AN INTEGRATED GEOPHYSICAL STUDY OF THE LITHOSPHERIC STRUCTURE BENEATH LIBYA

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ABSTRACT

The tectonic evolution of Libya has yielded a complex crustal structure and is composed of a series of basins and uplifts. In order to constrain this complex crustal structure, we have complied and reduced over 16000 gravity measurements in conjunction with other geologic and geophysical data to construct a 3-D model of density/geology for northern Libya and surrounding regions. The 3-D model is developed by calculating contributions from various crustal layers, including the Mesozoic surface as the elevation, the top of the Precambrian, the Moho, etc. The 3-D model will then be used to develop a regional velocity model that can be verified/modified by analysis of regional waveform data that we are collecting from earthquakes occurring within northern Libya.

Northern Libya is the most seismologically active and highly faulted portion of the country. For this reason, we have collected thirteen Landsat 5 satellite images covering the most seismically active and structurally significant regions of northeast and northwest Libya. The satellite images have been mosaicked using a seamless mosaicking technology based on ENVI's cutline feathering approach. The resulting mosaicked figures were then overlain with the previously mapped faults analyzed to identify the more recent faults.

We have examined regional waveforms from 30 Libyan earthquakes that occurred from January 1990 to May 2000. We used regional stations GFA, IDI, KEG, and WDD, which are all broadband digital stations and all members of the Mediterranean Network (MEDNET). Event magnitudes ranged from 3.7 to 5.2, and all were shallow events. The great majority of events originated in the northeastern section of Libya bordering the Cyrenaica uplift. We find significant *Lg* blockage across the Mediterranean Sea, thus limiting any discrimination techniques that rely on *Lg*. We thus investigate the utility of *P*-wave cross spectral ratios and *Pn*/*Sn* phase ratios, recognizing our preliminary results lack explosion data.

OBJECTIVE

Our objective is to improve upon the existing crustal velocity model for Libya. We are building a 3-D density/geology model using a wealth of geophysical data. We will validate the models through the use of regional waveforms.

RESEARCH ACCOMPLISHED

3-D Gravity Analysis

Over 16000 gravity data points covering northern Libya and the southern portion of the Mediterranean Sea have been compiled and reduced. These gravity points were collected from a number of databases, about a half of which were collected from the worldwide gravity database maintained by the National Imagery and Mapping Agency (NIMA). The other points were gathered from our local database here at the University of Texas at El Paso (UTEP). Figure 1 shows the gravity points covering an area extending from 8°E, 35°N to 26°E, 19°N. These data have been gridded at three-minute intervals using a minimum curvature gridding technique.

The program "SURFGRAV" is a general-purpose 3-D gravity-modeling program that is being used to construct the 3-D gravity model of the study area. The computation is based on representing the Earth's surface as a gridded Digital Elevation Model (DEM) with an associated grid derived from mapped geologic units. This software is designed for conventional single-density terrain correction, variable geology/density terrain corrections, as well as general purpose modeling of subsurface structures. The software program is equipped to handle irregularly spaced gravity stations at arbitrary elevations, common to land surveys. For this computation, the geologic map of Libya (Figure 2) has been digitized, gridded and will be used in conjunction with the DEM of the study area (Figure 3a). The output computed gravity (a kernel file) is presented as a matrix or spreadsheet dataset with each row a gravity station, and the columns containing unit-density gravity contributions for each of the geologic units in the area of computation. Spreadsheet, Matlab or other specialized software can then combine these kernel files to give terrain-corrections, regional/local contributions, tests of forward models at different densities, or the Jacobian for use in inverse algorithms (Baker 2001).

Figure 2 is a generalized geologic map of Libya showing polygons bordering individual geologic outcrops. These polygons have been assigned their various densities from the rock description obtained from a 1:2,000,000 scaled geologic map of the Kingdom of Libya, compiled by Constant *et al*. (1964). Neighboring polygons that were found to vary by less than 0.02g/cc were merged to form a single polygon as a tradeoff for processing time. The nearest neighbor gridding technique was used to produce the grid map shown as Figure 4. In all other cases, the Kriging technique was used to produce various grids. A gridded map of the surface of Libya as well as a contour map of the study areas are shown in Figures 3a and 3b. These two grids (DEM and geology/density) along with a file containing the gravity readings are fed into SURFGRAV and the gravity contribution of each polygon is calculated at infinite depth. The same process is repeated for subsequent layers: the Paleozoic layer that has been assigned a uniform density of 2.55g/cc (Figure 5), the Precambrian with a uniform density of 2.7g/cc (Figure 6), the lower crust with a uniform density of 3.0g/cc and from the Moho down to a depth of approximately 50 km was assigned a uniform density of 3.3g/cc.

