MATERIALS AND METHODS

FIELD STUDIES

The Narmada Son Fault is expressed by the ENE-WSW trending north facing escarpment which is tectonically active, and the lower Narmada valley in Gujarat, astride this seismically active fault. To the north of this scarp, steep northward sloping alluvial plain comprises of loose sand, sandy gravels, silty sand and clayey sediments. The present study is carried out in the NSF zone, confined between the NSF scarp and the alluvial plain that extends up to the Narmada River. Extensive field studies were carried out in the NSF zone with a purpose to understand the field setting of the NSF, to identify the evidence of neotectonic activity, to select the sites for the Ground Penetrating Radar (GPR) survey and to understand the palaeoenvironmental and depositional conditions of the Quaternary sediments of the study area. .

Conspicuous geomorphic features such as straight river course, anomalous channel pattern, sudden change in the channel pattern, conspicuous locations of ridges were identified prior to the field with the help of satellite imageries and Survey of India topographic sheet. Tectono-geomorphic features were chosen as the significant spots for the detailed field studies. As the drainages are very sensitive indicators of minute changes in the terrain, they were studied in great detail. Rivers change their regular flow path or pattern and adopt the change to maintain the equilibrium between various parameters. For example, river course become sinuous to maintain the equilibrium between slope and discharge. Such type of river behavior was identified from the topographic sheet and satellite imageries. The drainage anomalies could be attributed to the change in the rock types or tectonic activity. Hence, it becomes necessary to verify them through field studies. Several locations were identified in the study area for carrying out detailed field studies along the NSF zone. In most of the cases occurrence of anomalous features were found to be related to the tectonic activity along NSF and transverse faults, as they were associated with shear zones, slickensides, zone of knick points and waterfalls and fault plane. These have been discussed in detail in Chapter-7.

Field studies were carried out in the western part of the study area, in the vicinity of the scarp, where the terrain comprises of Deccan Trap. The fault zone which comprises of master fault and associated faults, and related damaged zone were identified. Conspicuous change in the dips of the various basaltic flows were measured and noted. It was found that

the main change in the dips of the basaltic flows is within the fault zone. To the north of the master fault, dips of the basaltic flows are in the north while to the south of the fault, they are dipping in the south. This helped in understanding not only the surface projection of the NSF but also the probable location of NSF all along the study area. Sites for GPR studies were selected based on these findings which has been discussed in the Chapter-7 and 8. In the extreme western part of the study area, the NSF scarp is manifested on surface by steep wall like cliffs of Pleistocene sediments which appear as the palaeobank of the Narmada River. Field studies were carried out along the length of the palaeobank and the suitable sites were selected for the GPR surveys. Field studies carried out in the eastern part of the study area revealed the reverse nature of the NSF. Here, the Tertiary rocks are deformed in various anticlinal folds and bounded by reverse fault. As the folds and faults are exposed over the surface, it was easy to locate the NSF and understand the nature of fault movement. Further, field studies carried in the rivers flowing across the NSF to know the role of neotectonic activities in deposition of the Quaternary sediments and to understand the depositional environment. Lithologs were prepared for the exposed section along the incised cliffs and lithofacies associations were identified. The association of certain types of facies provided better understanding of the depositional environment, while the morphology of the deposition pointed out their relation with tectonic activities. The study of vertical and lateral lithologs was helpful in identifying the group of the fan in the western and middle part of the study area. The fabric of the fan sediments has further suggested cycles of aggradation and erosion which related to the pulses of tectonic uplift. In the present study, these deposits are termed as 'bajada surface' and discussed in the Chapter-6.

REMOTE SENSING AND GIS STUDIES

Although anomalous drainage characteristics are related to the tectonic activities, their systematic representation in the form of quantitative data is necessary. This was attempted by the quantitative geomorphic analysis of the landscape using remote sensing and Geographic Information System (GIS) techniques. In this study, the baseline data which was used includes Digital Elevation Model (DEM) of 90 m Shuttle Radar Topographic Mission (SRTM), Landsat TM and ETM+ data. The methodology followed in the present study is illustrated in the flow chart below (Fig.3.1).

