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An Investigation Of The Seismic Hazards Of The El Paso-Juarez Region: The Nature And Extent Of The Southern East Franklin Mountains Fault Zone

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AN INVESTIGATION OF THE SEISMIC HAZARDS OF THE EL PASO-JUAREZ REGION:
THE NATURE AND EXTENT OF THE SOUTHERN
EAST FRANKLIN MOUNTAINS FAULT ZONE

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DEDICATION

I dedicate this thesis to my parents Manuel Avila and Irma Amaya, and thank them for their support in my academic pursuits. I also dedicate this thesis to my fiancé Iralva who motivated me in all my efforts to be a better person and student.

Finally this thesis is dedicated to Watchman Nee for his spiritual inspiration.

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VICTOR MANUEL AVILA

THESIS

Presented to the Faculty of the Graduate School of
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in Partial Fulfillment
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for the Degree of
MASTER OF SCIENCE

Department of Geological Sciences
THE UNIVERSITY OF TEXAS AT EL PASO

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ABSTRACT

The El Paso-Ciudad Juarez Region is situated at the southern end of the active Rio Grande Rift within the Mesilla and Hueco basins. The Hueco basin is separated from the eastern Franklin Mountains by a prominent fault, the Eastern Boundary Fault. Studies of this fault have revealed fault scarps that displace Quaternary deposits (Keaton et al., 1995; Raney and Collins, 1990; Lovejoy, 1976). This fault is cataloged as an active fault in the National Seismic Hazard Map with an estimated slip rate of 0.1 mm/yr. A fault with similar characteristics as the Eastern Boundary Fault extends further to the south into Mexico. This continuation of the Eastern Boundary Fault is comprised of two segments that are hypothesized to lie beneath the urbanized portion of El Paso and Ciudad Juarez. The location of these segments is inferred by an earthquake hazards study of the El Paso region (Keaton, 1993). The objective of this research was to locate and attempt to determine how the fault segments in downtown El Paso-Ciudad Juarez interconnect using precise gravity readings. For this I used two gravimeters; for the El Paso area a Lacoste Romberg was used and then a CG5 gravimeter was used in Ciudad Juarez. The tilt derivative filter applied to the gravity data taken reveals the fault segments correspond well to those inferred by previous researchers who did not have any geophysical data for use in their interpretation. The results help to assess seismic hazards within the El Paso- Ciudad Juarez region. The data also reveal several new intriguing anomalies related to basement structure and faults that need to be more closely investigated in planned geophysical surveys.

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INTRODUCTION

El Paso and Ciudad Juarez are cities situated in the seismically active Rio Grande rift (figure 1) (Keller et al, 1990; Haller et al, 2002). Both cities contain Quaternary faults (Figure 1.1) that have been studied by previous researches. It is important to better delineate these Quaternary faults especially where they are buried beneath urbanized and in order to understand the hazards that they may pose to the metropolitan area.

The Eastern Boundary Fault of the Franklin Mountains (Figure 1.1) is the focus of this study. This fault is located along the eastern flank of the Franklin Mountains, and forms the western boundary of the Hueco Bolson, with the Hueco Bolson down dropped to the east. The Eastern Boundary Fault trends southwest in east-central El Paso, and appears to cross the Rio Grande. It is joined to the south by a southeast trending segment in west central Ciudad Juarez. The southern extent of the Eastern Boundary Fault appears to be located just west of Azteca Avenue in Ciudad Juarez (Drewes and Dyer, 1993).

The purpose of the study was to locate the Eastern Boundary Fault beneath the urbanized area of El Paso and Ciudad Juarez using two gravimeters one in El Paso (Lacoste-Romberg) and the other in Juarez (CG-5 gravimeter), both having microGal precision, and differential GPS to conduct a precision gravity survey across the suspected locations of these faults. The survey will complemented previous work done around the area and along with water well logs in the Hueco basin and from Juarez, helped to constrain the geometry of the Eastern Boundary Fault. The data collected were analyzed and modeled to determine location and orientation of the fault which helps to evaluate the seismic risk posed to the El Paso- Ciudad Juarez by the Eastern Boundary Fault Zone (Figure 1.2)

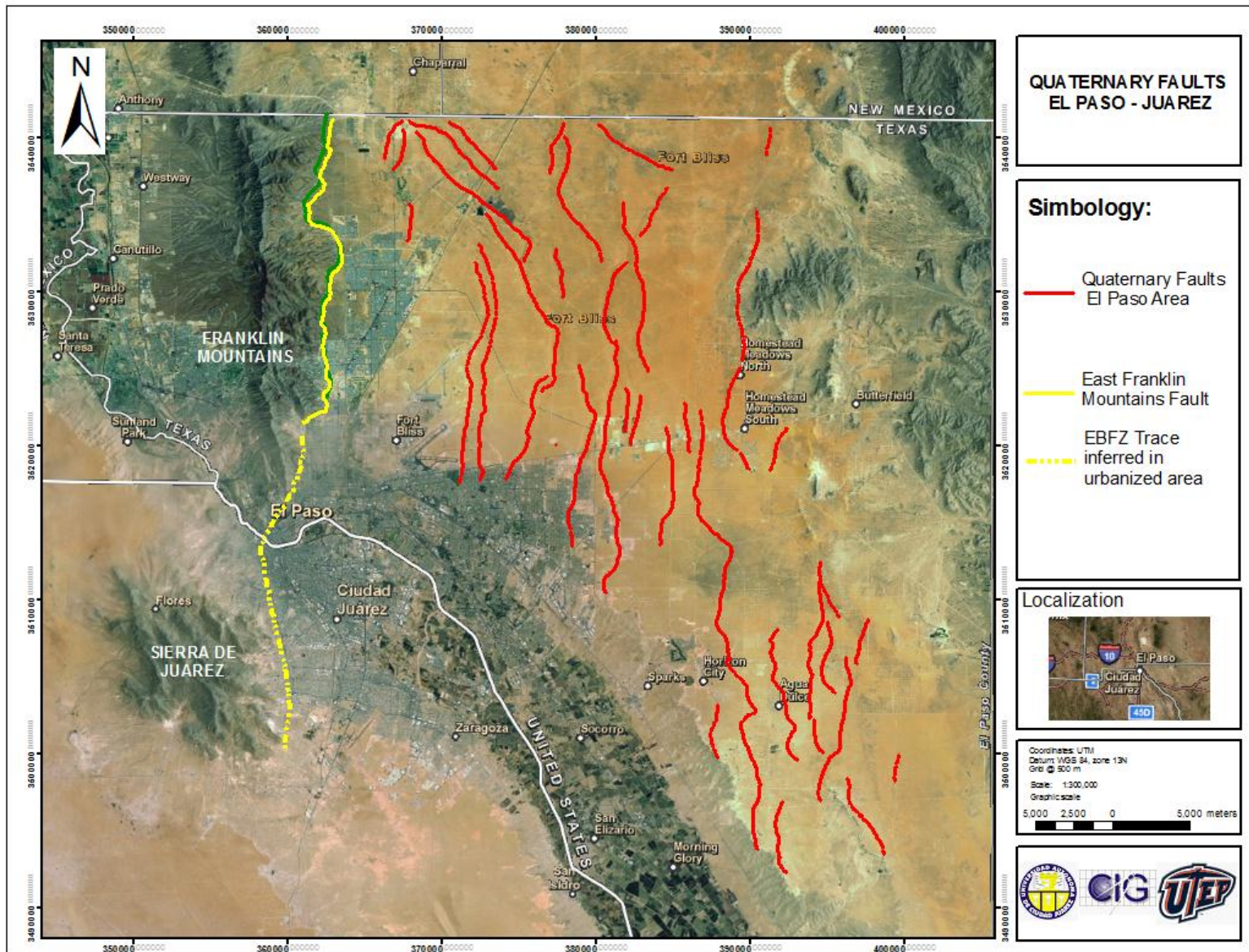


Figure 1.1 Quaternary Faults in the El Paso- Ciudad Juárez modified from Collins and Raney (2000). Eastern Boundary Fault Zone (EBFZ) indicated by dashed line

0.2 sec Spectral Acceleration (%g) with 2% Probability of Exceedance in 50 Years

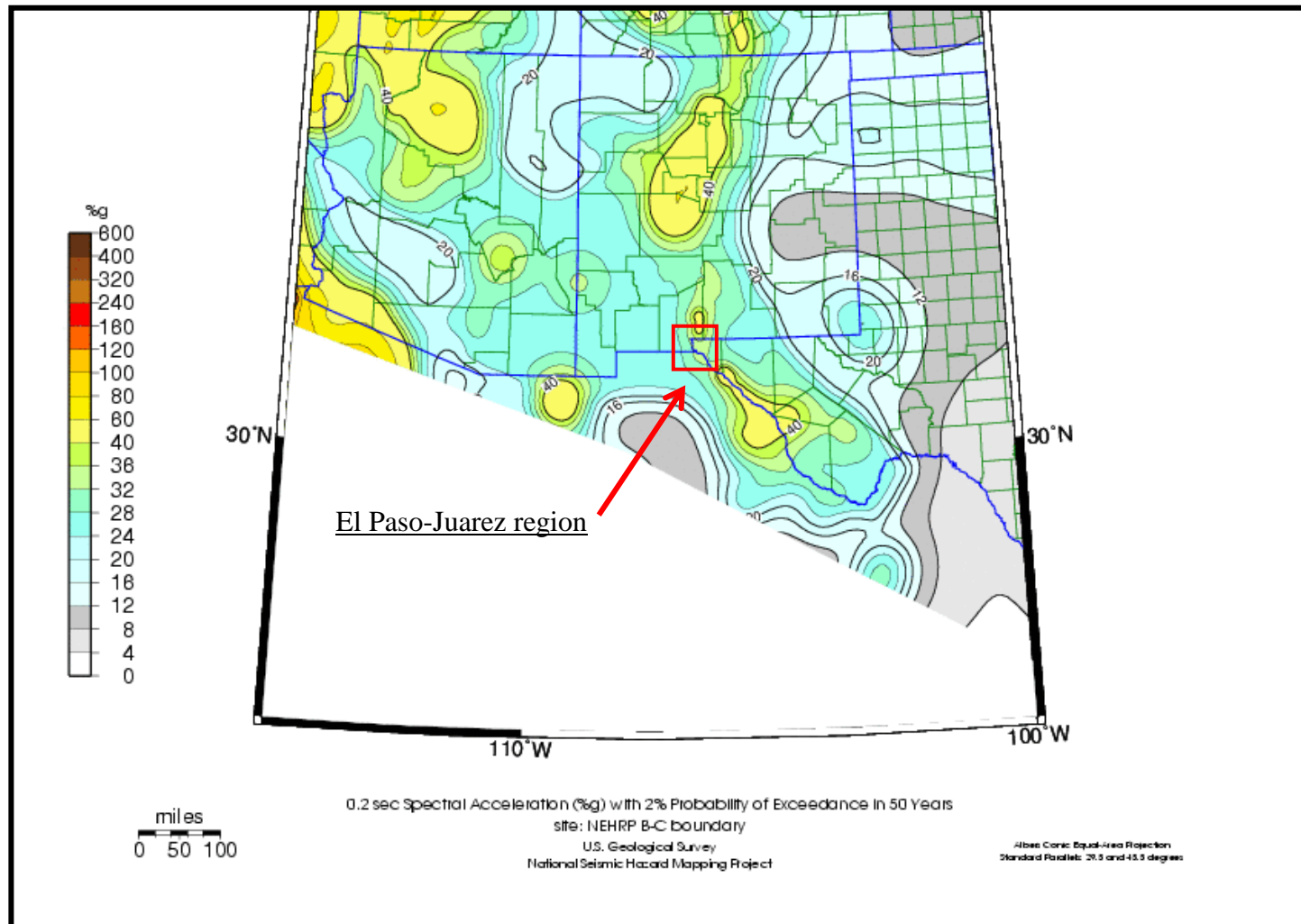


Figure 1.2 El Paso-Juarez region (box) has a 2% risk of having ground accelerations exceed a peak value of 40%g in the next 50 years. Modified from USGS National Seismic Hazard Map. (http://earthquake.usgs.gov/research/hazmaps/interactive/cmaps/custom2002_2006.php).

GEOLOGIC SETTING

Location of the Area

The study was conducted in The El Paso-Ciudad Juarez area which is located in the southernmost part of New Mexico, the western part of Texas, and the northern part of Chihuahua, Mexico (Figure 2.1). This area includes the Hueco basin and the Mesilla basin. These basins are bounded by the Potrillo Mountains and the Sierra de Juarez to the west, by the Hueco Mountains to the east and to the south by Sierra el Presidio and Sierra de Guadalupe (Figure 2.1). These basins contain alluvial aquifers that serve as sources of water for the municipal and industrial needs of El Paso and Juarez.

Geology of the Area

There is a large contrast in structure and stratigraphy between the Franklin Mountains in El Paso TX and Sierra de Juarez in Mexico. The Franklin Mountains exhibit Proterozoic, metasedimentary and igneous rocks that are capped by 2,500 m of Paleozoic sedimentary rocks with minor amounts of high angle reverse faulting during the Paleocene. The Franklin Mountains currently tilt west (average 35°) due to the faster rate of uplift of the eastern side of the range along the East Franklin fault (Harbour, 1972; Richardson 1909). The Sierra de Juarez on the other hand, is composed mainly of Cretaceous sedimentary rocks deformed by folding and thrust faulting during the Paleocene or Eocene age (Drewes 1993). In a large scale the Sierra de Juarez structures form a small synclinorium, or a composite syncline, of older Cretaceous rocks, which was thrust faulted northeastward over younger Cretaceous rocks (Drewes 1993). These Mountains lie in the middle of two major basins the Hueco Bolson and Mesilla Bolson, thus forming intermontane basins (Figure 2.2) similar to other basins in central new Mexico, West

Texas and the northern Chihuahua Mexico. The basin, were formed by Cenozoic extensional tectonism related to the development of the southern basin and Range and the Rio Grande Rift. (Keller et al., 1990). These basins are underlain by Cretaceous and older strata and filled with Tertiary and Quaternary sediments.

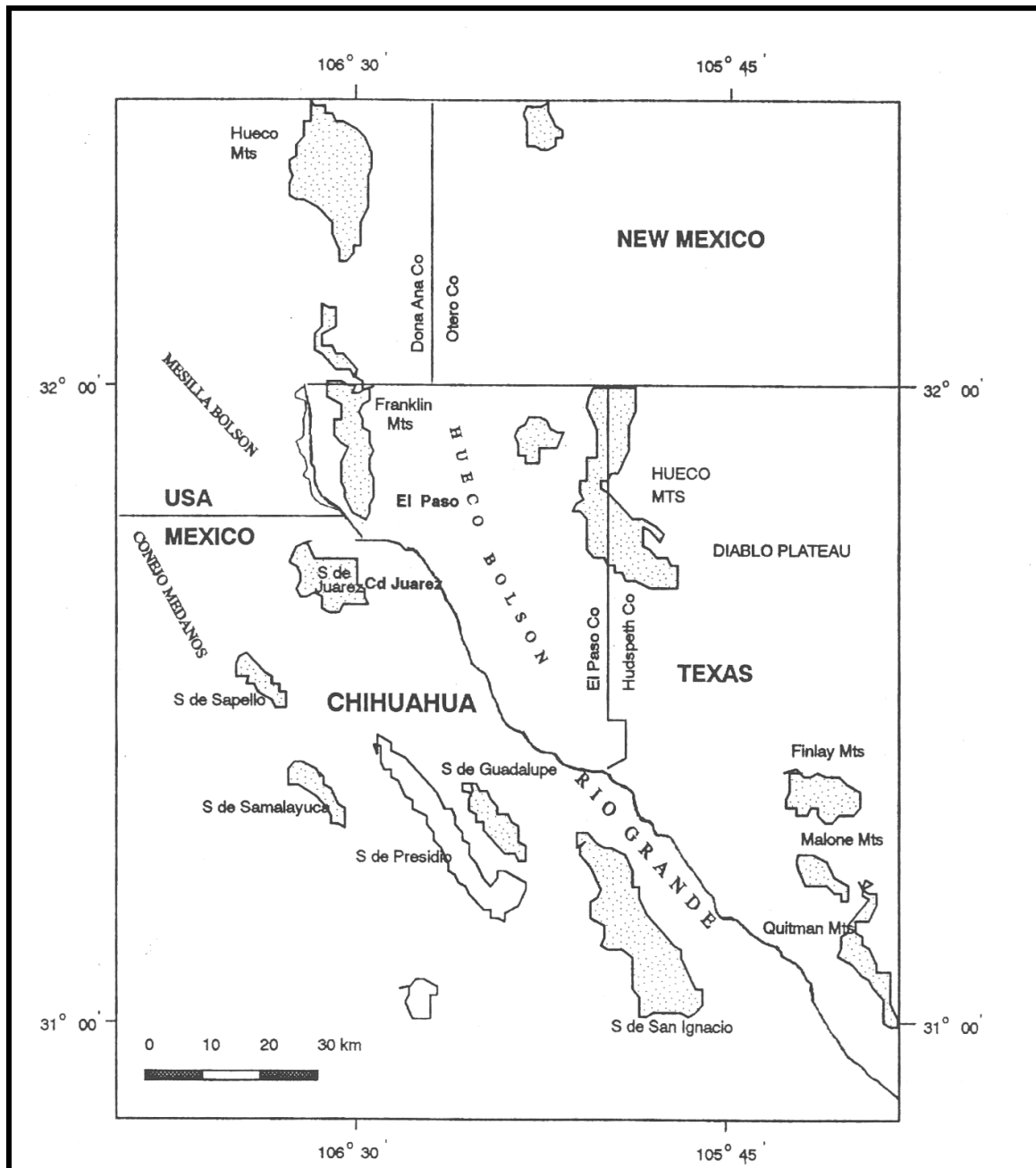


Figure 2.1. Location Map of El Paso-Ciudad Juarez region, showing the bordering Mountains in Texas, New Mexico, and Chihuahua Mexico (modify from Burgos1993)