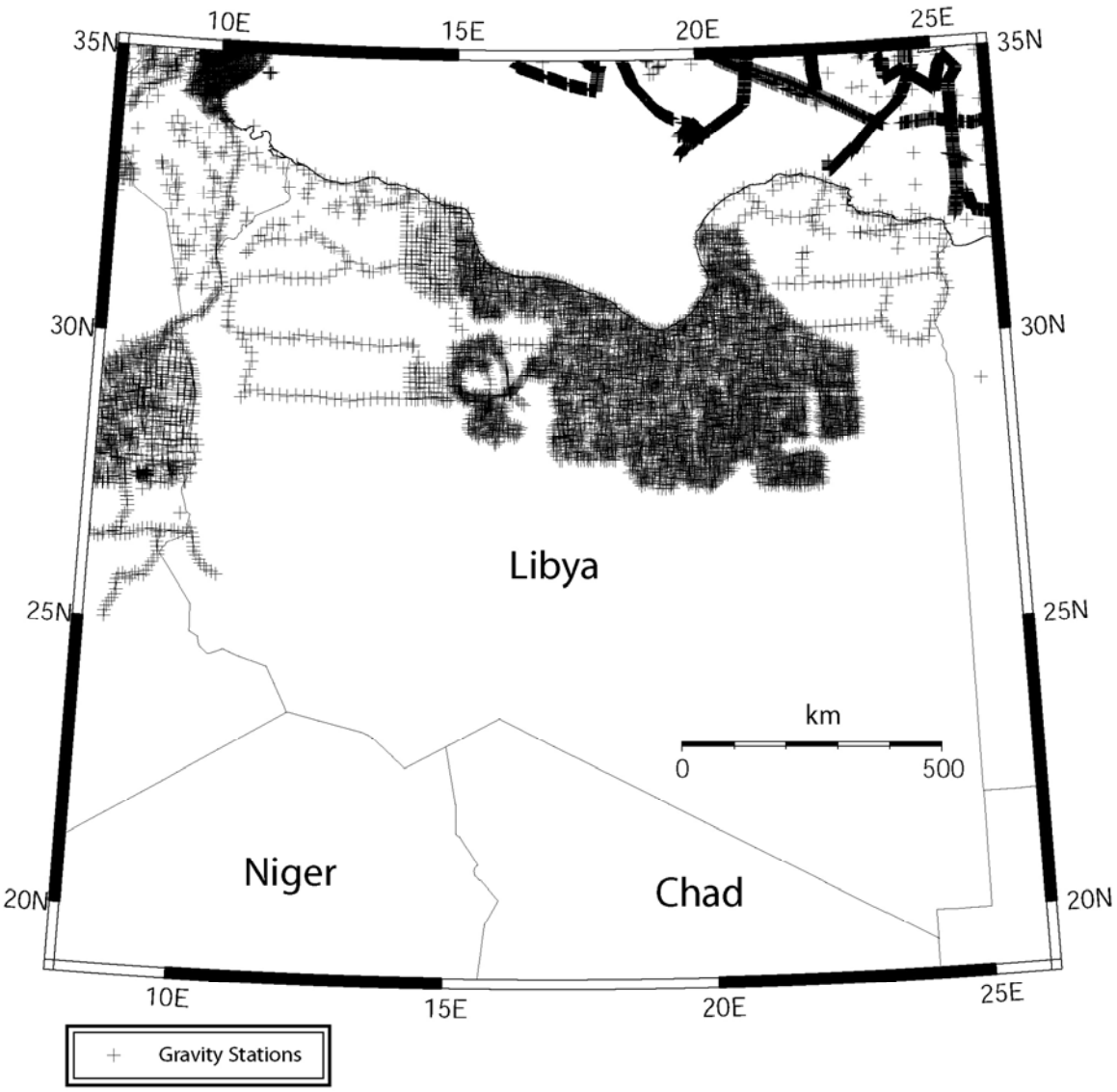

Figure 1. Map of Libya showing the locations of gravity stations that have been reduced and are being used in the gravity-modeling portion of this study.

