercalation of $Fm_{SILT+VFS}$ (T) and $Fm_{SILT+VFS+FS}$ subfacies: 72 cm: lithounit 4). The most significant aspect of $Fm_{SILT+VFS}$ of CMS_CU deposit is the presence of benthic and planktonic microfossils compared to

$Fm_{SILT+VFS}$ of OBD. The suite analysis suggests CMS_CU deposits got accreted at higher elevation over the channel deposits under catastrophic storm condition resulting in tidal upwelling and influx of tidal water. Similar events arise from Arabian Sea and extend inland in majority of cases during erratic pre monsoon and monsoon time.

8.3 Model for Aggradation History of Late Holocene Flood plain

The OSL chronology [three OSL dates: 495 ± 60 years before 2009 (Year 1514 AD: 0-2cm), 515 ± 40 years before 2009 (Year 1492 AD: 600-602 cm) and 130 ± 30 years old (Year 1879 AD: 750-752cm)]. The laboratory has opined that the aggradation sediments from base up to 600 cm from base be deposited within relatively a very short time span (not more than 100 years) suggesting significant land-forming activity which took place in the 15^{th} century AD and at the onset of the 16^{th} century AD. The global climatic records identify this period under influence of Little Ice Age (LIA), where monsoon became erratic and weak. The onset of the Little Ice Age in the higher latitudes in the Northern hemisphere dates to the early 14th century A.D with relatively delayed response in lower latitudes (Grove, 1988; Wang et al., 2005).

The historical records on the Fort wall built on the right bank of Narmada at Bharuch city advocate that construction of the Fort Wall was done during the tenure of Hon. Sidh Raj Jaisinhji of Anhilwara during 1094 AD to 1143 AD (Bombay Presidency Gazetteer, 1877-1950, page 551). A primary objective for building the Fort Wall was to protect city from floods and prevent erosion of land. The time span (1094 AD to 1143 AD) on global climatic records evoke for Medieval Warm Epoch (Crowley, 2000; Crowley and Lowery, 2000; Cronin et al., 2003; Yamada et al., 2010). The Narmada channel during this time phase flowed along both the banks throughout the year which made Hon. Sidh Raj Jaisinhji of Anhilwara feel the necessity of building the Fort wall. The Bombay Presidency

Gazetteer, 1877-1950 further records strengthening and rebuilding of the Fort wall during 1526 to 1536, in the tenure of Hon. Bahadur Shah. The record hints at prior to 1526 (onset of 16th Century), the Fort wall was badly damaged. The cause of destruction could be possibly none other than catastrophic flooding in the Narmada River at the onset of 16th Century. The strengthening and rebuilding of the Fort Wall therefore imply change in the river dynamics under the influence of climate transformation from Medieval Warm Epoch to Little Ice Age, leading to increase in uncertainty.

The sedimentological and chronological records on Uchediya sequence suggest that channel deposits exposed at the base of the sequence (0-114 cm) got initiated to accrete during the onset of 16th Century (Year 1514 AD OSL date), advocating for large scale sand movement within the channel under high energy condition. The coarse sandy facies with occasional presence of basalt pebbles suggests source in the immediate upstream within channel. During this phase, the River was on its way to adjust the thalweg line, scour the floor of the channel in upstream and to deposit the sandy facies further downstream.

The CD is further overlaid by CMS_CU deposits (116 cm to 150 cm). These deposits are characterized by sedimentology, magnetics and microfossil assemblage records. During CMS_CU arises from Arabian Sea dynamics, upwelling the coastal waters and raise of High Water Line leading to inlet of tidal flux inland the Narmada channel for a short time span. The evidence of CMS_CU deposits suggests erratic behaviour of southwest Indian Monsoon.

The CMS_CU deposits were preserved as a result of rapid deposits of CD inland (152 cm to 342 cm). The unique feature with this sediment unit is that sediment facies gradually increase from finer sandy facies to coarser sandy facies, reach the peak followed by gradual decrease in sediment facies from coarser sandy facies to finer sandy facies, capturing increase and decrease in overall movement of sand within the channel. The event further justifies partial stabilization of a bar.

The CD is further overlaid by second event of CMS_CU deposits (344 cm to 416 cm). The second event of CMS_CU deposits further justifies erratic southwest Indian monsoon in epoch of Little Ice Age (Figure 8-).