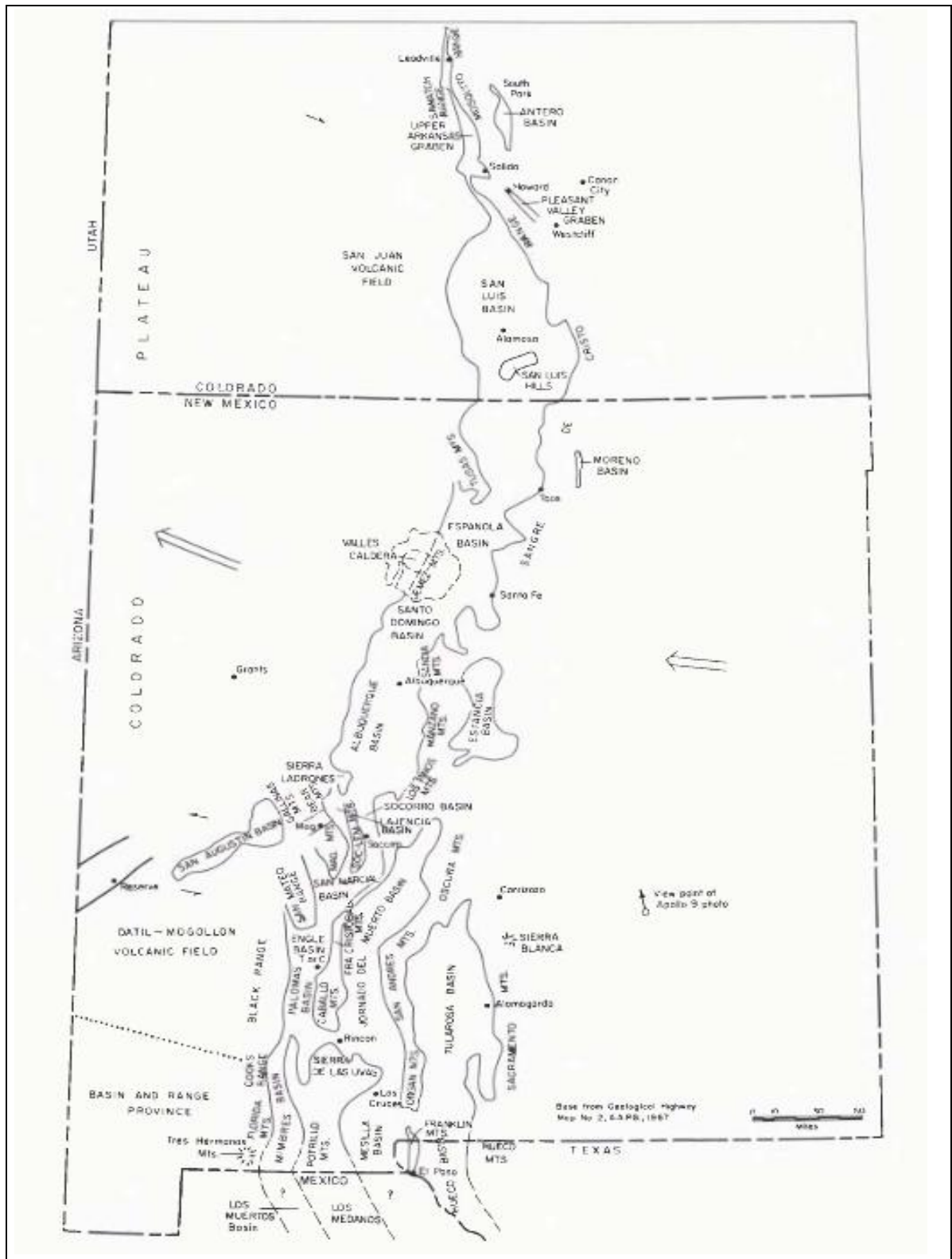


Figure 2.2 Intermontane Basin Structures formed by the Rio Grande Rift.

Regional Tectonics - Rio Grande Rift deformation.

The outcrops around Juarez and El Paso range from Precambrian to Holocene in age, although the current geologic features are due to Tertiary and Quaternary extension of the southern Basin and Range followed by development of the Rio Grande Rift (Keller 1990; Haller 2002). The regional tectonic history is complex prior to the onset of Rio Grande rift related extension, since there is a transition zone between the southern Basin and Range province of southern Arizona and southwestern New Mexico, The High Plains province of eastern New Mexico and part of West Texas, and the Chihuahua Tectonic belt (Denison 1971). The Chihuahua trough was a NW-SE trending basin that formed by the deposition of sediments during Jurassic and Cretaceous periods (figure 2.3). This basin was located westernmost Texas, southern New Mexico and northern Chihuahua (Henry et al., 1985). This period of sedimentation was followed by the Laramide orogeny, which began in late Cretaceous time and lasted into the early Eocene. (Chapin and Cather, 1981; Seager 2004). The crustal shortening and uplift occurred during the orogeny, as well “thin-skinned” overthrusting (Corbitt and Woodward, 1973; Drewes, 1978, Seager and Mack 1986; Seager 2004) and follow a NW-SE trending structural fabric (Keller et al, 1990). Then intense magmatic activity occurred during middle Eocene to Oligocene time (Henry et al., 1985, Keller, 1990). The intrusion of Cerro de Cristo Rey, the Campus Andesite, and more intrusive bodies in Sierra de Juarez region all located around the study area form during this time. The inception of the Rio Grande rift extension reflected a change in stress orientation, most likely a result of the cessation of subduction off southwestern North America. The Rio Grande Rift extends from southern Colorado and northern Chihuahua in Mexico through the middle of New Mexico and far west Texas (figure 2.2) and is characterized by young volcanic activity, high heat flow anomalies, large intermontane basins, and young

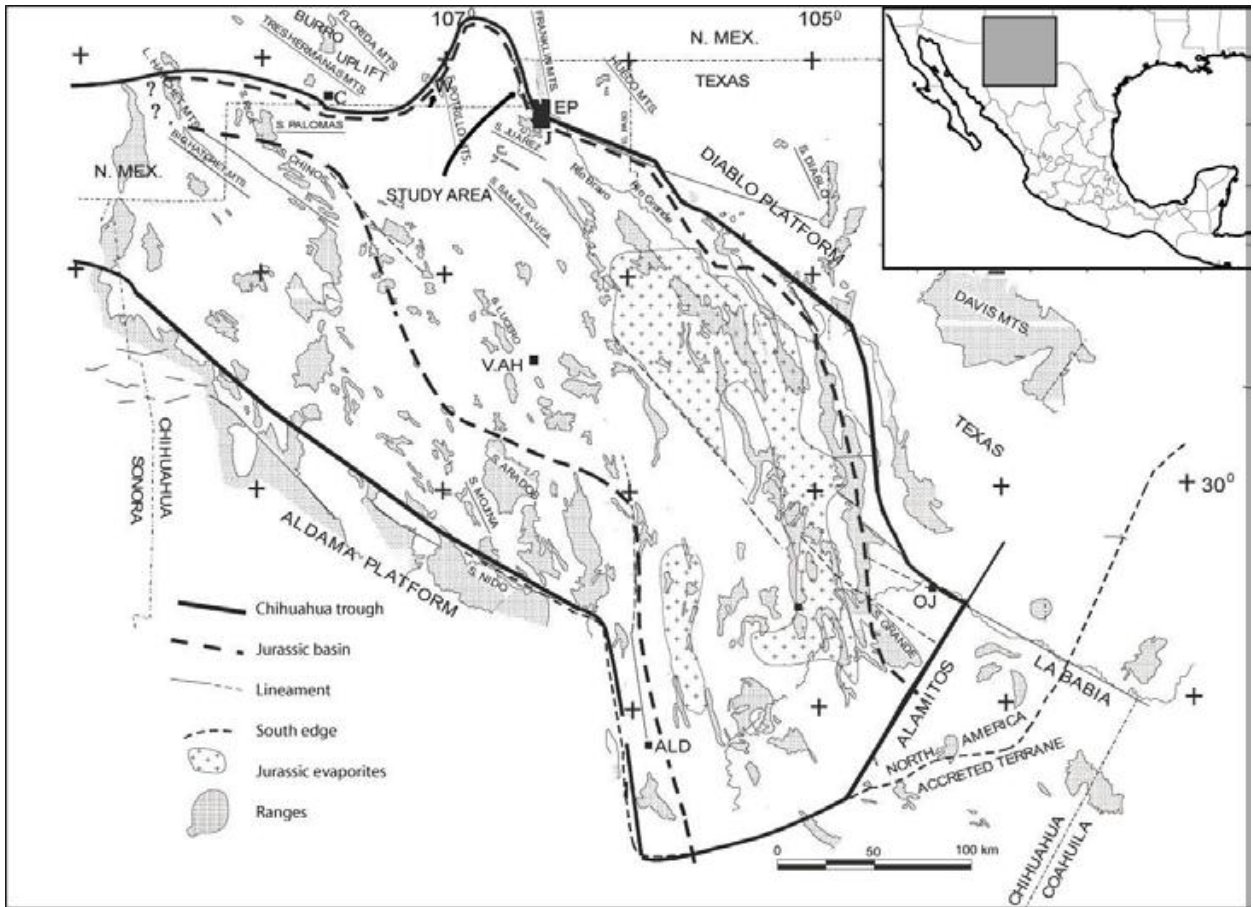


Figure 2.3. Figure Showing the Chihuahuan trough. Modified from Carciumaru 2005

episodes of normal faulting (Seager and Morgan, 1979; Keller et al., 1990; Chapin and Cather, 1994). The transition period from Laramide orogeny to Rio Grande rift extension showed very little tectonic activity (Chapin 1974; Aldrich et al., 1986). There are two separate periods of the rift development (Keller et al., 1990). An early rift phase began 35 and 15 Ma (Morgan et al., 1986; Keller et al 1990; Seager and Mack, 2003). This early phase formed northwest striking normal faults and basins and also produced volcanism. The extension direction of the rift at this stage was oriented east-northeast-west-southwest (Aldrich et al, 1986). According to Keller et al (1990), the second stage of the rift began between approximately 15 to 10 Ma and continues to

the present day. The orientation of the second stage of rift extension is east-west along north-south oriented normal faults and associated basins (Baldrige et al., 1984; Keller et al., 1984; Lewis and Baldrige, 1994). The second phase of rifting is also characterized by a large reduction of volcanic activity (Mack, 2004). The extension of the Rio Grande rift is still active at present day along Quaternary normal faults, such as the concealed ones in the heavily urbanized areas of El Paso and Ciudad Juarez that I propose to map in this thesis, using geophysical techniques.

Fault Description– Study Area

The Franklin Mountains are bounded by two major fault zones the Western Boundary fault zone and The Eastern Boundary fault zone. (see figure 2.4). The Western Boundary Fault Zone (WBFZ) was a named proposed by Lovejoy (1976) and Richardson (1909) was the first to identify this feature. This fault explains the observed offset of the upper Santa Fe Group and change in the course of the Rio Grande on western side of the Franklin Mountains. Lovejoy (1975), Drewes (1988), Wu (2002) have documented that the WBFZ includes an east dipping reverse, and west dipping high angle normal fault. The Eastern Boundary Fault Zone (EBFZ) is the one that is driving this study. Since it has been identified by the USGS as having movement within <15,000 years and poses a seismic risk to the urbanized area. This fault zone forms a series of range front scraps along the eastern base of the Franklin Mountains and Sierra de Juarez. This fault zone is part of a longer system that includes the Artillery Range, Organ Mountains and the San Andres faults in New Mexico. At the surface the main fault of dips 76° as measured near its northern end (Keaton and Barnes, 1995).

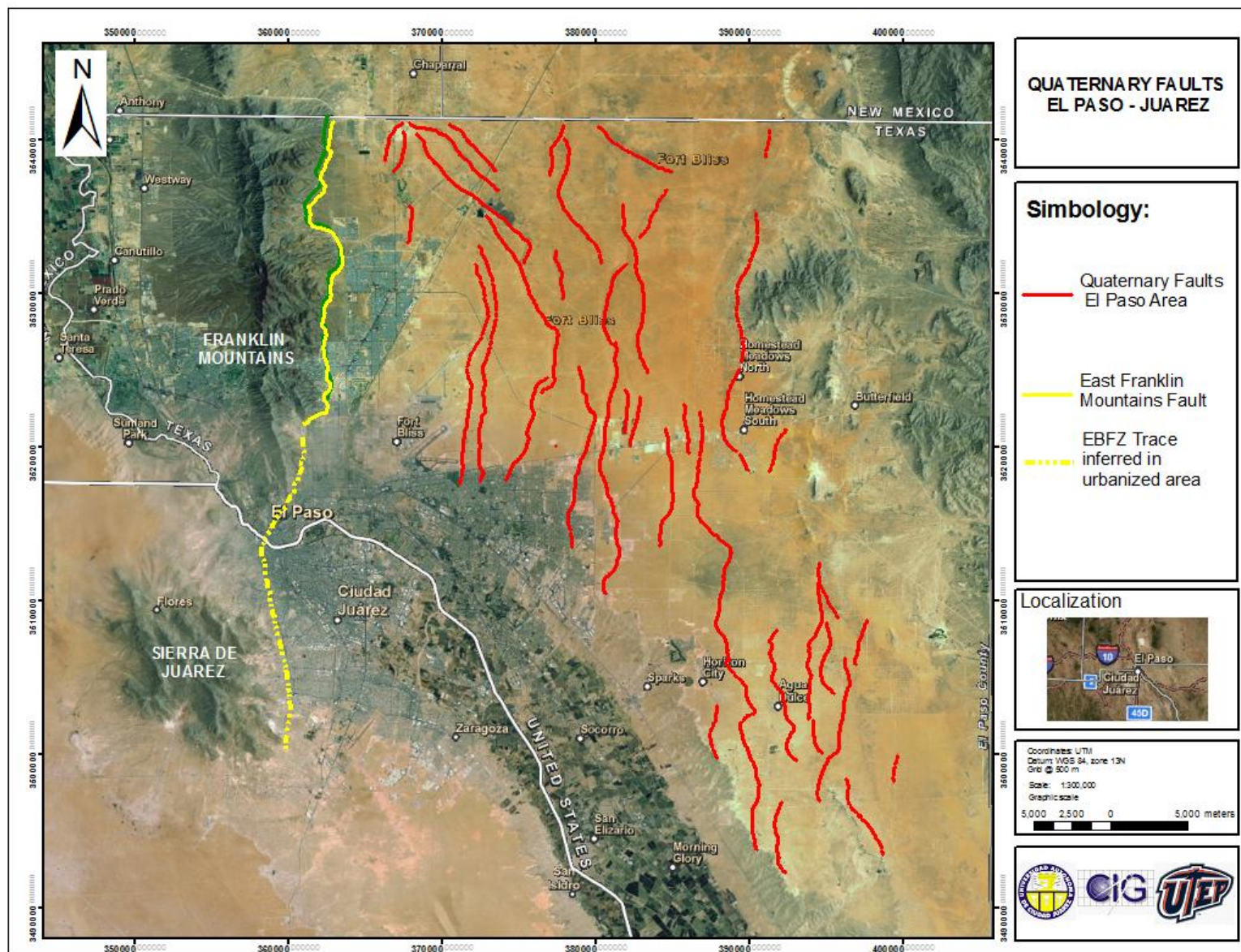


Figure 2.4. Map from USGS Quaternary Faults data base. Showing the East Franklin Mountain Boundary Fault Zone.