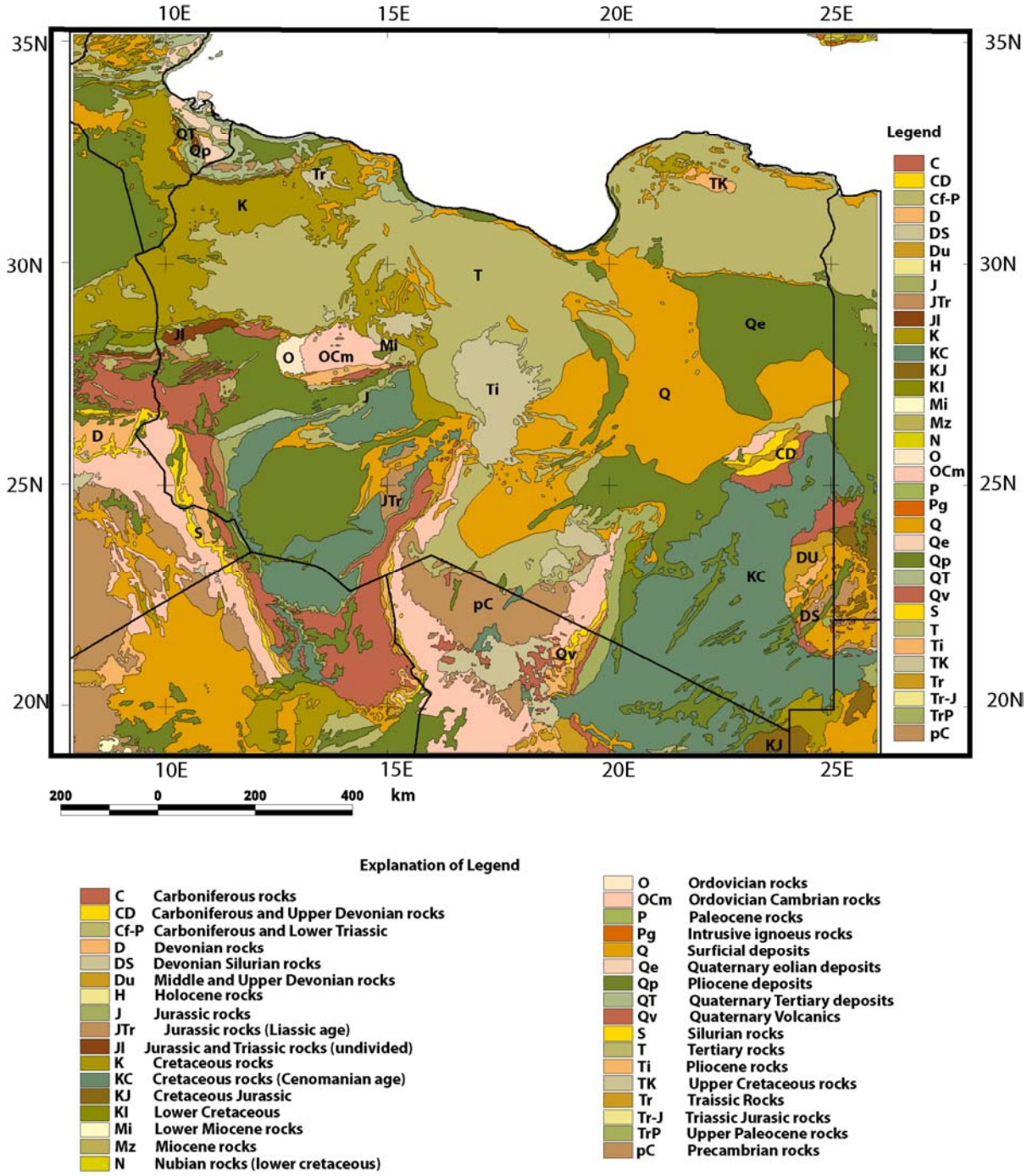

Figure 2. Generalized geologic map of Libya and adjacent areas (modified from Hearn, 2001)

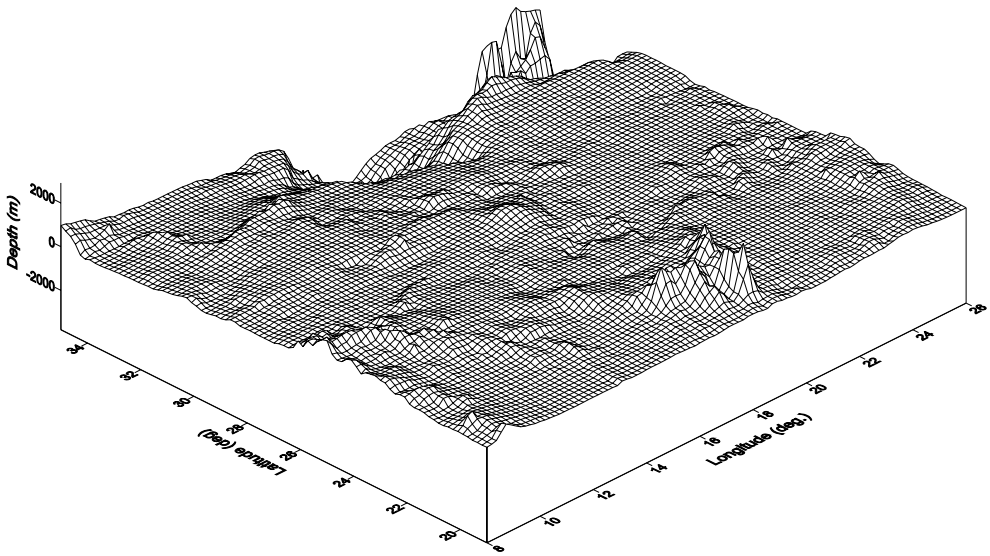

Figure 3a Vertically exaggerated gridded DEM for the topographic surface of Libya. Libya is a generally flat country, except for the Tibesti Mountains in the south there is not much topography. The gridding interval used for the SURFGRAV software is at a 3 minute interval but has been reduced for ease of display in this figure.