In the first stage, the Landsat TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper) of the study area were downloaded from NASA sponsored Global Land Cover Facility (GLCF). The 90 m USGS SRTM Digital Elevation Model (DEM) was downloaded from www. *http://srtm.csi.cgiar.org*. In this web site, the Consortium for

Spatial Information (CGIAR-CSI) of the Consultative Group for International Agricultural Research (CGIAR) is offering post-processed 3-arc second (90 m) DEM data according to the method described by Reuter et al. (2007) for the globe. The data were analyzed using GIS software, which is a precise, fast and inexpensive way for calculating morphometric parameters (Farr and Kobrick, 2000; Grohmann, 2004). The basic processing steps were done in ERDAS Imagine (v. 9.1) that included stacking, re-projection, mosaicking, clipping, etc. The common projection type, Universal Transverse Mercator (UTM) was applied to all digital databases so the overlapping of different layers is made possible. For further analysis, ArcGIS (v.9.3) has been used.
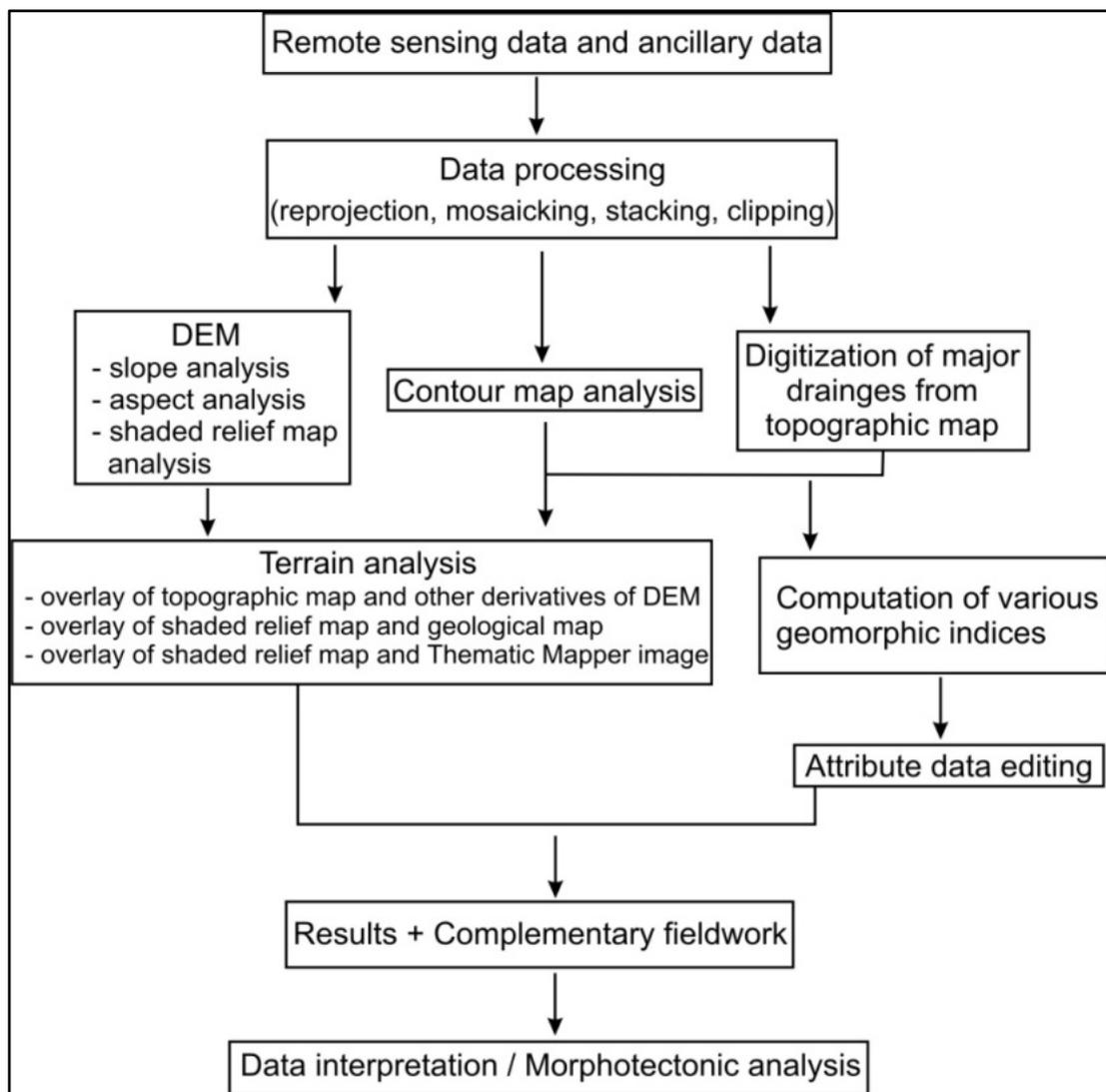

Figure 3.1 Flow chart showing the methodology adopted in the present study.

In the ArcGIS, ten drainage basins traversing the NSF zone were extracted from the DEM and contour maps were generated at 10 m interval for each basin with help of 3D Analyst tool of Arc Toolbox. Basic geomorphic maps and longitudinal profiles of the rivers were prepared from digitized Survey of India topographic sheets of 1:50,000 scale.