PREVIOUS WORK

This section reviews previous gravity studies conducted in both the Mesilla bolson and Hueco Bolson. One of the most significant geophysical studies in the Mesilla bolson basin was done by Imana (2003). An integrated study that used a gravity method that was constrained with DC Resistivity and well logs data, to develop models of density variation within the basin. Although the main objective of Imana's was not to delineate faults within the basin structure, he was able to propose the existence of several faults within the bolson. These faults that were not identified before in earlier geological or geophysical studies, were named the Three Sister fault, the I-10 west fault, and Rio Grande fault. These faults (Figure 3.1) trend N/S and NW/SE, and play a major role in the hydrological process in the basin and. Imana also used a different gravity reduction technique instead of the standard gravity reduction. He first calculated a theoretical gravity value, that was obtained by developing a two dimensional model of the topography and surface geology along a profile. Then he subtracted these calculated values from the observed free-air anomaly values, and proceeded to model these residuals (termed residual1) to obtain the probable longer wavelength, deeper geologic features along the profiles. Next the gravity values estimated from these longer wavelength structures were subtracted from the first residual to acquire a second set of residual values (residual2). It is this second set of residuals that Imana modeled to determine the shallow geologic structures observed in the Mesilla bolson.

Khatun (2003) and Khatun et al. (2007) continued studying faults in the Mesilla bolson, Khatun objectives were to look for faults in the southern part of the Mesilla bolson basin and augment the resolution of the faults mapped by Imana. Her gravity transect lines consisted of three N-S gravity oriented transects that were perpendicular to Imana's transects (Figure 3.1).

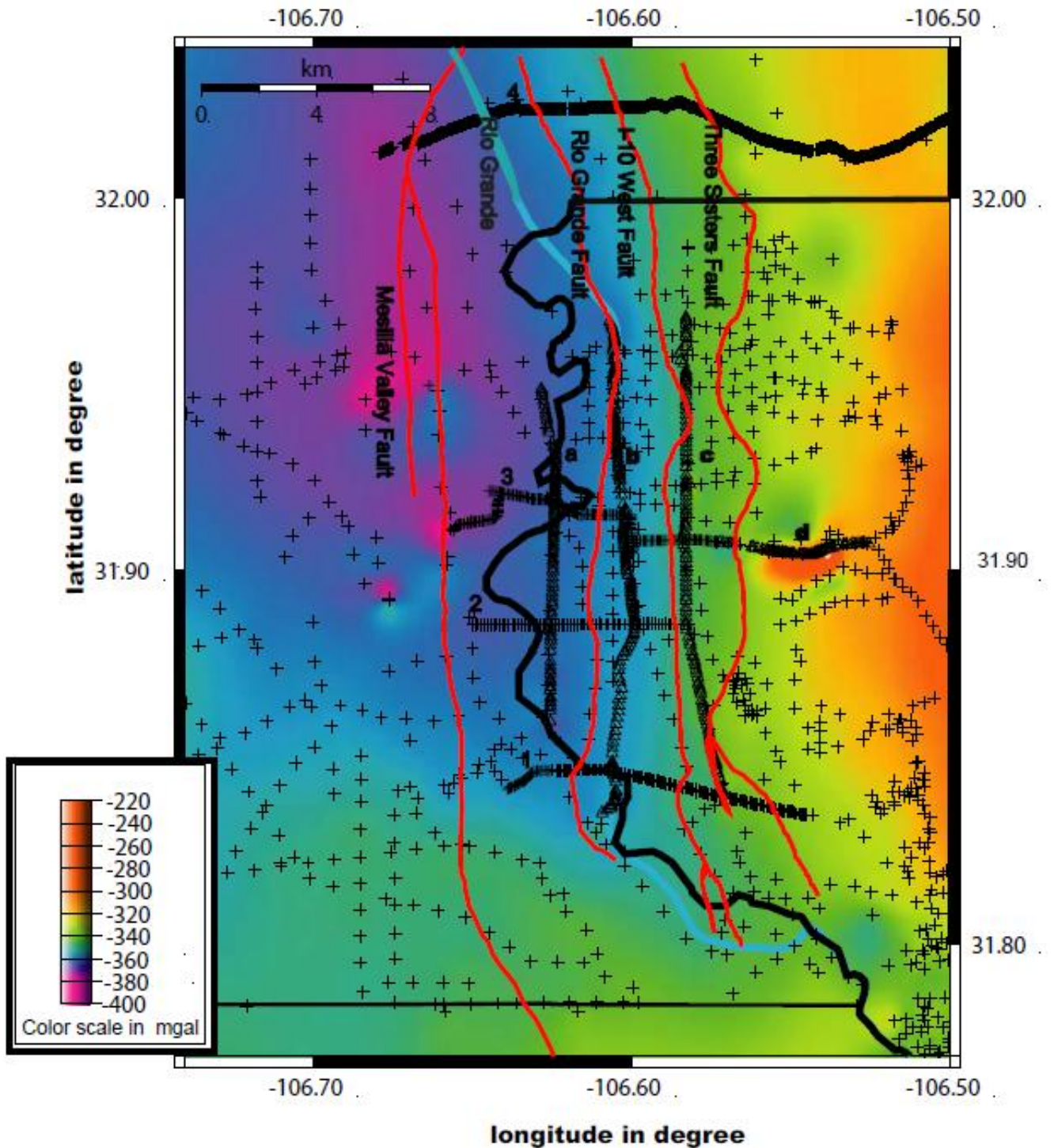


Figure 3.1: Free Air Anomaly Map of the Mesilla Valley area. The Three Sisters, I-10 West and Rio Grande faults are based on the gravity modeling studies of Imana (2002). Black lines indicate state and national borders. Plus signs are gravity observations points. The blue line is the Rio Grande. The Mesilla Valley fault is from Hawley (1992). Lines 1, 2, 3 are from Imana (2002). Line 4 is from Figueroa (1987). Lines a, b, c and d were collected by Khatun (2003). Modified from Khatun (2003).

Khatun also used Imana's technique but also tested a newly develop 3-D gravity modeling technique, created by Baker and Crain (2003) is called SURFGRAV.

The original algorithm was based on the 3-D triangular prism method of Zhou et al (1990) but was modified to use line elements to model gravitation attraction due to density distributions, considerably speeding computational process. Khatun suggested different orientations for the three faults previously named by Imana (Blue lines, Figure 3.2) in addition to evidence for a transverse fault located north of Mt Cristo Rey that truncates the north-south trending faults (magenta line, Figure 3.2).

Another study that complements the findings by Imana and Khatun is the work by Sellepack (2003) who studied the stratigraphy of the Pliocene-Pleistocene of the Santa Fe group in the Mesilla Basin. Sellepack was able to corroborate the existence of faults found by Imana, using well logs and measured sections of outcrop, She illustrated large off-sets on the model cross-sections constructed from well log information that were interpreted to be a series of sub-parallel, high angle normal faults.

Two major gravity studies have been conducted by Burgos (1993) and Hadi (1991) within the Hueco Bolson. Hadi's study focused on modeling Bouguer anomaly data collected on the U.S. side of the basin. He developed density models based on well logs, seismic velocities, and measurements of samples from outcrops.

Hadi Suggested that the Hueco Bolson was composed of two deep elongated basins that separated by shallow hinge zone located between San Isidro and Zaragoza.

The objective of Burgos study was to determine the thickness of the unconsolidated sediments with the basin. His work consisted in consolidating data collected in Ciudad Juarez with the existing UTEP gravity database. He took approximately 240 gravity measurements in Ciudad Juarez using a Worden gravimeter with precision of 0.01 miliGal. In order to constrain his gravity data he used density models developed by Hadi (1991) in order to be consistent with the previous study and to give continuity to Hadi's work.

Burgos produced several of gravity cross-section profiles across the Hueco bolson based on Bouguer anomaly values. These profiles showed the variation in the thickness of the basin and also a sub-basin within the Hueco bolson. Other features that were identified in his cross-section profiles, was faults cutting Quaternary and Tertiary sediments deposited in the basin. One main fault identified by Burgos was the East Franklin Mountain Fault or called the East Boundary Fault Zone (EBFZ) in this thesis (see Figure 3.4). The EBFZ was also is very prominently shown in a Bouguer anomaly map made by Burgos (Figure 3.3) where the values decrease towards the southeastern part of the study area. Burgos also found that in the Juarez area is located in the deepest part of the basin (2.3 km).

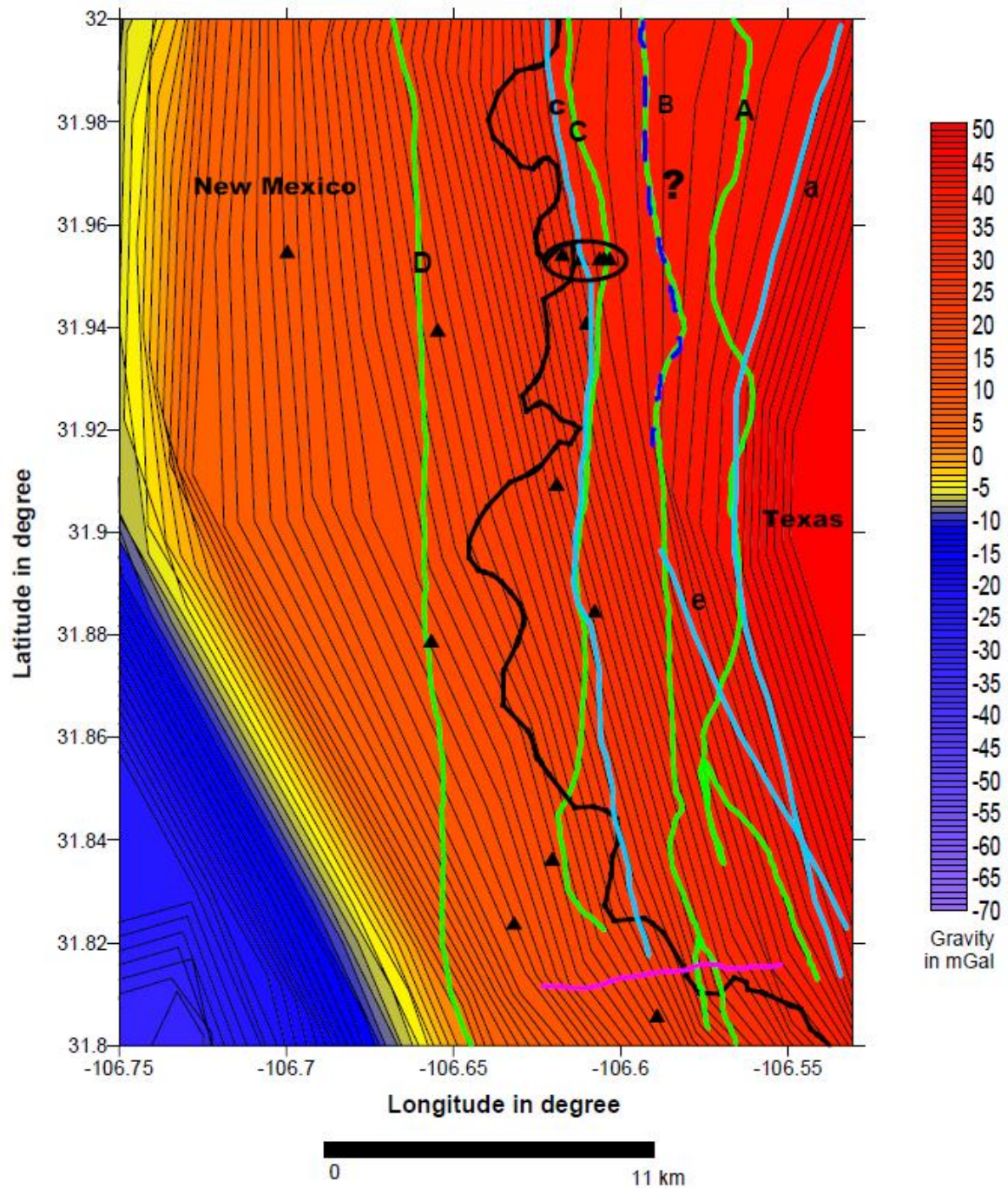


Figure 3.2 Free air anomaly map showing the residual gravity over the Mesilla bolson study area. Green lines labeled A, B, C and D are the Three Sisters fault, I-10 west fault Rio Grande fault (Imana, 2003) and Mesilla Valley fault (Hawley, 1992), respectively. Pink line is an accommodation zone and the blue lines labeled a,b, c and e are the faults interpreted by Khatun (2003). According to Khatun (2003) part of fault B shown as dotted line may not exist. Triangles are wells (Imana, 2003). Contour interval is 1 mGal. Black line is Texas-New Mexico border. Modified from Khatun (2003)

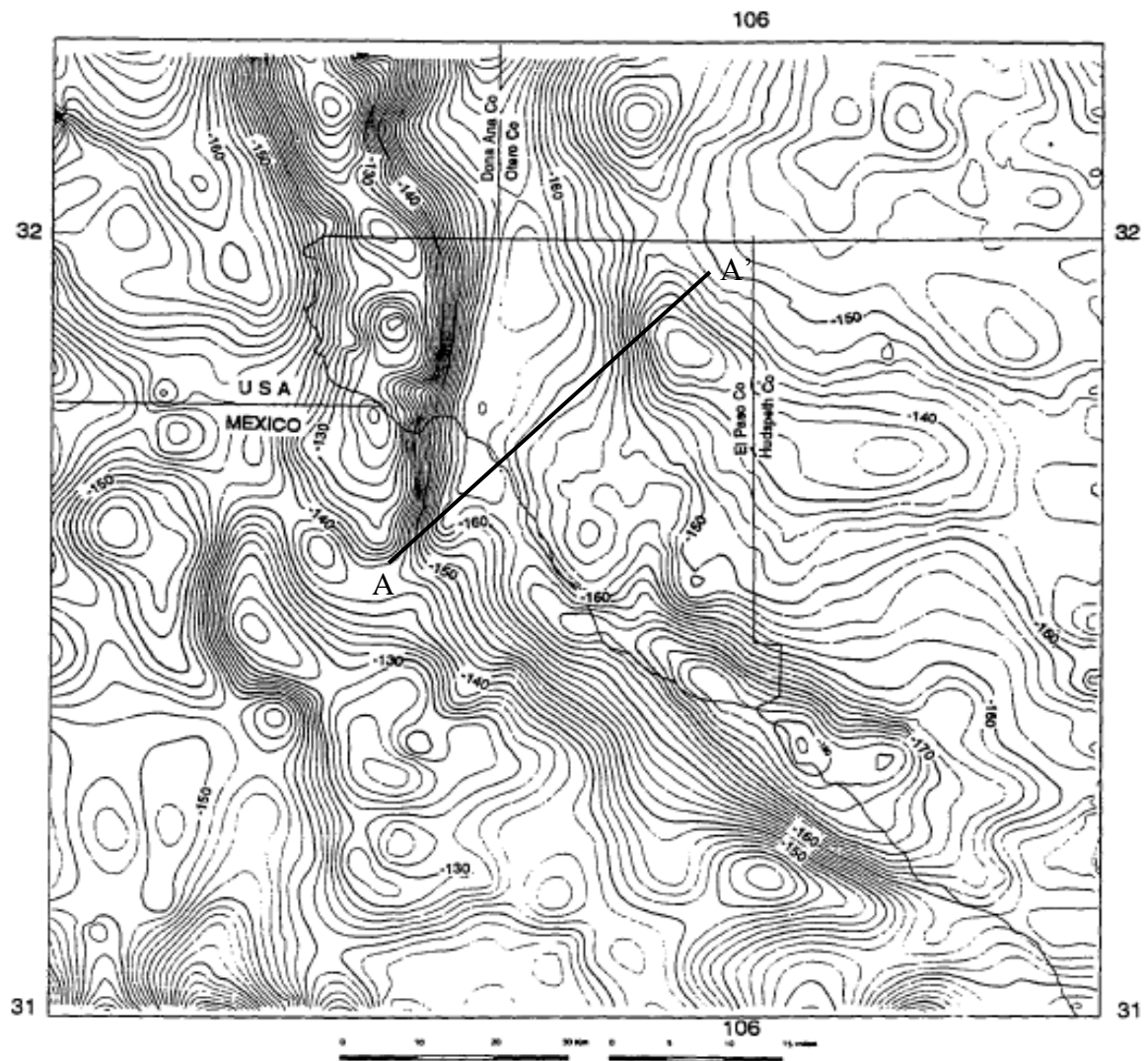


Figure 3.3 Bouguer Anomaly map from showing profile A-A'. Modified from Burgos (1993).