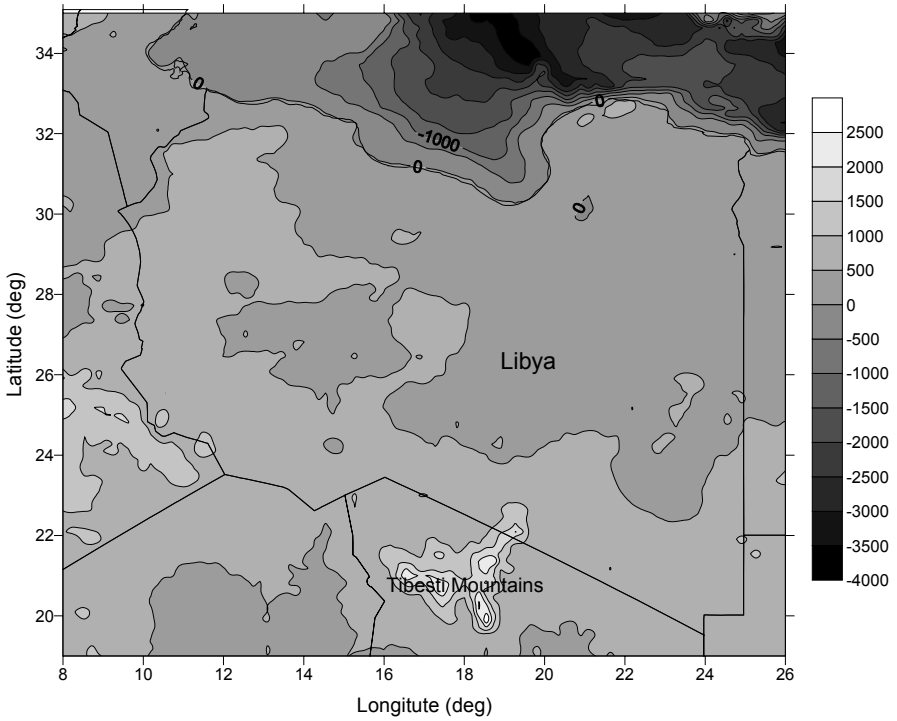

Figure 3b. Contour map of the Libya region. Contour lines are drawn at intervals of 500m.

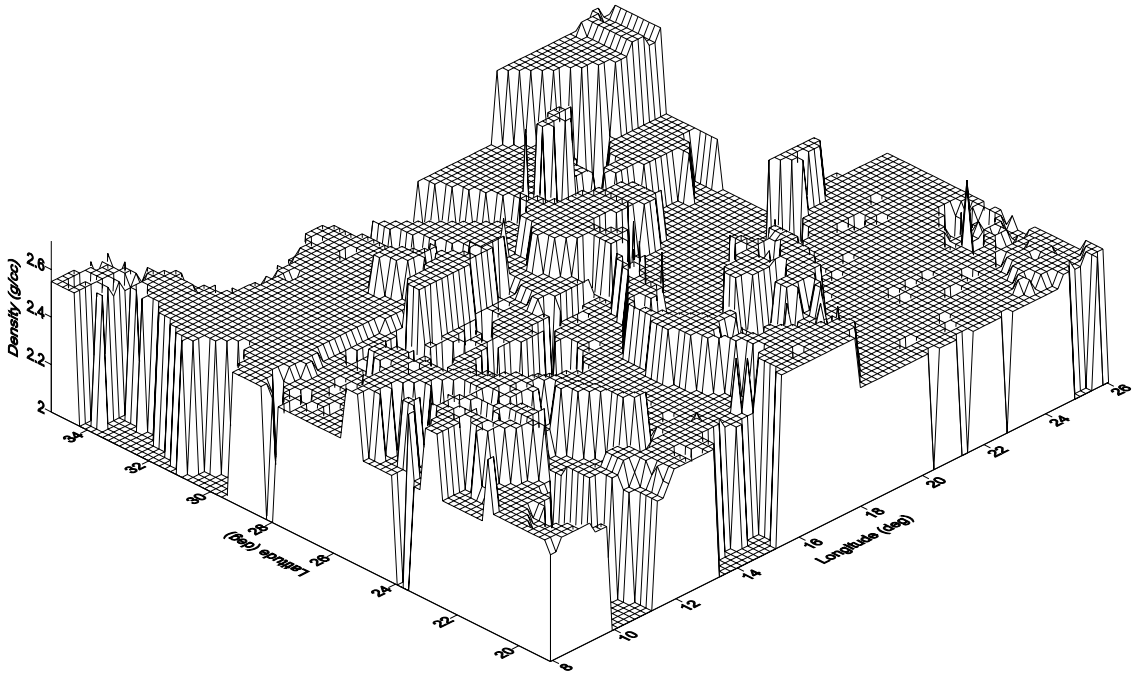

Figure 4. Representation the gridded surface geology/density of the study area. The nearest neighbor technique is used to do the gridding so that the sharp changes in geology/densities can be more accurately represented.