Subsequently, the terrain analysis was carried out using DEM that included image tone, slope analysis and aspect analysis along with Survey of India topographic sheets and the satellite imageries used for verification purpose. From this database, various geomorphic indices were calculated, interpreted and correlated with field observations. However, it is always necessary to verify the results with the field observations. Hence, extensive field observations was also an integral part of the study as it has helped in confirming, consolidating and interpreting the results obtained from geomorphic analysis.

GROUND PENETRATING RADAR STUDIES

Ground Penetrating Radar (GPR) is a high resolution electromagnetic technique which is designed primarily to investigate the shallow subsurface of the earth. The fundamental principle of the GPR survey is the same as that used to detect aircraft overhead, but with GPR that antennas are moved over the surface rather than rotating about a fixed point (Fig. 3.2).
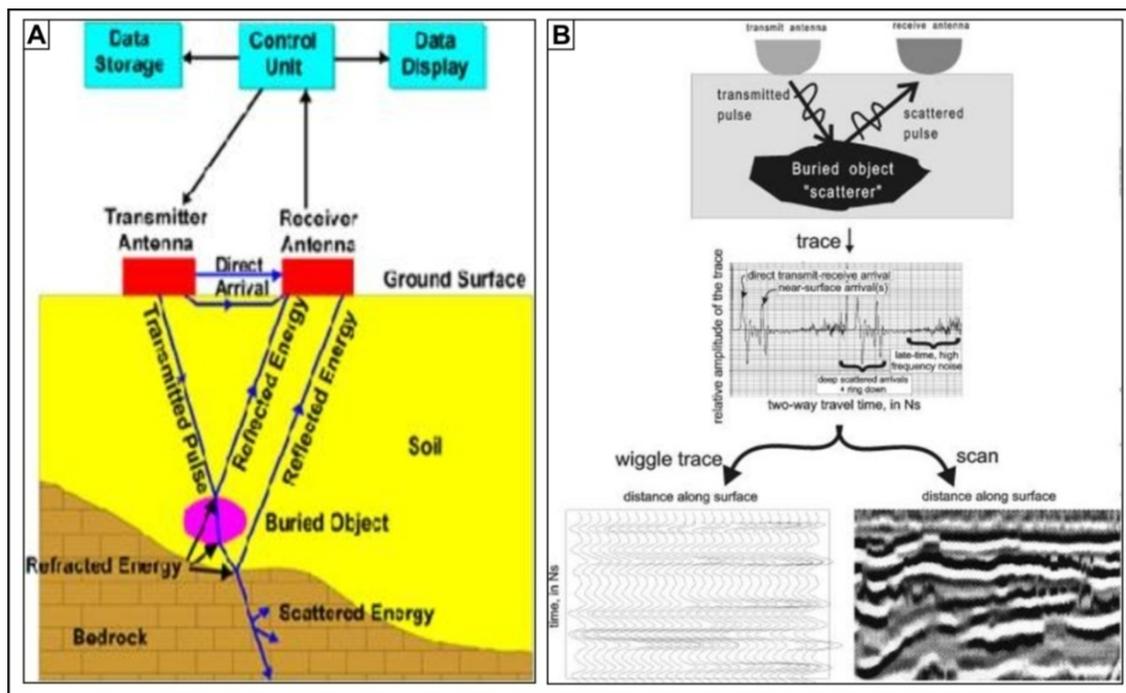

Figure 3.2 (A) Diagram Showing the principle of GPR. (B) Diagram showing sequence of producing GPR profile.

GPR profiling is similar to seismic reflection surveying but is based on the propagation and reflection of electromagnetic wave. The electromagnetic waves (EM waves) are sensitive with variations in physical properties and composition of the subsurface material like, grain size, water moisture, dielectric permittivity and electric conductivity. The radar waves are a type of electromagnetic waves which spreads out by

transmitter antenna and travels downward until it hits an edge of subsurface material having contrasting electromagnetic properties from the surrounding medium, is scattered back to the surface and detected by a receiving antenna (Fig. 3.2). The radar waves travel at a specific velocity that is determined primarily by the permittivity of the material.

In the GPR survey, the fundamental basic of investigation is the estimation of propagation speed (velocity) of the transmitted waves, which is controlled by electromagnetic properties of the examining objects (Davis and Annan 1989). Further, the electrical properties of the geological material are governed primarily by water content, dissolved minerals, clay and heavy mineral content which introduce significant changes in the reflection strength of the signals (Olhoeft 1984, Beares and Haeni 1991, Topp et al., 1980). Usually, material having significant clay content or heavy mineral will result in poor GPR profile. Because during the propagation of RADAR waves in the clay enrich material, there will be ironic reactions between the waves and mineral particle, which will diffuse the wave energy and also restrict the depth of RADAR wave propagation.