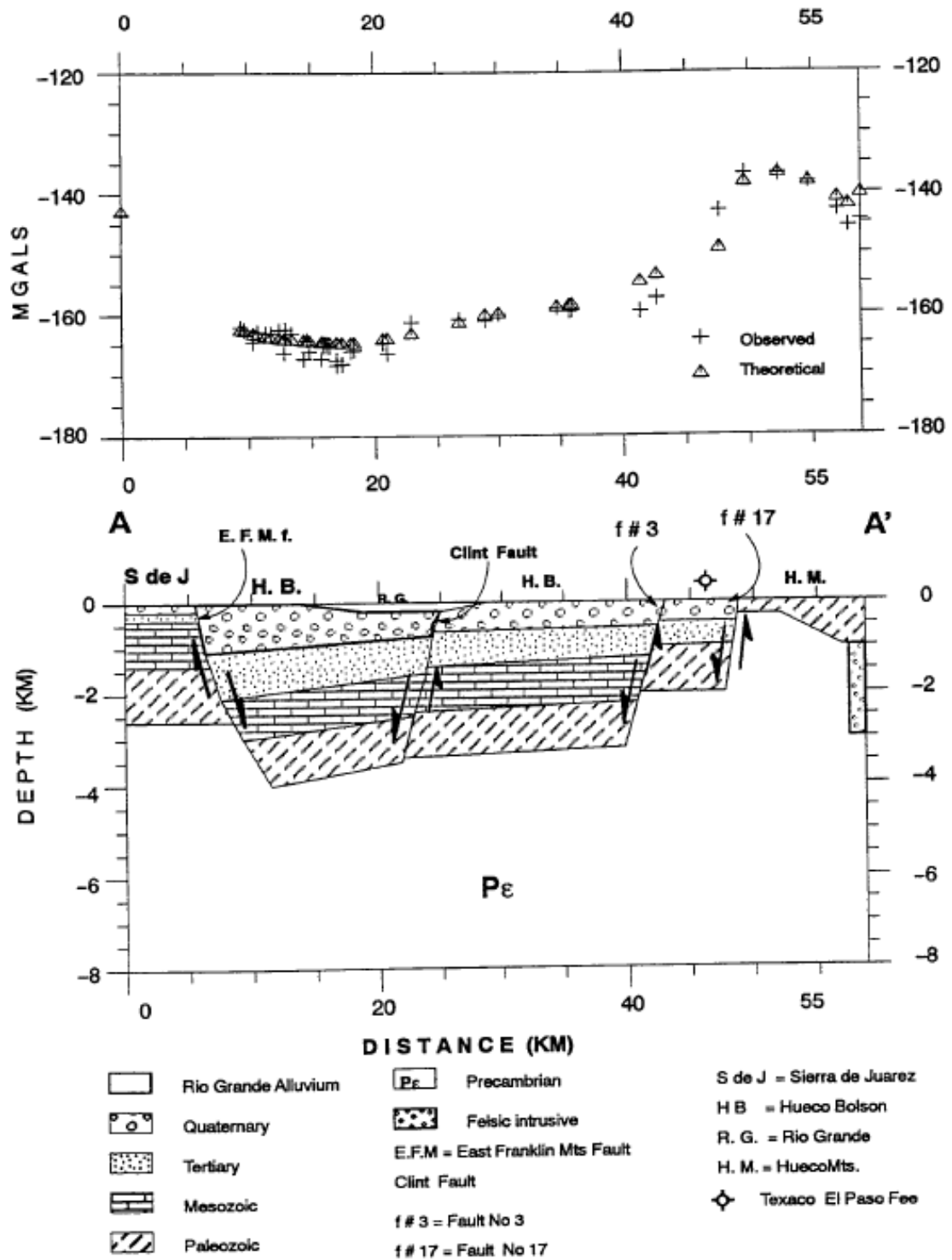


Figure 3.4 Gravity cross-section profile from Burgos (1993) showing the EFMF (EBFZ), where is cutting Quaternary sediment

DATA COLLECTION

Gravity is one of the few geophysical tools available to map The Eastern Boundary Fault Zone (EBFZ) that passes through the heavily urbanized area of El Paso and Ciudad Juarez, as gravity can differentiate the density contrast marked by the offsets of geological structures across the fault and is not strongly affected by cultural features. Several gravity observation transects were collected across the fault on both sides of the border. For the collection of El Paso gravity data a LaCoste and Romberg gravity meter was used. Precise elevations for the El Paso surveys were obtained by taking gravity readings next to city monuments located at the edges city blocks. These monuments locations have been precisely determined through traditional surveying and differential GPS surveys. Gravity data in Ciudad Juarez was collected with a CG-5 gravity meter, owned by Universidad Autonoma de Ciudad Juarez (UACJ). Real time kinematic (RTK) GPS (using a Sokkia GNSS L1/L2-System) was employed to obtain precise locations (elevations to within 2 mm) for gravity measurements in Ciudad Juarez Figure 4.1 shows the location of gravity data collected across the EBFZ. GPS data was handled in WGS84 datum.

Survey Operations

The first part of the gravity survey focused on El Paso and a gravity base station was established at the Kidd Memorial Seismic Observatory. Data were collected during night time (2 a.m. and 6 a.m.) to avoid traffic vibrations due that could affect the gravity readings. Data were collected in loops, where the first reading was taken at the base station, then readings were taken along the transect, and the last reading was again take at the base station. Ideally the loops were completed in about five hours. This was done to correct for drift correction and tidal effects. Spacing for the gravity measurements in El Paso were controlled by the distances the distances between the city blocks, approximately 150 meters.

The second part of the survey was conducted in Ciudad Juarez, Mexico. Data were collected using a gravity base station provided by INEGI (Instituto Nacional de Estadística y Geografía) with station ID# 12091. For safety and security reasons gravity measurements in Juarez were done during day light hours. Once the CG-5 gravimeter is level it can automatically take repeated readings at a station, providing the statistics for each reading. In this study the CG-5 was setup to take 30 readings and average them and then two average readings per station need it to be repeatable in order to accept the measurement. Also this measurement was not accepted unless it had a standard deviation of less 0.30 mGal. This allowed me to take readings during the day time where there was traffic that could add noise to the gravity data. For opening and closing at the gravity base station three readings were repeated in order to accept the measurement and also to complete the gravity closure at the base station, it had to have a standard <50 microGals. By using this procedure allowed quality and consistency in the gravity data and served to filter out readings with a lot a noise.

Data Pre-Processing

Before the collected data could be merged with another gravity database standard gravity reductions were done. First tide, dial (for Lacoste-Romberg data) and drift corrections were applied to produce absolute gravity. Then corrections that account for the flattening of earth (latitude), and free air and terrain corrections were applied and finally a complete Bouguer anomaly was obtained with a reduction density of 2.67 g/cc was used. This process was to ensure that the data were consisted with UTEP's gravity database. Complete Bouguer anomaly is a result of the following equation:

$$\Delta g_{cb} = g_{obs} - g_{fa} - g_{sb} - g_t - g_0$$

Where:

Δg_{cb} = complete Bouguer anomaly

g_{obs} = Observed Gravity

g_{fa} = Free Air Anomaly

g_{sb} = Bouguer Correction

g_{gt} = terrain Correction

g_0 = theoretical gravity

Gravity Data Base

The data collected in El Paso and Ciudad Juarez was merged with UTEP database which is a larger gravity database of the region. Additional data were obtained through the Pan-American Center for Earth and Environmental Studies (PACES) website. This larger scale gravity database was compile with the intention of insuring that the data I collected were consistent with these previous data sets and to make larger scale interpretations. The datum of all databases was converted to WGS84 in order to be consisting. Figure 4.2 shows the gravity stations collected in Juarez (red), gravity stations collected in El Paso (yellow) and green dots represent data from UTEP's gravity data base and PACES. These merged data were used with the *Oasis Montaj*TM software package to process and analyzed the Bouguer anomaly values.

Another pre-processing step that was needed to calculate the complete Bouguer anomaly was to subtract the terrain correction which compensates for the measurements made near the topographic features. A regional Digital Elevation Model (DEM) of the area was provided by CIG (Geographic information Center) a department of UACJ and used in the correction. The DEM of the area is shown in figure 4.3.

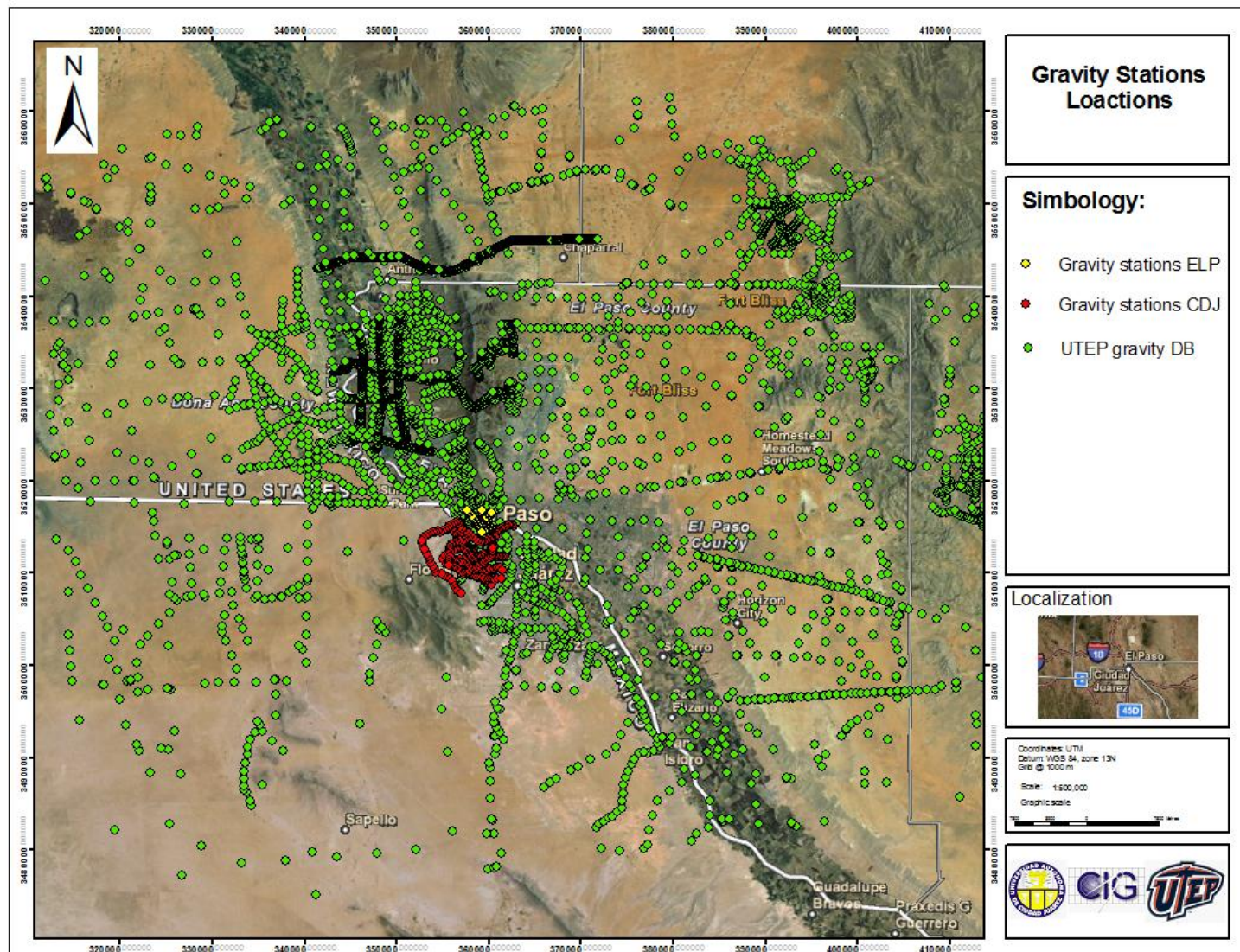


Figure 4.1 Map Showing Gravity measurements Juarez and El Paso TX. Red dots show stations in Ciudad Juarez. Yellow dots shows data collected in El Paso. Green dots UTEP'S gravity stations for the El Paso-Juarez area

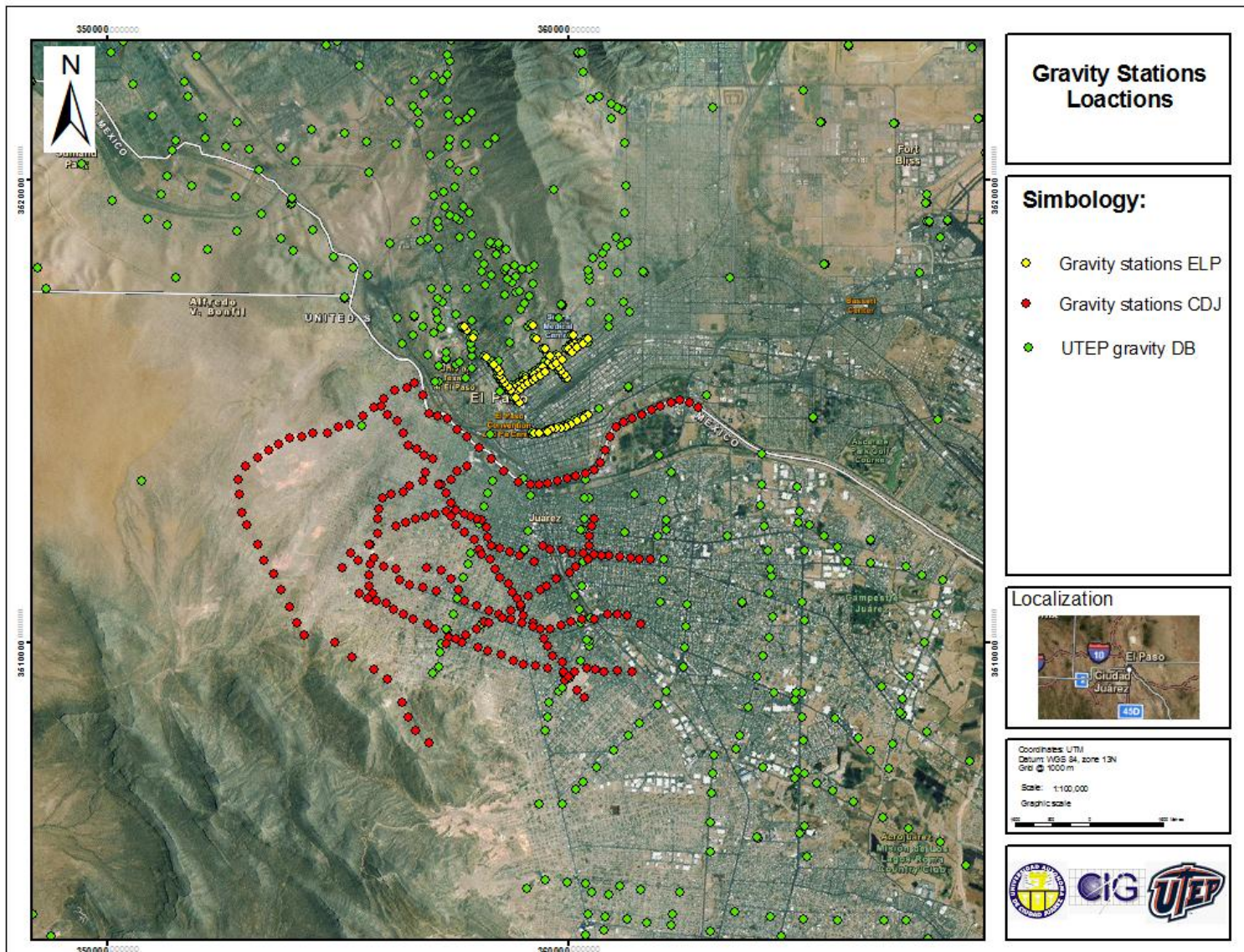


Figure 4.2 UTEP's database merge with gravity collected. Green dots UTEP's gravity data base. Red dots Juarez data. Yellow El Paso data collected

The Complete Bouguer anomaly map was produced by using a minimum curvature gridding process, since the merge data were not acquired at regular spacing and for additional data analysis, such as filtering studies. The minimum curvature surface is the smoothest possible surface that will fit the data values measured. The Map in figure 4.4 shows the complete Bouguer anomaly values of the region.

The map shows a good match with the existing gravity database, with low values within the Hueco bolson and Mesilla basin and high anomaly values around mountains and igneous intrusions in the area. Also visible the steep gradient associated with the EBFZ. Note the lower anomaly values southwest of the Sierra de Juarez that suggest additional structure at the southern end of the mountains. The complete extent of this feature is not well known given the poorer gravity coverage within this region.