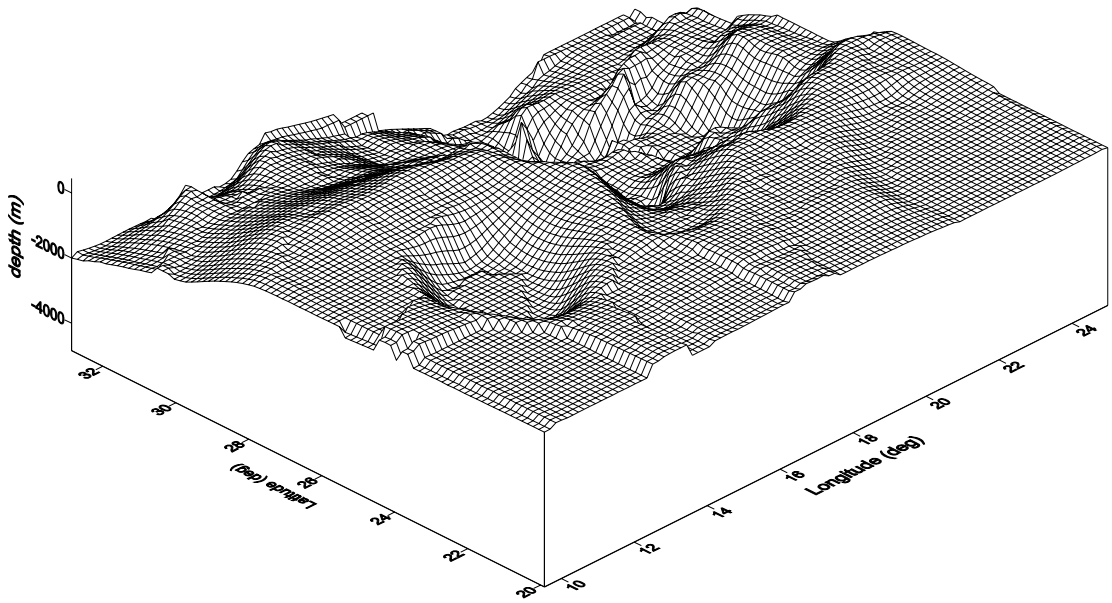

Figure 5. Gridded surface of the top Paleozoic Layer. These data were digitized from a preliminary structure-contour map of the Libyan Arab Republic and adjacent areas compiled by Goudarzi *et al.* (1978). The scale of the structure contour map is 1:2,000,000.

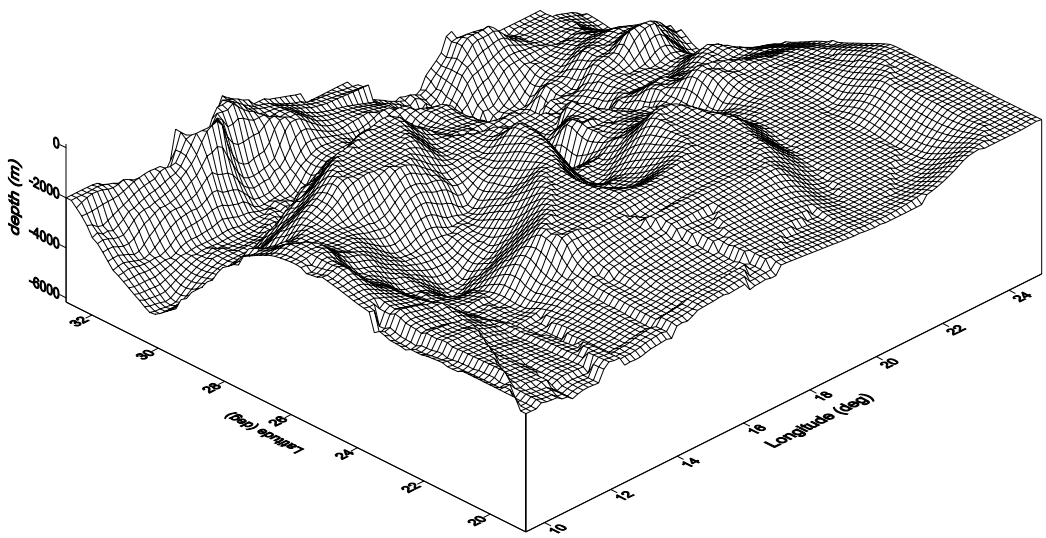

Figure 6. Gridded surface of the top Precambrian strata. These data were digitized from a structure-contour map of the Libyan Arab Republic and adjacent areas compiled by Goudarzi *et al.* (1978). The scale of the structure contour map is 1:2,000,000.

The surficial layer was grouped with the Cenozoic and Mesozoic layers and considered one layer since there is not enough data available to make the distinction between these layers. Below this layer is the Paleozoic layer which was hand digitized from the structure contour map of Goudarzi *et al*. (1978). Next layer is the Precambrian layer, which was extracted from the same source in a similar manner. The base of the Precambrian layer forms the top of the lower crust. The lower crust is assumed to terminate at a depth of approximately 19 km. The top of the Moho was digitized from Dial (1998) and was extended to an arbitrary depth of 50 km.