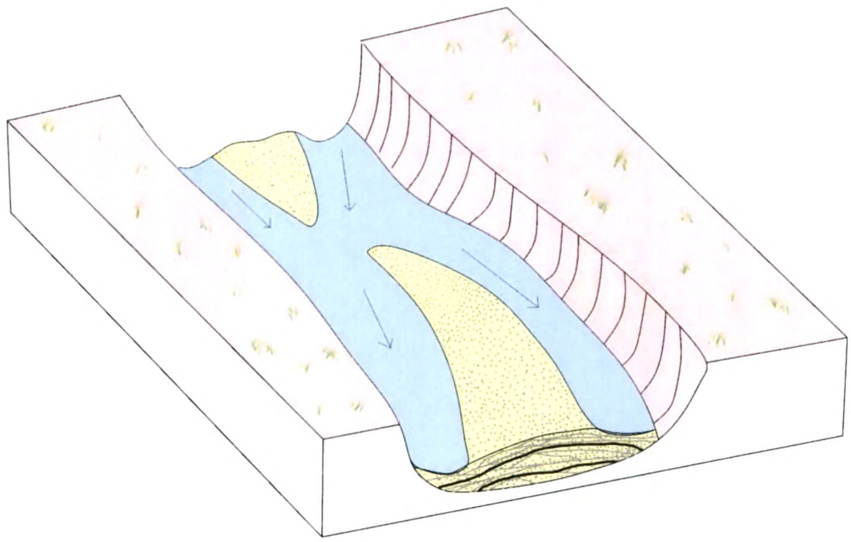


Figure 8-: Stabilisation of channel bar preserves CMS_CU deposit within CD.

The CMS_CU deposits are preserved as a result of rapid deposition of CMD (418 cm to 492 cm). The CMD is characterized by sedimentological records. CMD facies records continuation of high energy condition and state of floods in the river channel. During this phase, the thalweg line has shifted north, away from the discussed site of aggrading sediment facies (Figure 8-).

The CMD are overlaid by TrD (494 cm to 600 cm). The TrD facies are characterized by sedimentological, magnetic and ferrimangnetic mineral percentage records. The unique feature with this sediment unit is that, it incorporates thin beds of verity of sediment facies except St_{MS+CS} (recorded only in second CD). The heterogeneity in the sediment facies captures rapid variation in energy condition during short time span and on-going shift in thalweg line to the south eroding the aggraded bar.

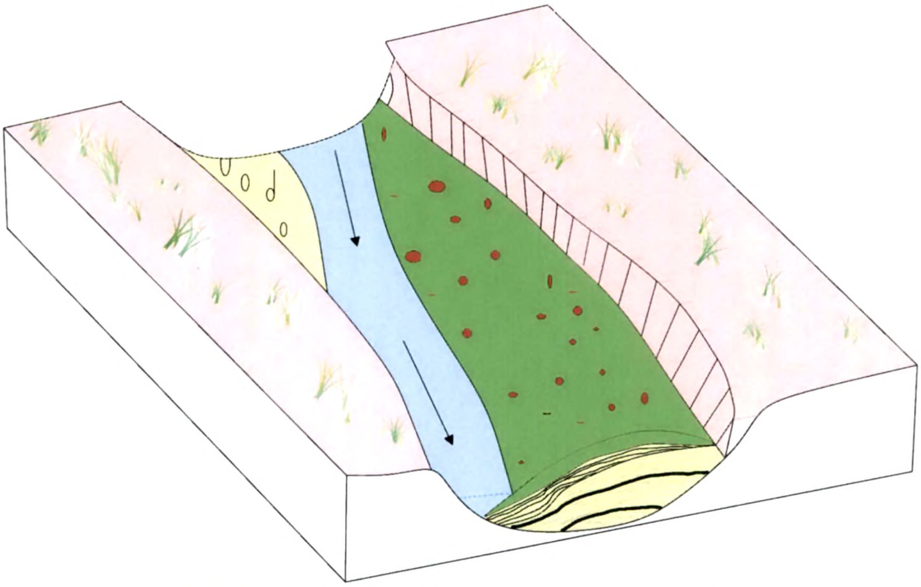


Figure 8-: Northward shifting of thalweg line and aggradation of bar. CMD & TrD accreated along River bank.

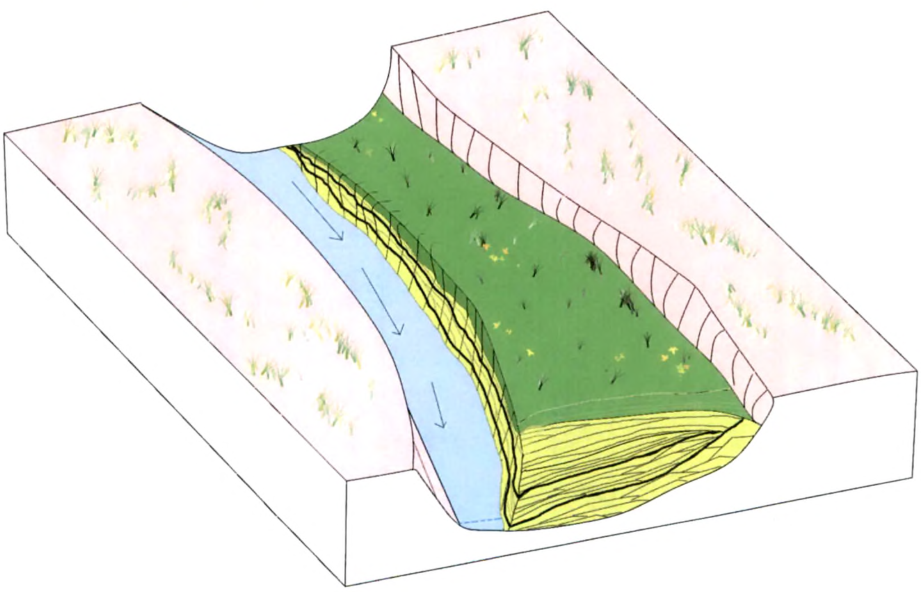


Figure 8-: Aggradetion of OBD, stabilisation of Uchediya through periodic flooding.