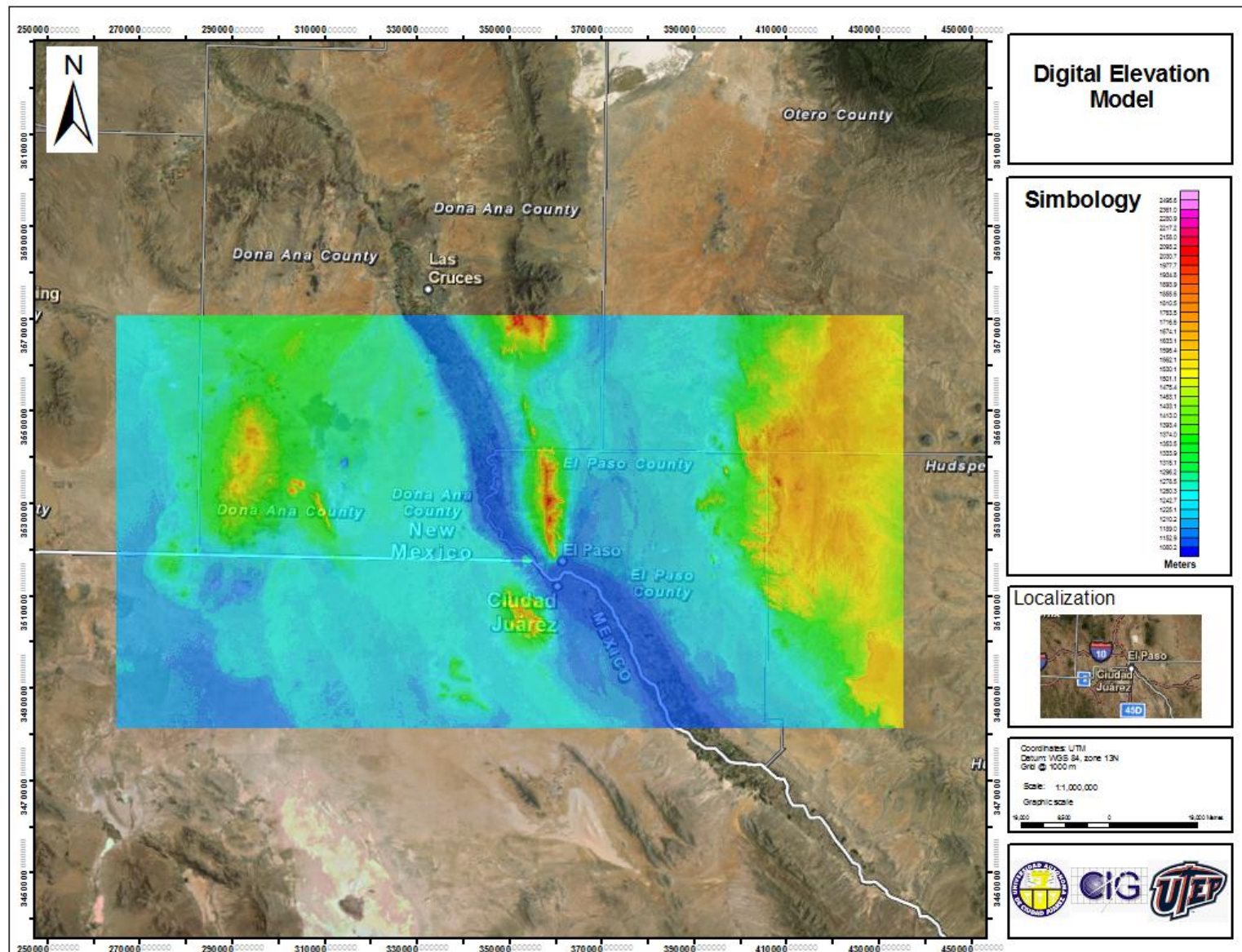


Figure 4.3 DEM for the study area

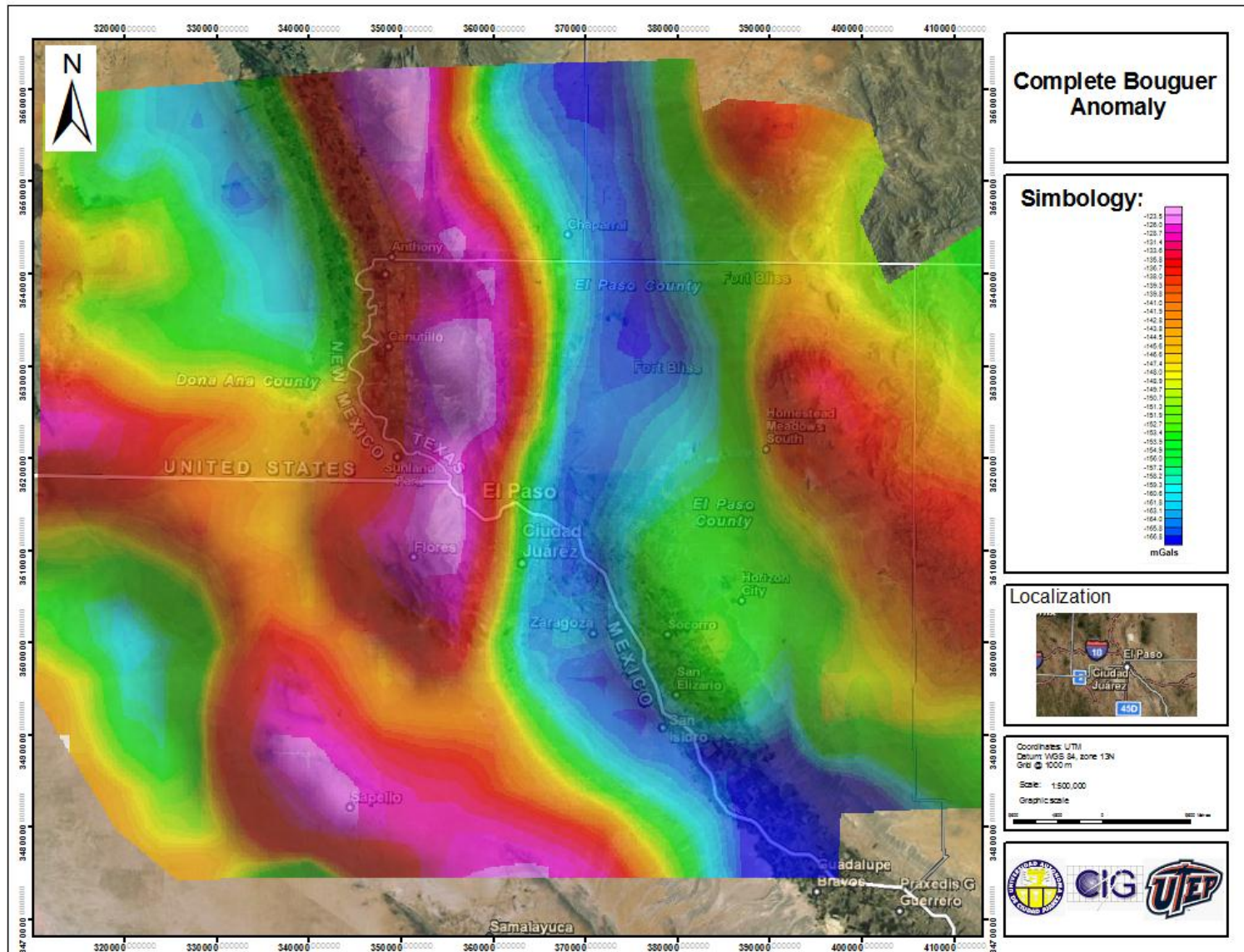


Figure 4.4 Complete Bouguer anomaly map showing steep gradient change from high to low density where the EBFZ is located.

DATA ANALYSIS

The Complete Bouguer anomaly map varies with the main geologic features surrounding the study area (Figure 5.1). High gravity values are associated with the mountain ranges; (Franklin Mountains, Sierra de Juarez and Hueco Mountains). Between them are gravity lows trending north-south and southeast-northwest related to the Hueco. There is a sharp contrast in values on the east side of the Franklin Mountains that marks the trace of the East Boundary Fault Zone. This contrast continues into Chihuahua through the urbanized area of El Paso-Ciudad Juarez. West of the Franklin Mountains are low gravity values associated with the Mesilla Bolson area. Note that there is an interesting NW-SE anomaly trending low located south of the Sierra de Juarez but there are not enough gravity stations in that area to better delineate this geological structure.

Since the objective of this study is to focus on locating the East Boundary Fault Zone in the downtown area of El Paso and Ciudad Juarez, I have extracted gravity values from the larger regional map (Figure 5.1) to obtain a map of the study area (Figure 5.2). This map was enhanced by applying a color shaded relief to the data set; I used Oasis MontajTM software for gridding, and filtering the data. The Grid cell size allowed for Figure 5.1 is 2 km due to the poor coverage of the larger region. In (Figure 5.2) my closely spaced surveys allowed for a grid size is 500 meters.

The Complete Bouguer anomaly is the result of the effects caused by regional and local features that deviate from the standard Bouguer reduction density of 2.67 g/cc. Regional features create long wavelength anomalies and local features short wavelength anomalies.

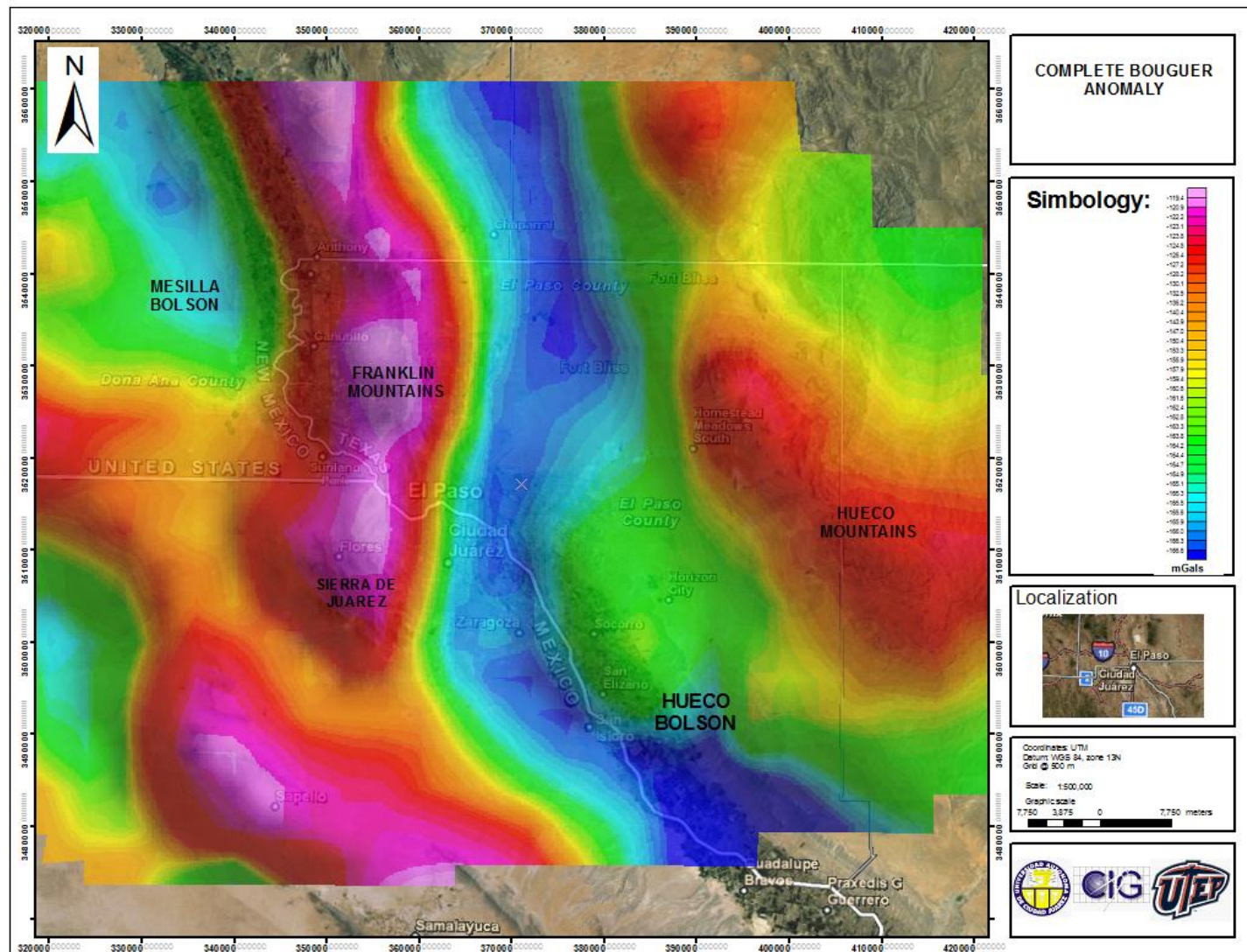


Figure 5.1 Complete Bouguer Anomaly map showing major geological features surrounding study area. High gravity values for Mountains, FM, SJ, HM, Low gravity Values for basins (Hueco and Mesilla).

The complete Bouguer anomaly map is the starting point for subsequent processing. In order to remove some of the high intensity anomalies caused by the large regional gravity values, a filter that removes the trend surface from the gridded area (Baher, 2001) was applied, obtaining Figure 5.3. In this case a third order polynomial was used in order to remove the deep seated regional gravity field from the Complete Bouguer anomaly map. This leaves a residual Bouguer anomaly produced by the variations in the thickness of the low density basin fill surrounding the El Paso and Juarez region. The map shows sharp contrasts between the low gravity values within the Hueco basin and the high values of the Franklin Mountains at the west side of the basin.

The next step in the analysis was to apply a derivative filters. The vertical derivatives of anomalies provide a powerful technique for enhancing anomalies of smaller and near-surface geological features (Sharma 1997) and delineating the edges of these features. This derivative filter was used in order to emphasize shallow basements structures, although it responds equally well to both shallow and deep structures.

The residual Bouguer anomaly values were used as input and a tilt derivative filter was applied using Oasis MontajTM software (see Figure 5.4). The tilt filter is defined as the arctangent of the ratio of the vertical derivative to the absolute value of the magnitude of the horizontal gradient of the field. For isolated sources, the tilt angle is positive over the source, crosses through zero at or near the edge of a vertical sided source, and is negative outside the source region (Verduzco, et al., 2004). This filter acts like an automatic gain control (AGC) filter and tends to equalize the amplitudes of the Bouguer gravity anomalies across the grid.