Preliminary Waveform Analysis

We have found that regional seismic data is difficult to obtain due to the lack of instrumentation at regional distances around Libya. The dataset consists of thirty Libyan earthquake events that occurred from January 1990 to May 2000. Event magnitudes ranged from 3.7 to 5.2 Mb and all were shallow events. A majority of the events originated in the vicinity of the Cyrenaica uplift in the northeast section of Libya. The stations used for this study are Gafsa, Tunisia (GFA), Anoyia, Crete (IDI), Kottamia, Egypt (KEG), and Wield Dalam, Malta (WDD), which are all broadband digital stations of the Mediterranean Network (MEDNET). Our strategy is to gather as many events as possible within regional distances and to produce usable seismic records for the purpose of discrimination. Records are then being cataloged and seismic phases are being picked to best identify which phases and discriminatory methods will work best in now and in the future.

Component velocity seismograms were corrected for instrument response, tapered, and band passed with a Butterworth filter at five different frequency bands: 0.5-1 Hz, 1-2Hz, 2-4Hz, 4-6Hz, and 6-8 Hz. Signal to noise ratios (SNR) were then measured and evaluated. We chose an SNR of two for our analysis. We calculated theoretical phase arrival times, picked arrival times, and measured the largest amplitude within three seconds of the predicted arrival time.

We find significant *Lg* blockage across the Mediterranean Sea, making any use of *Lg* for discrimination difficult. Thus, we must rely on *Pn* cross-spectral ratios and/or *Pn*/*Sn* phase ratios for discrimination. *Sn* is present in some of the records; but not sufficiently to construct a *Pn*/*Sn* phase ratio diagram. Since we do not have identified explosions in our dataset, we cannot make any conclusion about the effectiveness of phase and cross-spectral ratios for

discrimination. However, we find good signal to noise for *Pn* 1-2/ 6-8 Hz spectral ratios as well as *Pn*/*Sn* phase ratios at 6-8 Hz (Figure 7). The earthquake events plotted on the *Pn* 1-2/6-8 Hz spectral ratio give similar results as previous work conducted with Nevada Test Site (NTS) data (e.g., Walter et al., 1995; Figure 2). This demonstrates that *Pn* maybe a useful discriminatory phase as more events and data become available.

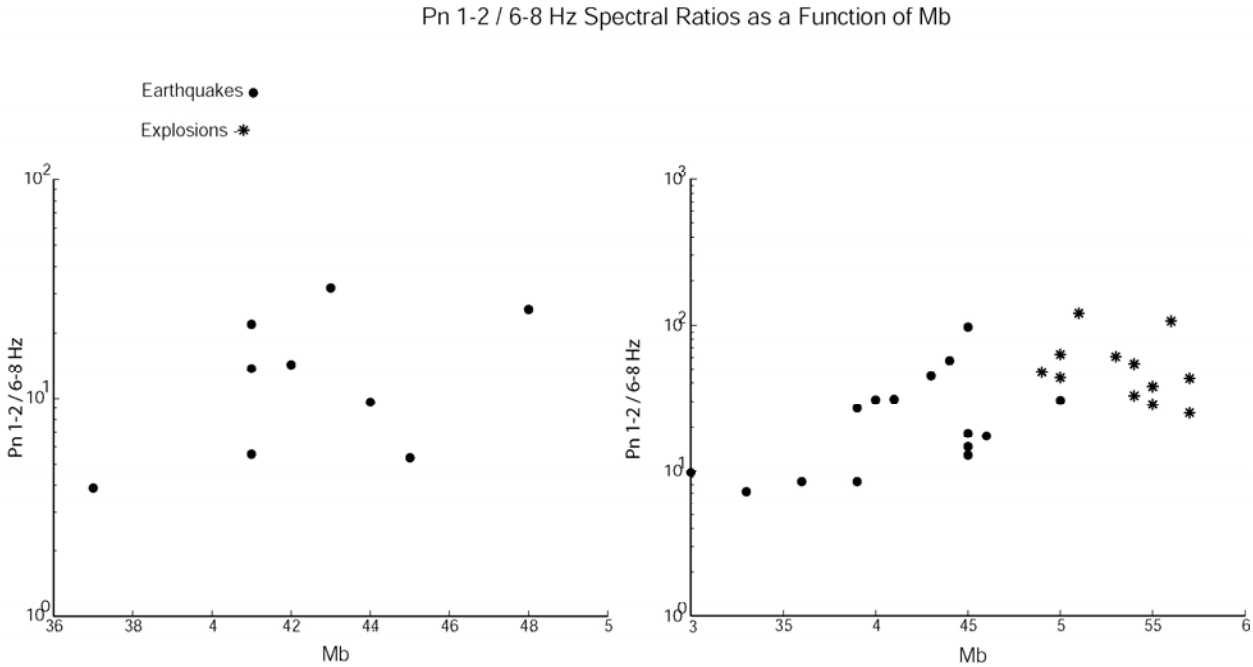

Figure 7. Comparison of Libyan spectral ratio diagram (left), compared to NTS spectral ratio diagram (right).