GPR data acquisition

GPR survey conducted at several sites in the NSF zone using the Subsurface Interface Radar-20 (SIR-20) GPR survey system of GSSI to trace the shallow subsurface nature NSF. The measurements from GPR can be made by two different ways. In continuous manner the shielded monostatic antenna is dragged along a transect line to record a high-resolution continuous cross-section of the subsurface. The monostatic antenna contains a pre-fixed unmovable configuration of transmitter and receiver inside a shielded cover, that can be attached with an odometer based survey wheel to determine the horizontal survey distance. The second manner contains transmitter and receiver as a separate entity and the measurements are made by manually shifting the points along the surface, known as bistatic antenna configuration. Initially, antenna of 80 MHz and 200 MHZ frequencies were applied to get an idea about the appropriate frequency range which can give precise picture of the subsurface. The 80 MHz antenna has provided satisfactory results in terms of both depth of the target and resolution required. The 200 MHz GPR profiles were acquired in the continuous mode. The 80 MHz GPR profiles acquired in Common Offset (CO) methods. In the CO method, antenna separations of 1 m and 0.25 m step size have yielded appropriate result. Accordingly, GPR survey was conducted at several sites along the survey lines which were oriented across the trend of the NSF (Fig. 3.3). Several preliminary GPR survey was carried out at sites to decide the appropriate file header parameter, that gives the best results**.** Accordingly, many GPR profiles were obtained on all segments across the trend of the NSF,

of them, appropriate representative profiles are described in the Chapter-8. Also CMP profiles were conducted using 80 MHz antenna. The average velocity 0.124 m/ns were selected for depth correction in post processing stage.
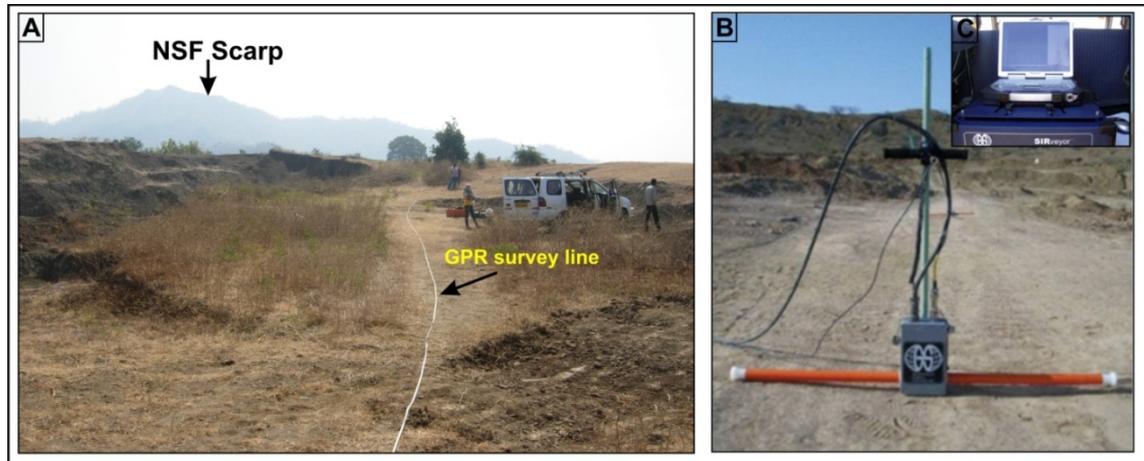

Figure 3.3 (A) Field photograph of one of the GPR survey site in the NSF zone. (B) Photograph showing 80 MHz antenna. (C) Photograph showing the control unit.

GPR post-survey processing

Post survey processing was done by in RADAN processing (v. 5.0) software of GSSI. The basic processing steps were applied to the profiles starting with editing of the file header, followed by topographic correction and horizontal scale normalization. This was followed by the application of appropriate vertical and horizontal (background removal) band pass filter to remove the noise of very low and very high frequency. For the 200 MHz GPR profiles, 30-400 MHz and for 80 MHz GPR profile 10-160 MHz band pass filter range were selected. Kirchhoff migration was applied to collapse the inclined diffraction and to make steeply dipping data to their correct subsurface position in some of the profiles. At last, Automatic Gain Control (AGC) and Exponential gain function was applied to artificially increase the amplitude of radar signals which was very low because of signal attenuation and some processing steps like background removal and migration. Prior to the processing, velocity analysis was carried out and average velocity of 0.124 m/ns was selected for depth correction. The velocity analysis is discussed in detail in the Chapter-8.