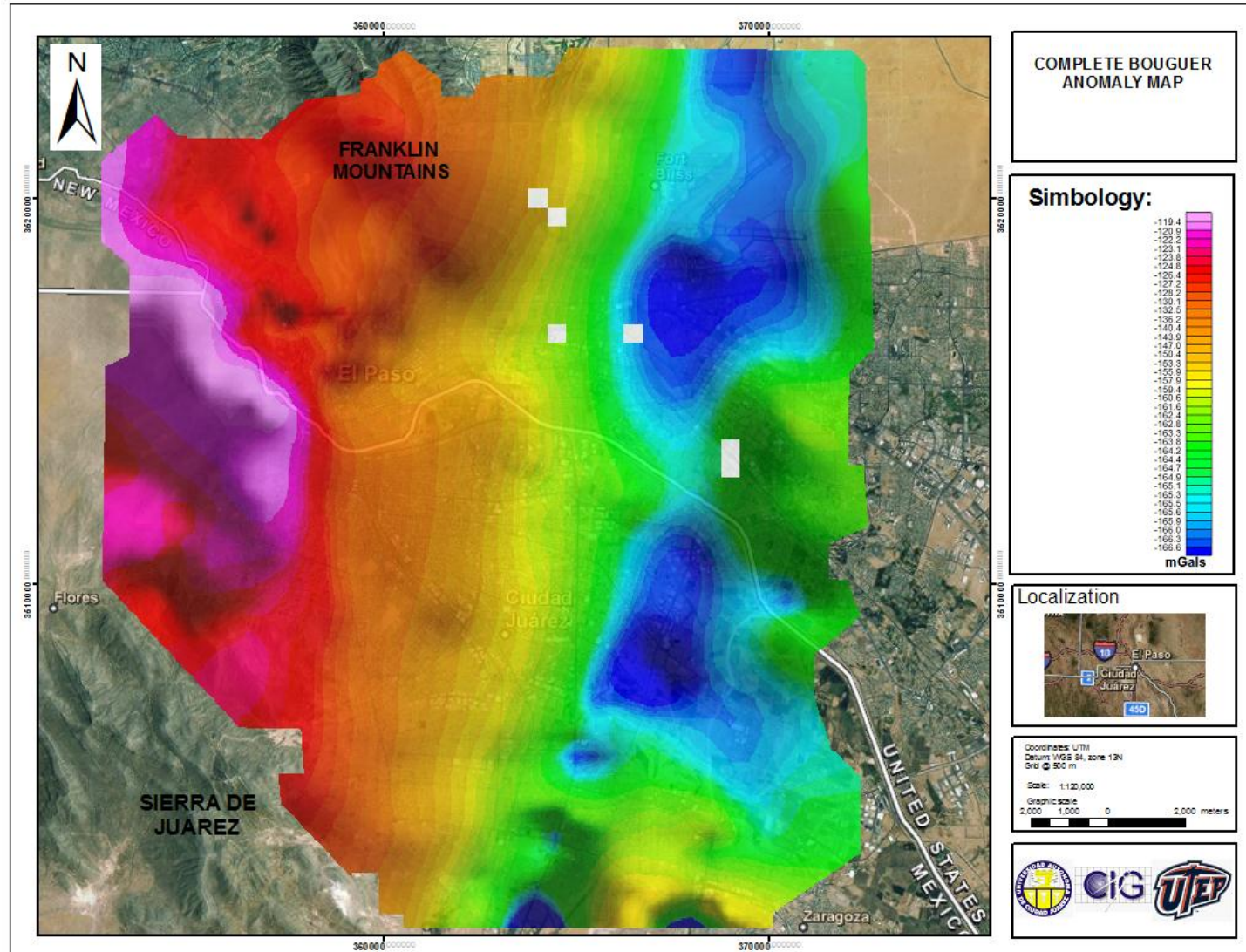


Figure 5.2 Complete Bouguer anomaly map. This map is a reduced scale to analyze with the downtown area of El Paso-Ciudad Juárez. High gravity values are associated with mountains and basins with gravity lows

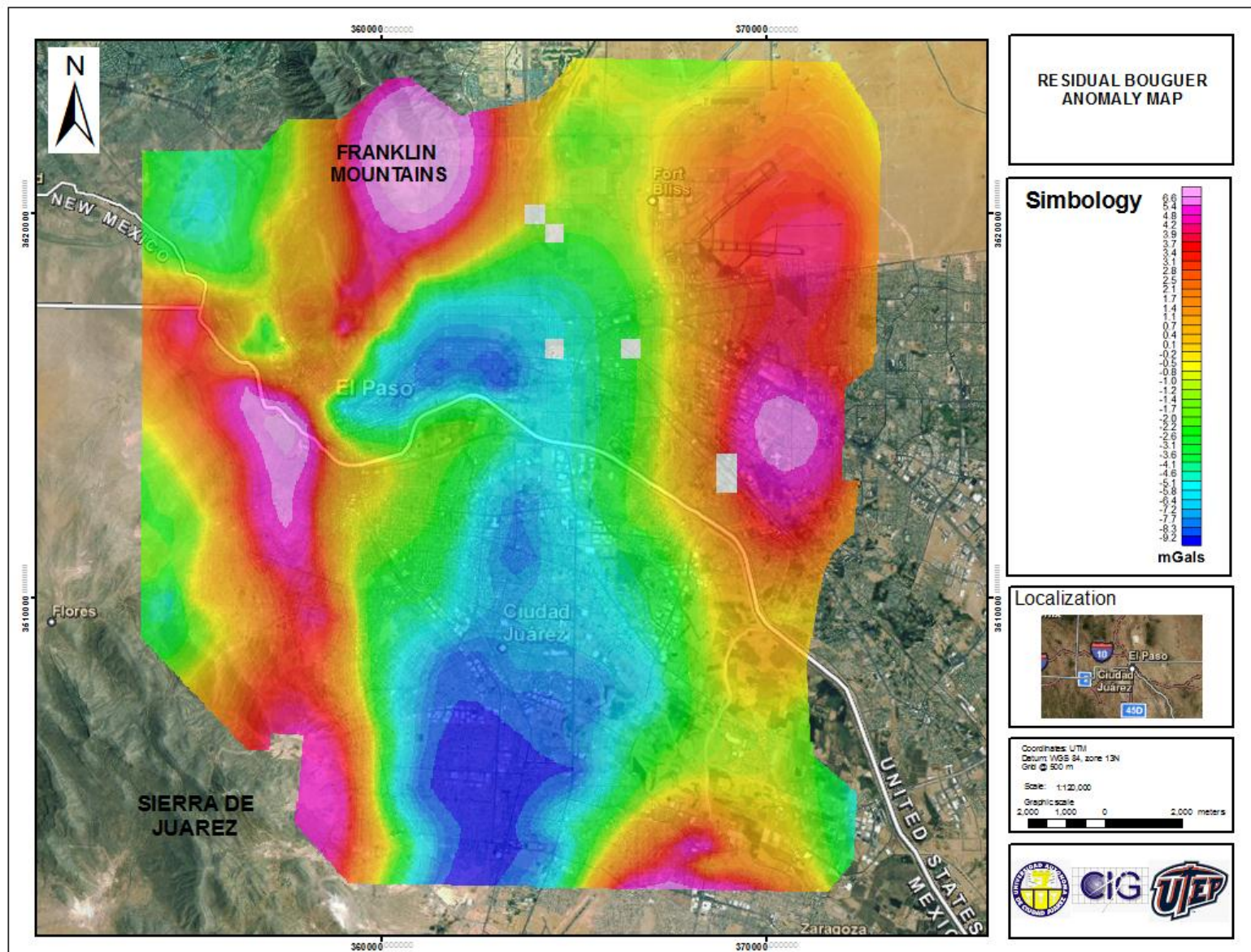


Figure 5.3 Residual Bouguer anomaly map. This was obtained by subtracting a third order polynomial surface to eliminate the deep seated regional gravity field from the basin (gravity lows).

Figure 5.4 shows positive values very close to the inferred position of the East Boundary Fault Zone (EBFZ). Figure 5.5 shows tilt derivative values versus the mapped location of the EBFZ based on an earthquake hazards study of the El Paso region (Keaton, 1993). The location of the fault is speculative through downtown El Paso and Ciudad Juarez. The speculative location of Keaton (1993) corresponds very well with the results obtained by the tilt derivative filter; only slight changes are recommended. Another feature shown in the map of Keaton (1993) is the boundary recommended for possible fault rupture hazards located 500 ft. from traces of EBFZ. This expected rupture zone is the limits of the tilt derivative's positive values. The boundary of fault rupture zone is only traced for the El Paso area, but a similar zone could be traced into the urbanized area of Juarez.

Figure 5.6 shows a reinterpretation of the location of the EBFZ using geophysical data and well data from JMAS (municipal water utilities at Juarez). The maps suggest that south of the Franklin Mountains the EBFZ becomes a more complicated structure. One east-west trending structure indicated by the tilt derivative map (located just south of the U.S border in Juarez) is at a point where a concealed Laramide thrust fault mapped by Collins and Raney (2000) would intersect the EBFZ. The tilt data also suggest a fault located west of the EBFZ that correlates with an arroyo in Juarez called Arroyo de las Vivoras. The tilt derivative map also suggests other faults located perpendicular to the Arroyo fault and suggest that more gravity data need to be collected to determine if there are more faults in this area.

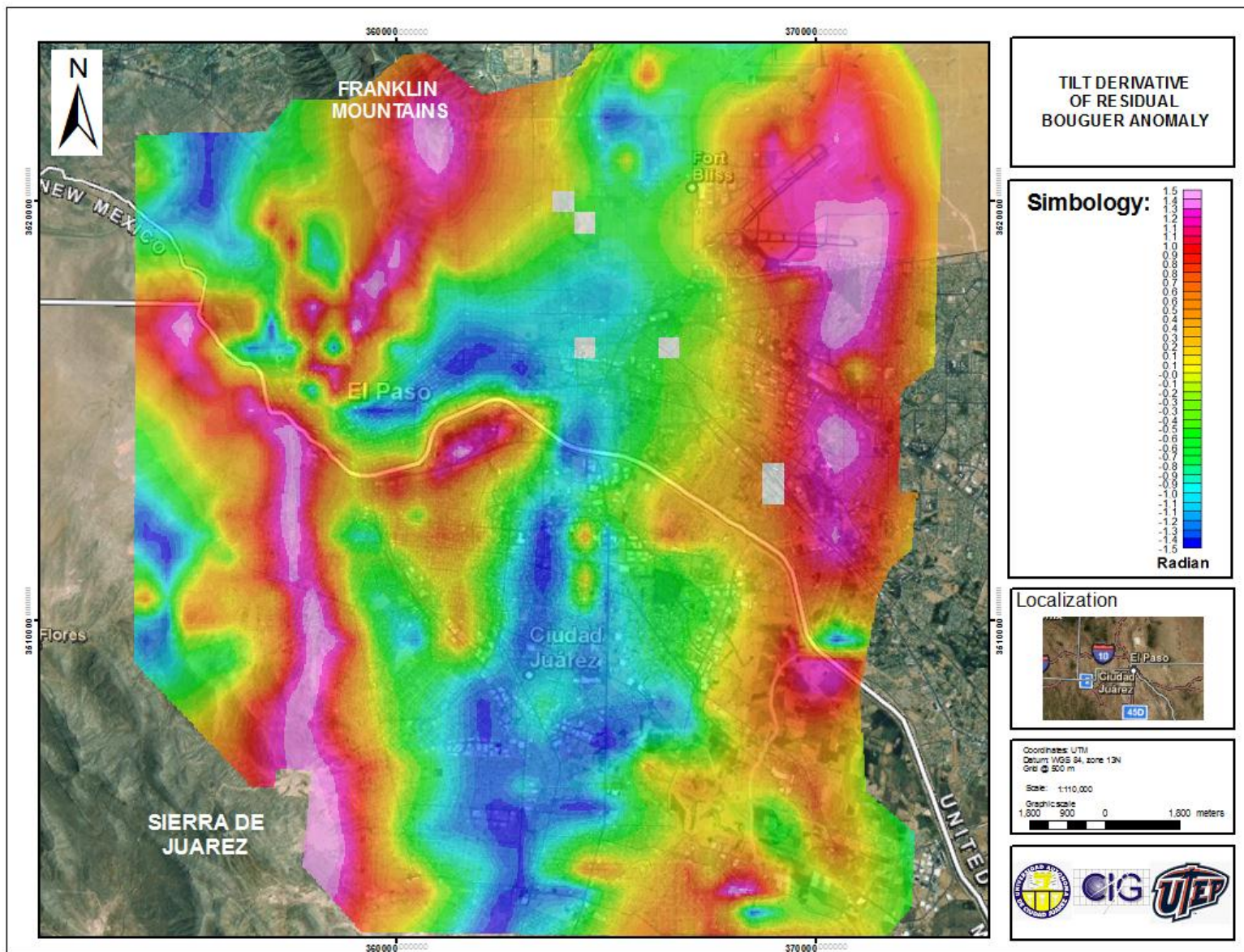


Figure 5.4 Tilt derivate filter applied to residual Bouguer anomaly. The tilt derivative gives positive values to source features and negative values outside the source region.

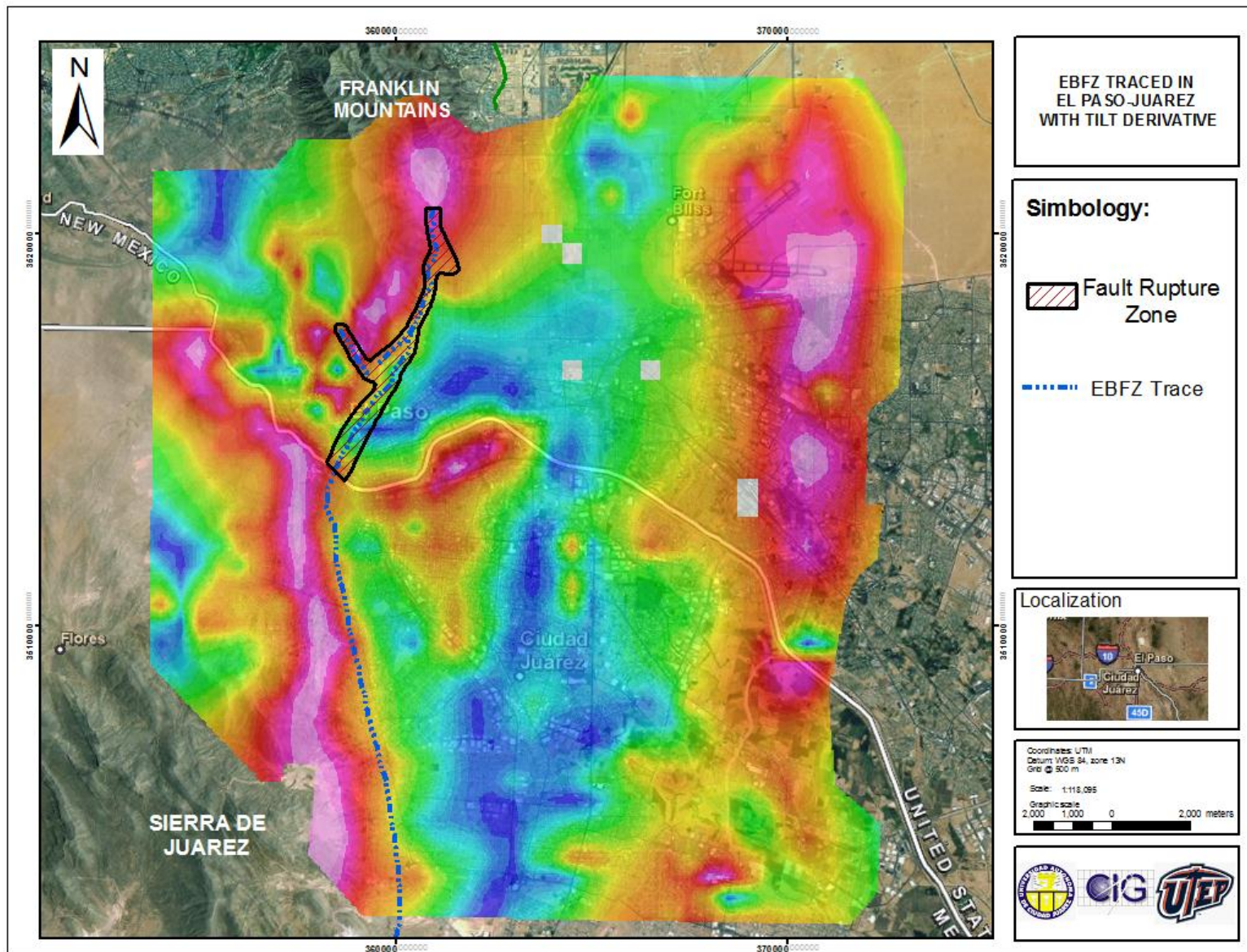


Figure 5.5 Shows the EBFZ inferred by the earthquakes hazards of El Paso study Keaton (1993). Shaded area is fault rupture zone located ± 500 ft. from fault trace.

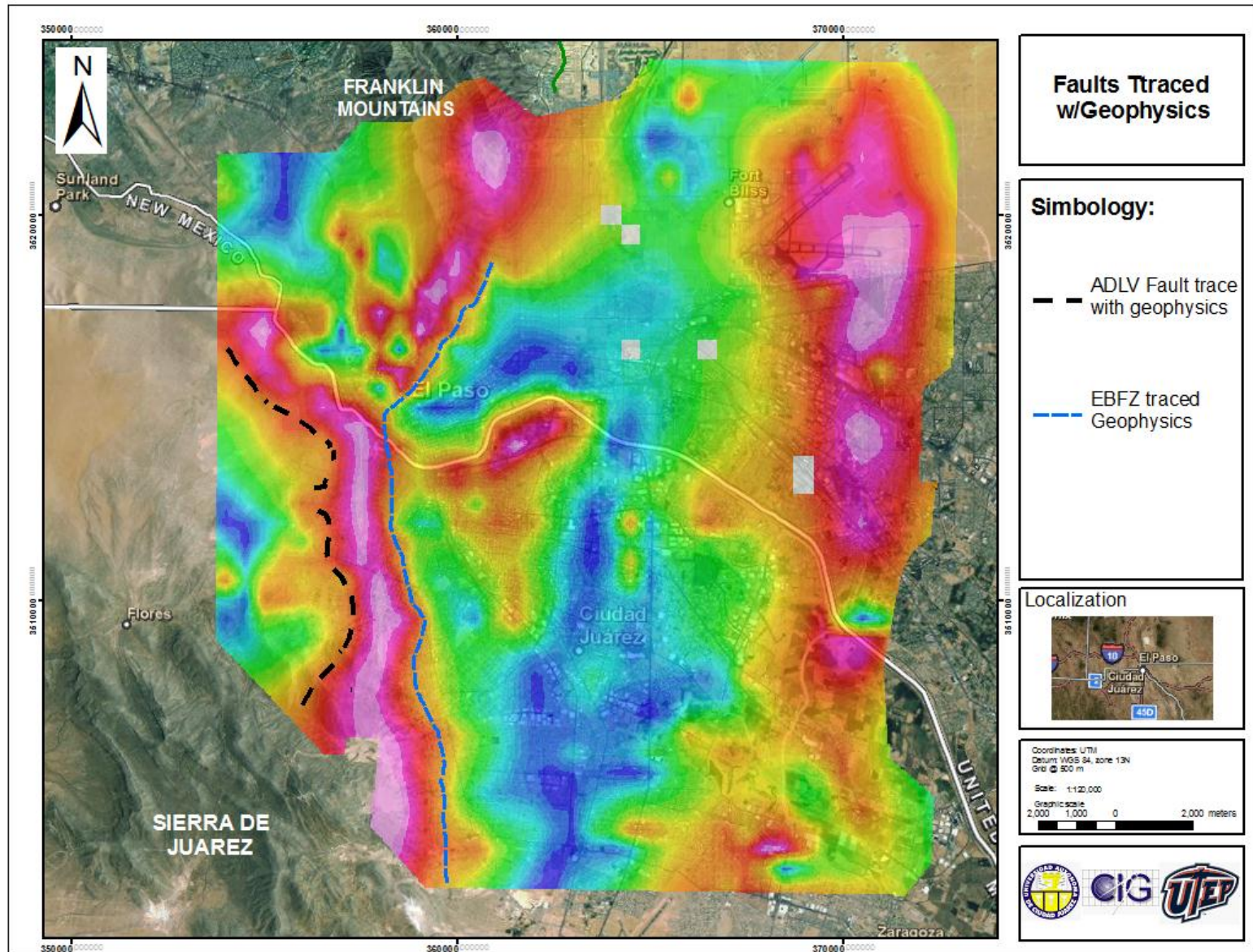


Figure 5.6. Shows the EBFZ traced according to this gravity study.