Remote Sensing Data

Remote sensing data were used to identify major geologic features and spatial correlations between various datasets. Thirteen remotely sensed images covering two different regions of Northern Libya were carefully selected. Four images covered a segment of northeastern Libya, which is the most seismically active portion of the country. The surface geology of this area is composed primarily of Triassic rocks and Quaternary surficial deposits. A few major basement faults are located in the area but the faulting style found in this area is that of thrust faulting which is different from those seen in the northwestern portion of the country. Nine of the remotely sensed images were collected for the northwestern portion of the country, which is the second most seismically active and is also the site of recent seismic activity. This area is highly faulted, much more geologically complex, and contains a portion of the Hun Graben and other prominent geological features in Libya. The faulting style exhibited in this region is that of strike-slip and normal faulting with a general northwesterly trend. Analyzing these images will help in identifying more recently active faults and may even help in identifying previously unmapped faults.

The first step in processing the remotely sense images was to create a mosaic of the two areas. We applied a seamless mosaicking technology that employs histogram matching, cutline feathering, and careful selection of the order in which images are overlain for the cuts. The images collected for the northeastern portion of Libya were Landsat 4 (path/Row): 182/38, 183/38, 184/38 and 183/37. These images were already georeferenced to UTM zone 34. Landsat 4 images are composed of 7 bands, and for the initial phase of our analysis, bands 3, 2, and 1 (in that order) were selected for processing as these bands best represent the natural color. The final mosaicked image is shown in Figure 8.

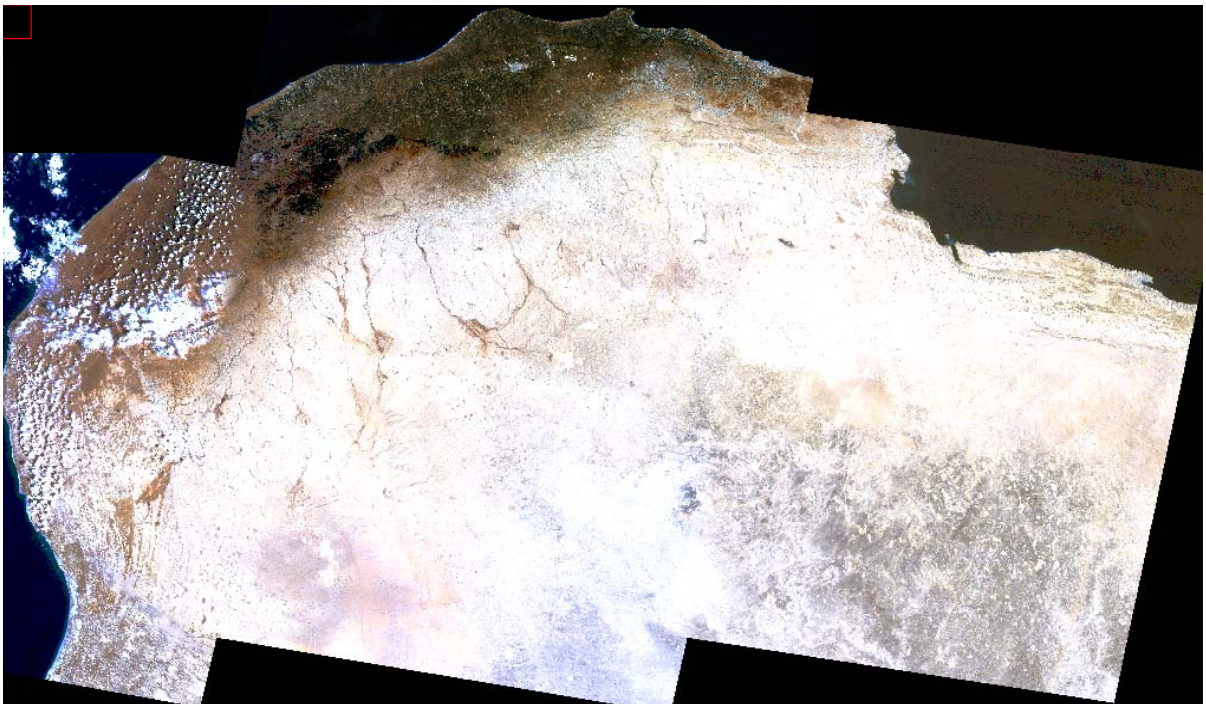

Figure 8. Final mosaicked image for the northeastern portion of Libya.