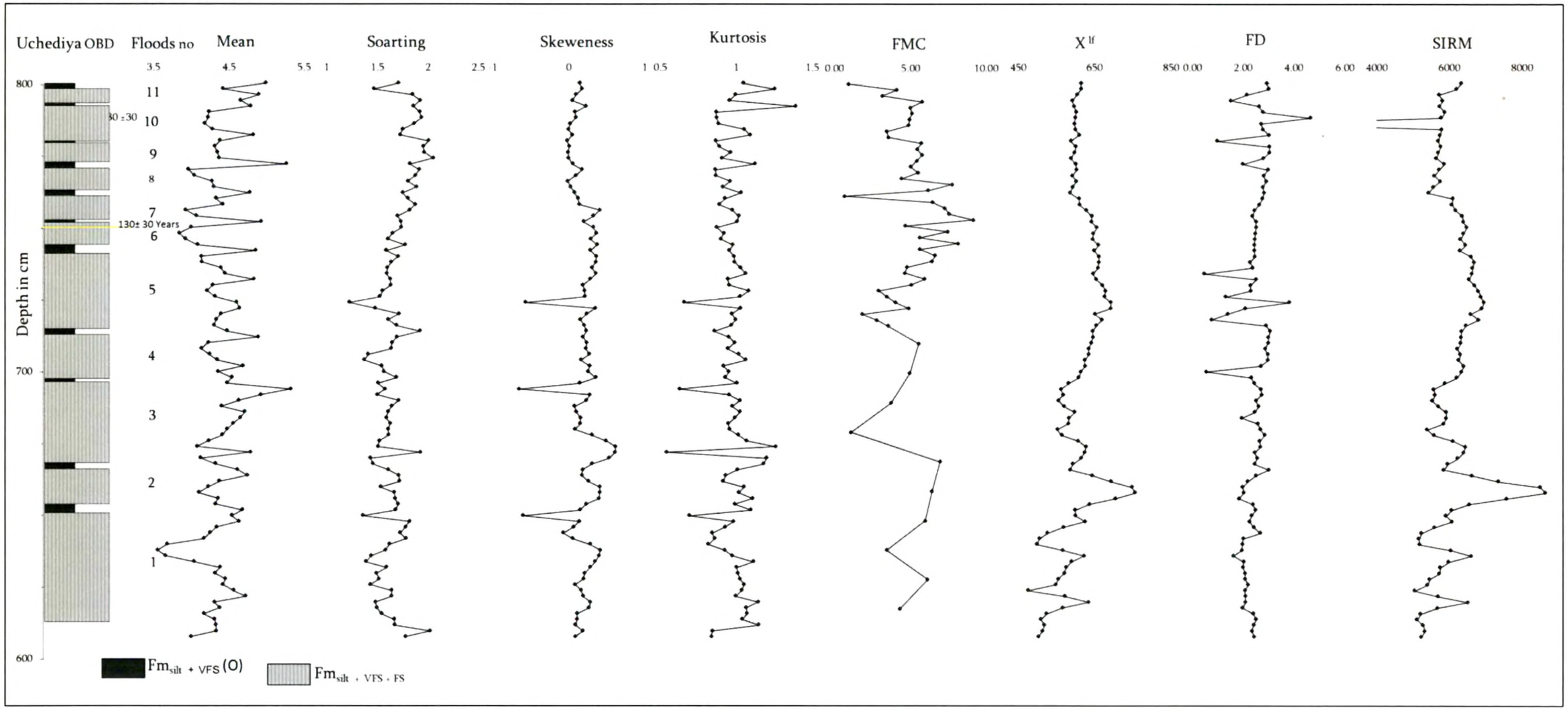


Figure 8-: Major flood events and their multi-proxy records from Over Bank Deposit

The TrD are overlaid by OBD (600 cm to 800 cm). The OBD facies are characterized by sedimentological, magnetic and ferrimangnetic mineral percentage records. The onset of deposition of OBD suggests stabilization of neo-bank (Figure 8-). The OBD aggraded over the neo bank during periodic significant flooding state of the river. The OBD from 600 cm to 750 cm records 6 major flooding events in the past 465 years whereas; from 750 cm to 800 cm preserves evidence of 5 major flood records in past 132 years (Figure 8-).

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