DATA MODELING

The final step in the investigation was the construction of four density cross-section profiles across the EBFZ and other features observed in the study area, in order to determine more accurately the geologic structure in the El Paso and Juarez area. The locations of these profiles are shown in Figure 6.1 and Figure 6.2. Two complete Bouguer anomaly maps were used to produce the models. The first is the large scale regional Bouguer anomaly map where two transects were chosen to constrain the density values for geologic formations in the study area and also aid in the characterization of faults as these profiles have been previously modeled. Then two transects were chosen on the smaller scale map of the urbanized portion of the study area where the fault is present. One of the two transects from Figure 6.1 was located in the north side of the Franklin Mountains section (A-A') where this profile crosses through the Anthony gap across the EBFZ into the Hueco basin. The second transect (B-B') is along transmountain road and very similar to the A-A' transect crosses from west to east across the EBFZ and part of the geologic structure of the Hueco Basin. The other two transects (Figure 6.2) are a cross the EBFZ through the downtown area of Juarez and in El Paso. El Paso transect is C-C' and Ciudad Juarez is D-D'. For transects located in the urbanized area, the same densities were used as the other profiles.

Gravity models were produced by forward modeling which consisted of creating a model a source body based on geology and geophysical data available for the area. Then the anomalies from the calculated and the observed data were compared and adjusted in order to match both. The final result was the model that fits better with the observed.

The densities used for the construction of the models were the same as used in previous studies on the perimeter of the area. These densities values were used by Burgos (1993), (Hadi 1991) and Figuers (1987). and were based on well logs, seismic velocities and measurements of samples of outcrops. Table 1 shows the density values of the geologic formations used for the models constructed.

FORMATIONS	LITHOLOGY	DENSITY g/cc
RECENT RIVER DEPOSITS	ALLUVIUM	1.9
QUATERNARY	SHALE	2.2 - 2.3
	SANDSTONE	
TERTIARY	SHALE	2.4
	SANDSTONE	
MESOZOIC	SANDSTONE, LIMESTONE SHALES	2.5
PALEOZOIC	SHALE, SANDSTONE, LIMESTONE, DOLOMITE	2.6
PRECAMBRIAN	GRANITE	2.7
FELSIC INTRUSION		2.5
MAFIC INTRUSION		3

Table 1. Shows the densities used for the construction of the models. Modified from Burgos (1993) and Hadi (1991)

In order to construct the geophysical models GM-SYSTM modeling software was used. This forward modeling technique is based on Talwani, et al. (1959), and Talwani and Heirtzler (1964) and it works by creating and interactively manipulating geologic models.

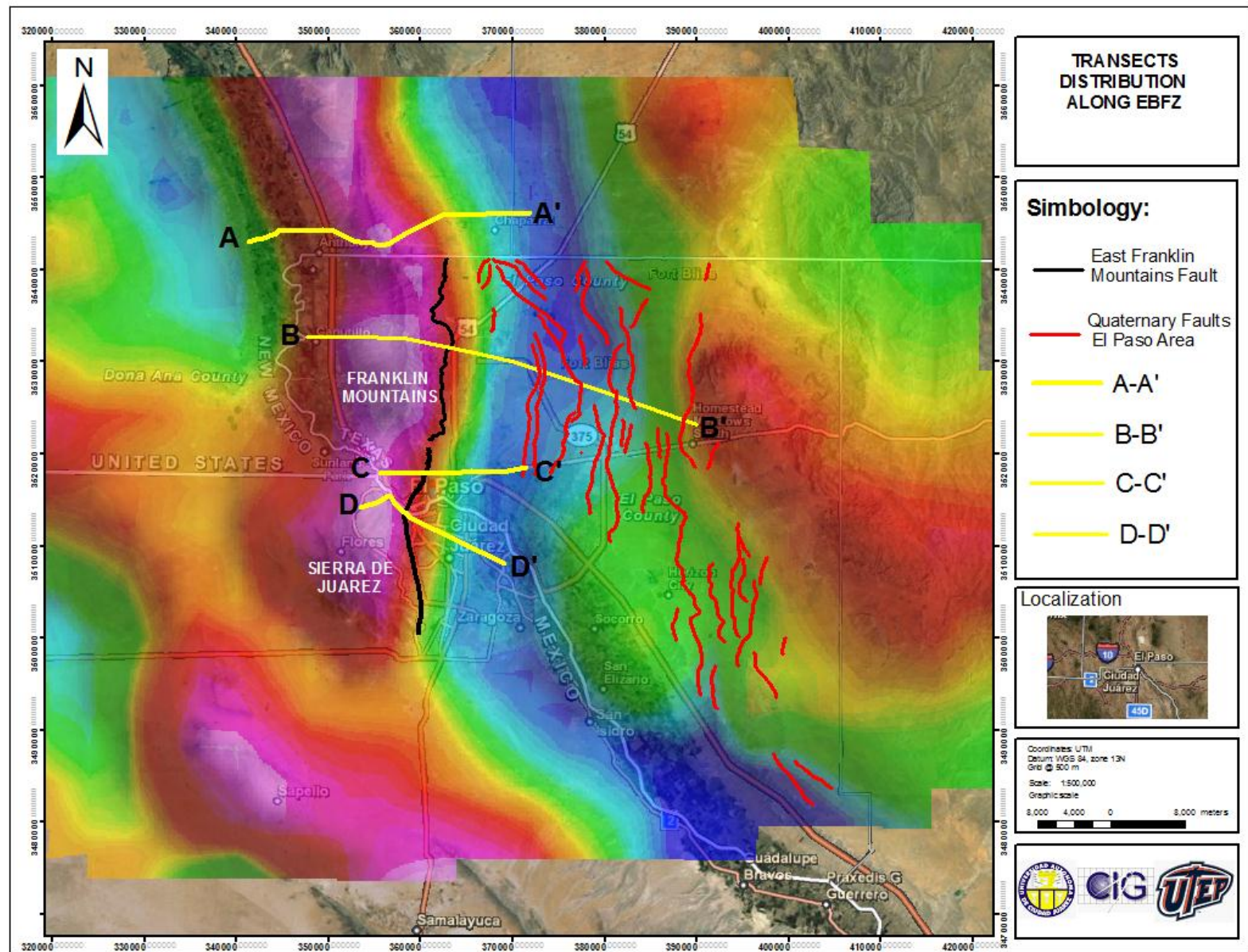


Figure 6.1 Transects along EBFZ with complete Bouguer anomaly map. Also shown here Quaternary faults in EL Paso.

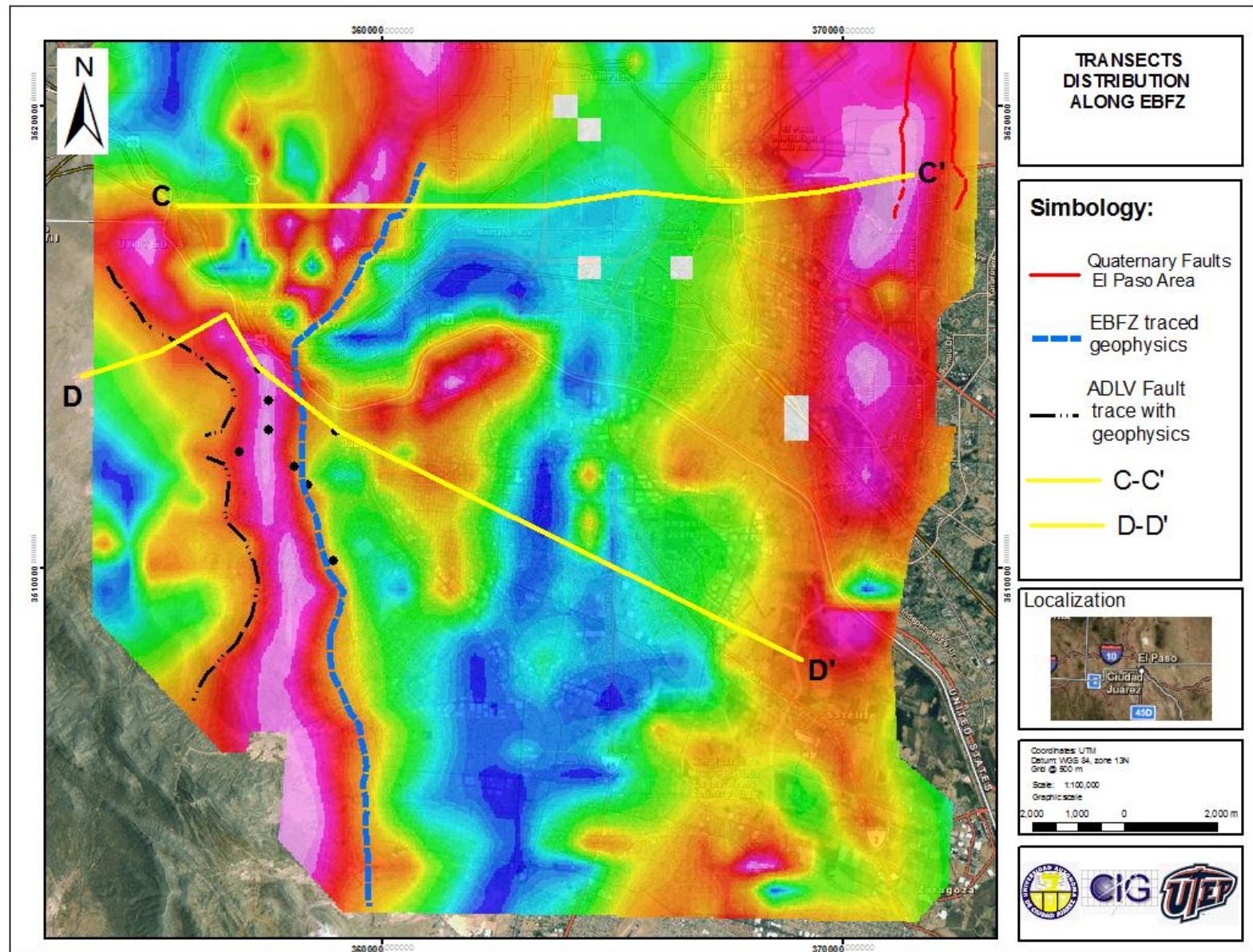


Figure 6.2 Tilt derivative map with transects along EBFZ to show the anomalies throughout the transects.

Interpretation of Gravity Profiles

Profile A-A'

The profile A-A' (Fig. 6.3) is located in the north part of the Franklin Mountains in Anthony Gap along O'Hara Road starts on the west side of the Rio Grande and crosses the EBFZ ending in Chaparral NM. It is approximately 9450 meters long. This profile consists of 1000 gravity points with 30 m spacing. This transect was originally modeled by Figuers (1987). I chose to re-evaluate this model to ensure GM-SYS gave similar results to the previous modeling which used an earlier version of Talwani 2.5 modeling software using the same densities. Figuers also constrained his model with an interpretation of seismic reflection data where he modeled EBFZ as a high angle (70° to 80°) east dipping normal fault. The anomaly related to the EBFZ corresponds to low density material consisting of fluvial material from ancestral Rio Grande. The dike along the profile is an anomaly previously observed by various studies and one possible setting is associated with an andesite intrusion post Franklin Mountain development. EBFZ is seen at the 21 km where there is a steep gravity gradient where the EBFZ marks the western edge of the Hueco basin. This profile shows that this basin is underlain by Paleozoic rocks accounting for the gravities values observed.

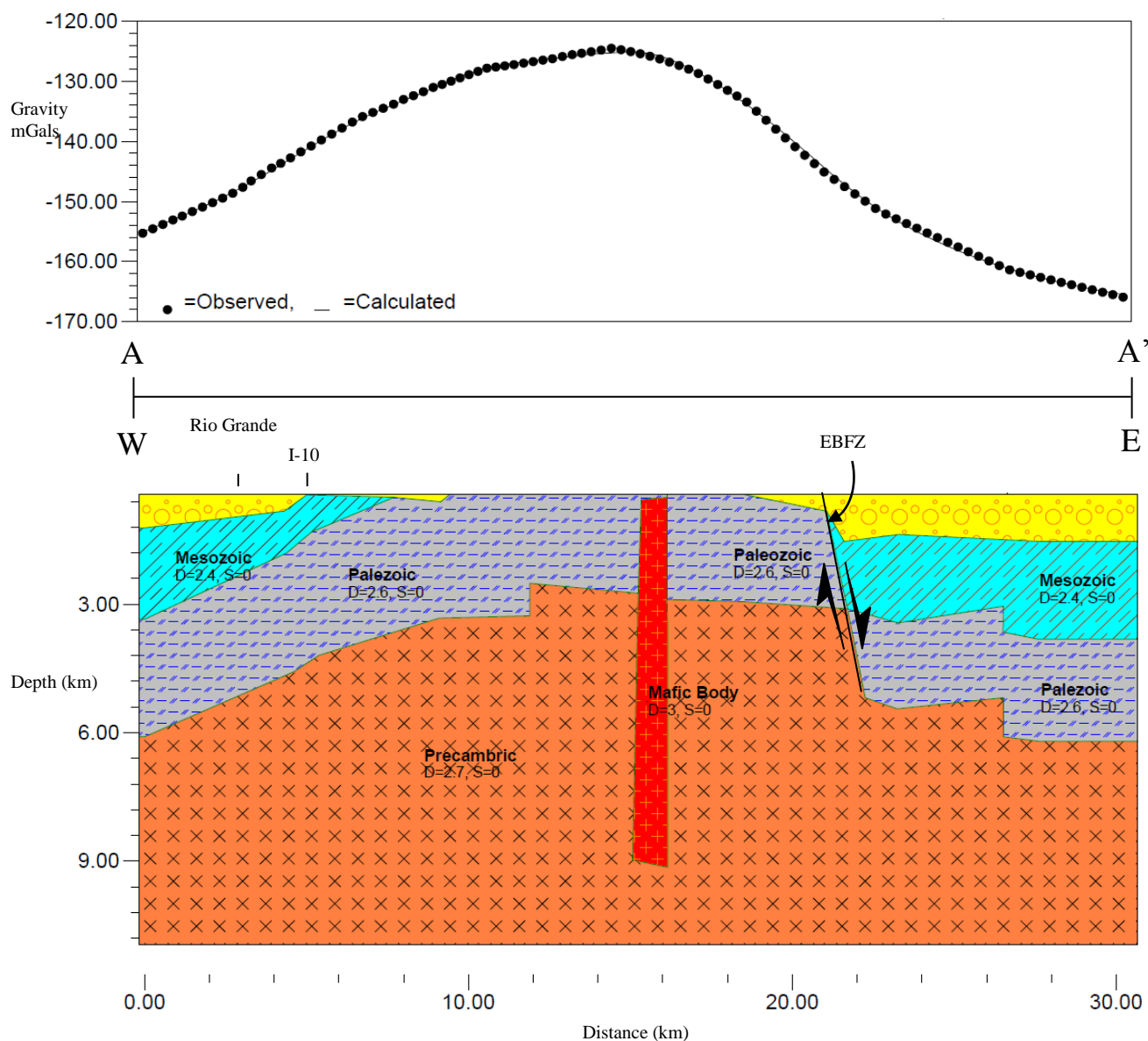


Figure 6.3 Density model for transect A-A'. This transect is located across Anthony gap, in the north Franklin Mountains. This transect was modeled to insure the consistency of my modeling technique with that of Figuers (1987). This model accounts for the density contrast of the EBFZ as normal fault at boundary between the Hueco basin and the Franklin Mountains.