Figure 9 shows some of the mapped faults in Libya overlaid on the two mosaicked images. There seems to be a correlation of the location of the faults with changes in vegetation, geology and drainage. It is noteworthy, however, that the images depict surface reflectance that is not always related to vegetation. Having the faults overlaid on the images helps in identifying the appearance of faults on the image. This will later help us in identifying suspect or unmapped faults, and we may be able associate an age with some of the previously undated faults. Since the faulting styles exhibited in the Cerenaica uplift and the Hün Graben area are so different, we may even be able to identify the styles of some of the unmapped faults based purely on the satellite images. We are constructing another overlay that includes the location of seismic events and will enable us to associate the events with the faults on which they occur.

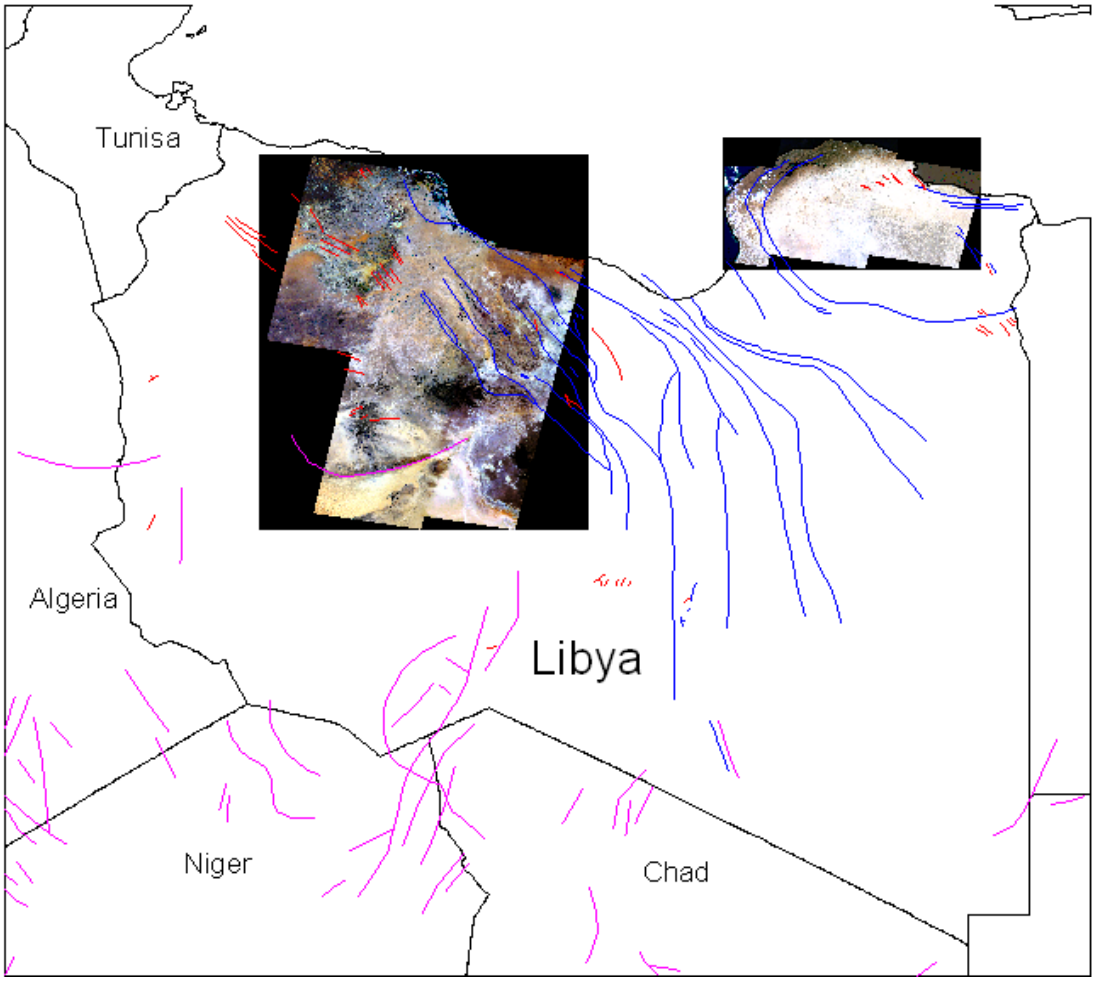

Figure 9. Two mosaicked areas overlain by mapped faults in Libya. The blue faults are faults cutting basement and younger rocks, the red faults cut only Mesozoic and younger rocks, and the magenta faults are other mapped faults in the region

CONCLUSIONS

We are in the process of calculating the gravity attraction of each layer in our 3-D model. This model will be a comprehensive model of the Libyan lithosphere. We will validate our 3-D model with regional waveforms. At this time the seismic data on hand presents no solid conclusion except that a couple possible discriminatory methods may be helpful in future verification work. The collection of more regional data is of key importance at this point. There are regional networks in Algeria and Egypt that could offer abundant records, however obtaining this data is difficult. On completion, we believe that our integrated analysis will be the most comprehensive study of the Libyan lithosphere ever undertaken and will provide significant insight on the tectonics and wave propagation in the area.

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