Profile B-B'

Profile B-B' (Figure 6.4) starts at Canutillo just north of transmountain road across the Franklin mountains throughout the EBFZ into the Hueco basin and ends west to the Hueco Mountains, the transect length is 43.6 km. The transect passes through some other Quaternary faults located within the Hueco basin. These faults have identified by the USGS. These faults are located in cross-section at 22, 34, 42, km. The EBFZ is located at 21 km. where there is the abruptly change in gravity value and is model here, where the less dense sediments have been deposited down the faulted block. The estimated thickness of the basin fills 2.3 km. given by the EBFZ as suggested by Burgos (1993). The thickness of the sediments decreases toward the Hueco Mountains indicated here with the change in gravity observed at 25 km to 40 km where at the end of the transect a fill of approximately 640 meters. Fault in west side of Franklins at 8 km. is a thrust fault which approximates edge of Laramide thrusting.

Profile C-C'

Profile C-C' (Figure 6.5) this transects runs throughout the urbanized area of El Paso going from west to east. Begins at the intersection of executive and paisano St. passing through a part of the intrusive formation and then continues across I-10 and N. Mesa St. going in to the Paleozoic part of south of the Franklin Mountains then the transects goes into the Hueco basin across I-54 then follows Montana St. and it ends in front of El Paso Airport. Transect length is 14 km approx. Main features from the 2D model shown in Figure 5.5 is again the EBFZ with a abrupt gravity value change on east of the Franklins the model fit the structure a step fault from 4.5 km to about 8km. Also the 2D model reveals 3 more faults one of them at before de 12 km

this fault has not been identified in the surface, and the last 2 faults seen at the end of the transect close to 14 km, are two faults than run parallel through the El Paso Airport. In west side of the Franklins Mountains is another fault that is modeled and this corresponds to the thrust fault of Laramide thrusting.

Profile D-D'

The profile D-D' is shown in Figure 6.6. Transect is close to 17 km long and starts in the on east part of the Camino Real avenue in Ciudad Juarez just north of Sierra de Juarez then goes north towards the border than is passes through the EBFZ going southeast into the Hueco basin. The 2D profile shows a fault at 2 km of the profile this fault goes according to a fault proposed in this study name the Arrollo de las Vivoras fault. This fault is localized with geophysics. Then the profile shows the EBFZ also with the sudden change in gravity value, also with a similar step fault geology structure to the one model in El Paso urbanized area going into the Hueco basin. The sediments thickness in this part is about 1.5 km and as it continues to increase right until 14 km where starts going up again. The model here also is underlain by Paleozoic rocks at the bottom. Fault at 16 km corresponds to the faults that run through the El Paso airport it seems that these faults extend in to Juarez.

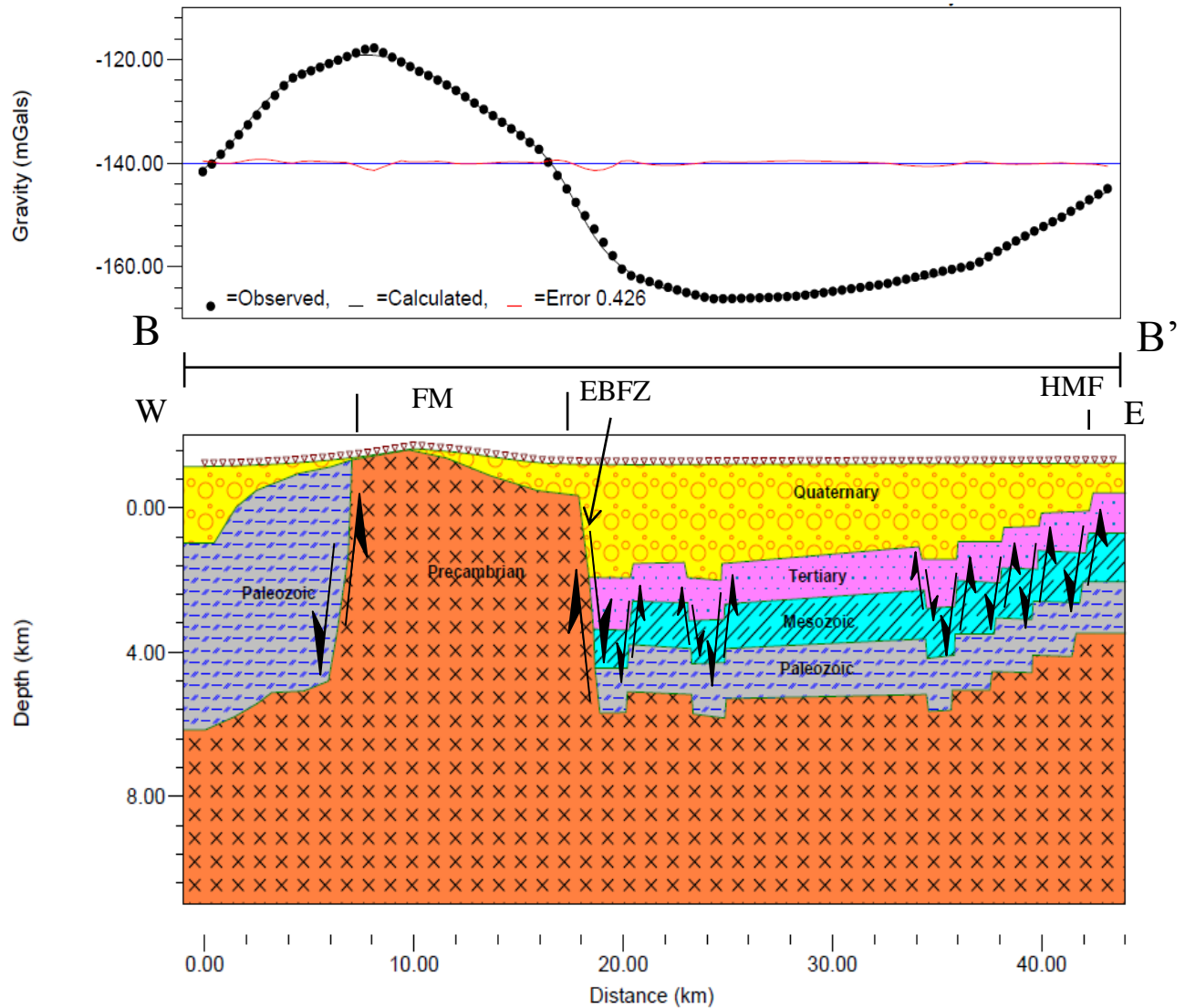


Figure 6.4 B-B' Density model for transect B-B' which crosses just above Transmountain Road, this model shows the EBFZ that is at the base of the Franklin Mountains with large density discrepancies into the Hueco basin. Then transect continues to show the other faults in the Hueco bolson as it extends to the East. HMF (Hueco Bolson fault)

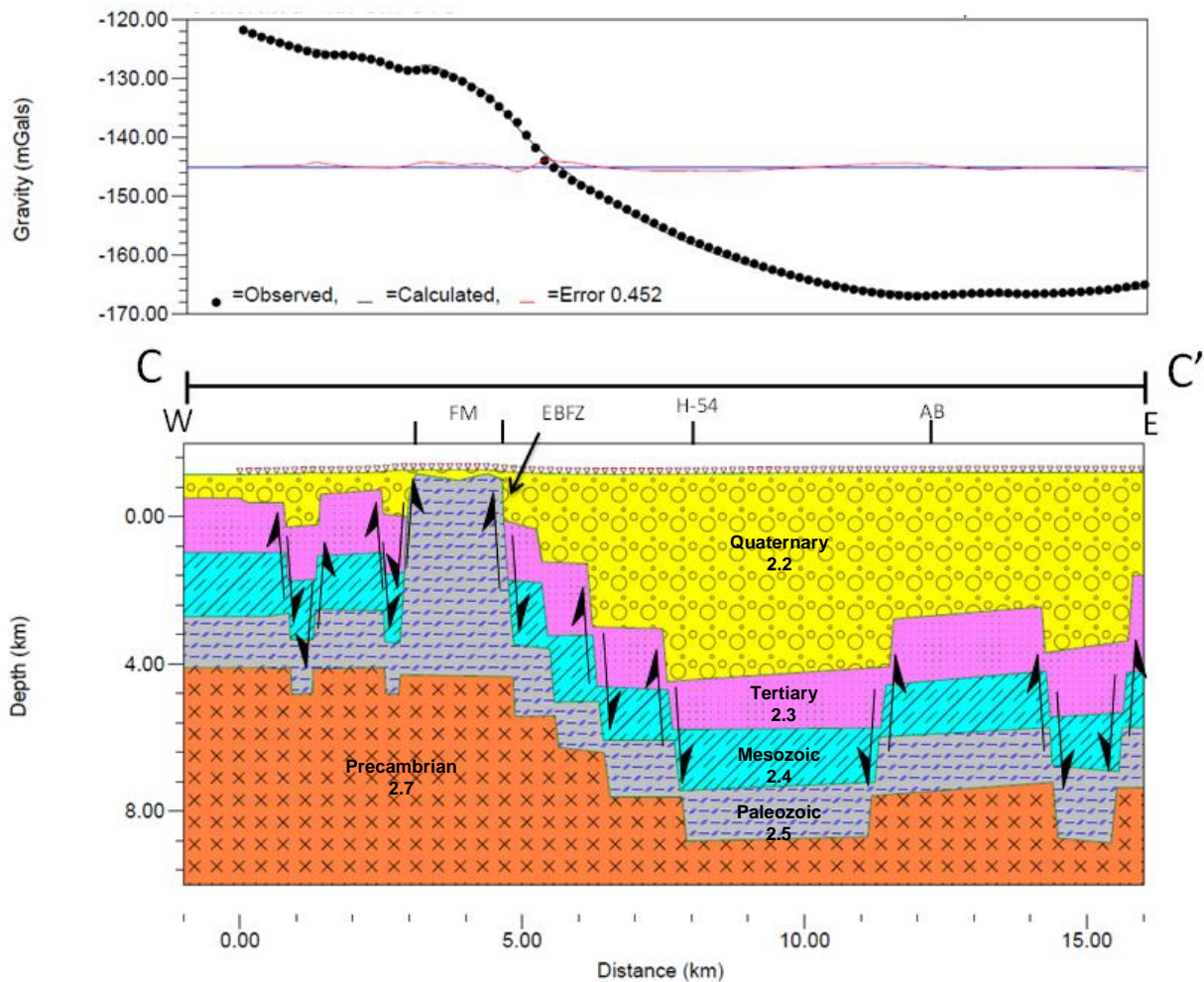


Figure 6.5 Density model for transect C-C' throughout the El Paso urbanized area. EBFZ again shown in the model is at the base of Franklin Mountains and then continues into the Hueco Bolson as step faults structure represented by a series of faults into the East of EBFZ. Then at the end the last 2 faults at 15 km approx. close to the El Paso Airport.

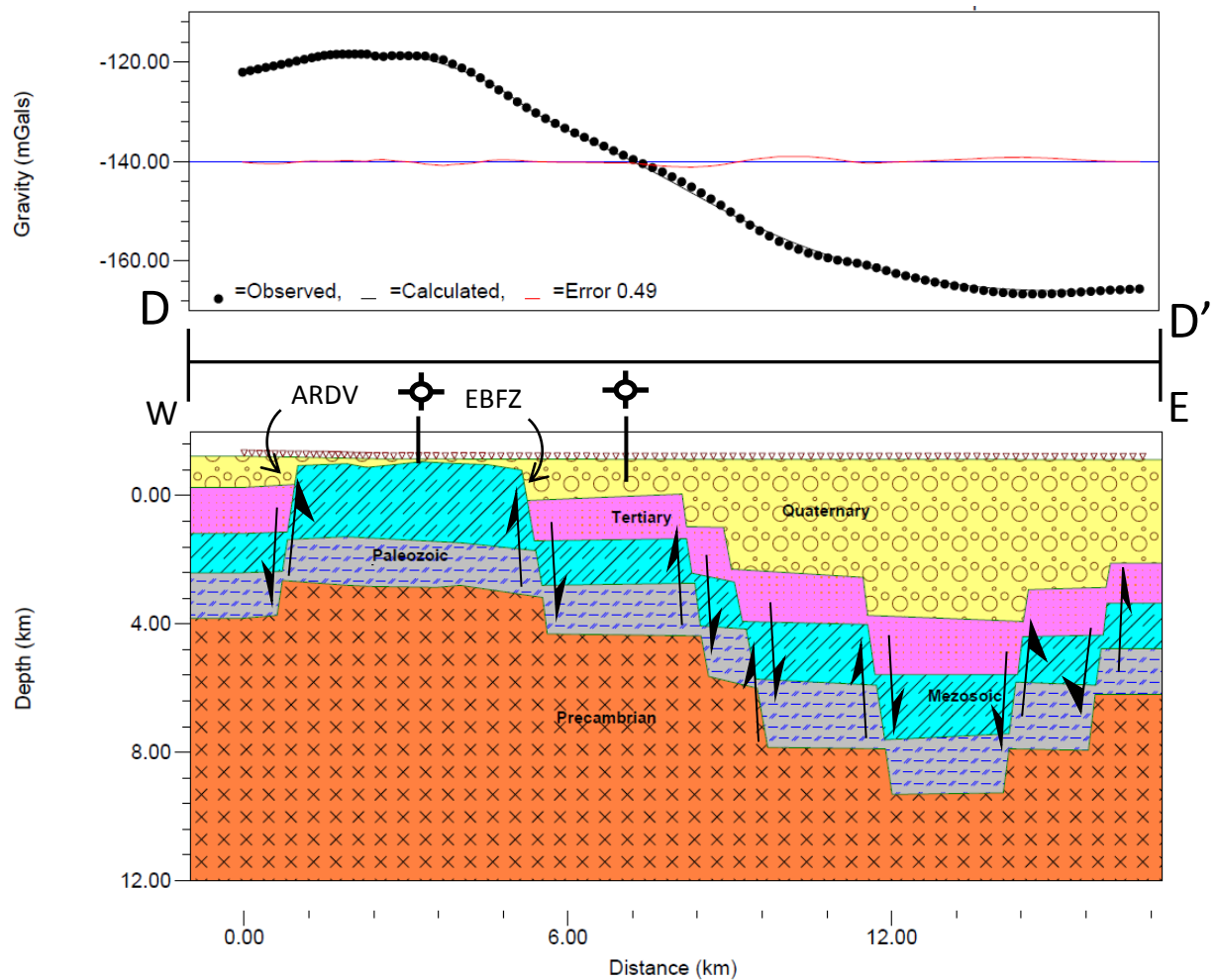


Figure 6.6 Density model for transect D-D' goes throughout the urbanized area of Ciudad Juarez, the model shows the ARDV (Arroyo de las Vivoras Fault) and the Eastern Boundary Fault Zone (EBFZ) this Model is constrained by Well logs within the city the first at 3 km where it hits bedrock at 60 meters, then the second at 7 km does not hit bedrock at 250 meters then the model shows a series of step faults into the Hueco Bolson

CONCLUSIONS

The gravity survey and the results obtained with the gravity data processing done in the study were able to substantiate gravity as an effective geophysical tool for urbanized areas, in spite of the difficulties caused by vibrational noise due to traffic and other activities.

The East Boundary Fault was best observed in the urban areas by using a tilt derivative filter applied to the Bouguer gravity residual, the trace mapped based on the gravity was comparable to that shown in an earthquake hazards study for the El Paso – Ciudad Juarez area (Keaton 1993). Keaton (1993) also delineated a rupture zone ± 500 ft. from the fault where the fault is visible in the Franklin Mountains. This inferred rupture zone was carried out into the urbanized portion of El Paso area. I have drawn a similar fault rupture zone for Ciudad Juarez with the data provided in this thesis.

I observed another fault was located west of the EBFZ. This correlates with an arrollo in Ciudad Juarez called Arrollo de las Vivas. More gravity data and also other geophysical tool such as resistivity could be used to better delineate this fault.

Also at the south end of the Franklin Mountains in the urbanized part of El Paso more gravity data are needed in order to delineate the geologic structures that appear very complicated. The gravity data suggest the presence of a number of East-West trending cross faults and a basement uplift (or intrusion) along the Rio Grande.

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