Chapter Three: study area

3.1: Introduction

Very little information exists to define the physiographic characteristics of the study area situated between the Basin of Mexico (South) and the Mezquital Valley (North, Hidalgo) (Fig 3.1). Although the Tequixquiac Basin forms part of the State of Mexico (see Fig 1.1), it is hydrologically independent of the Basin of Mexico (Figs 1.1 & 3.1). Other than regional, predominantly pre-Quaternary geological maps (Segerstrom, 1952, 1956; Mooser, 1975), the Tequixquiac Basin is poorly characterised regarding it is Quaternary geological, sedimentological, geomorphological, hydrological and structural features and its climate. This chapter describes the important physiographic features of the study area and Mexico.

3.2: Location

The town of Tequixquiac (19°54'29.14N - 99°08'44.64W) (Fig 3.1) lies within the northern hemisphere sub-tropics situated in Central-eastern Mexico, within the State of Mexico, (Fig 1.1). Tequixquiac town sits at the edge of a large depression known in this study as the Tequixquiac Basin (Fig 3.1). Within the Tequixquiac Basin, which lies between the Zumpango region of the Basin of Mexico (south, Mexico State) and the Mezquital Valley (north, Hidalgo region) (Fig 3.1), the towns of Hueypoxtla and Tlapanaloya lie to the east, and Apaxco de Ocampo is to the northeast (Figs 3.1).

3.3: The Tequixquiac Basin

The Tequixquiac Basin lies at the semi-arid end of the climatic gradient that runs from the north to south in the Basin of Mexico (see Figs 1.3), although there is a degree of local variability between cool/warm and humid/dry conditions mainly related to altitude. There is a wet season between June and October and average annual temperatures are between 17 – 18 ºC (Cervantes-Mendel & Armienta, 2004; Jiménez & Asano, 2008). Precipitation is around 400 – 536 mm in the lower catchment (Cervantes-Mendel & Armienta, 2004; Jiménez & Asano, 2008; Parsons 2008), 750 mm in the upper catchment (Cervantes-Mendel & Armienta, 2004) and evapotranspiration can be as much as 1750 mm yearly (based on Jiménez & Asano's (2008) study of the Mezquital Valley).

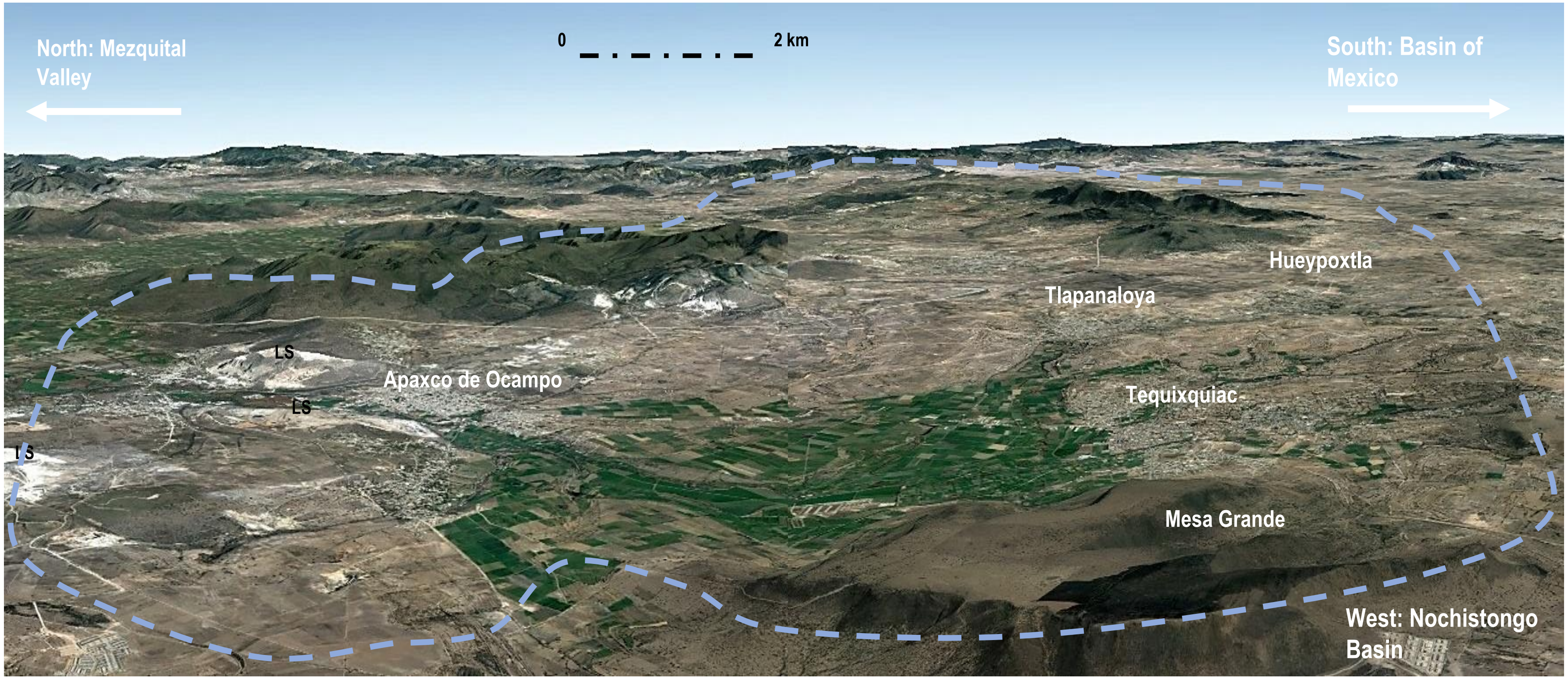


Figure 3.1: Google image of the study area, The Tequixquiac Basin, the dashed blue line indicates the limits of the basin

Rainfall is predominantly sourced from the Gulf of Mexico, but its delivery to the study area is restricted by regional (e.g. the Sierra Madre Oriental, Fig 3.2) and local (e.g. Sierra de Pachuca, Fig 3.2) mountains and hills (Segerstrom, 1962).

3.4: Topography

The topography of the study area corresponds to the physiographic province of the Trans Mexican Volcanic Belt where board flat-floored valleys, between 1,600 – 2,400 m a.s.l dominate (Segerstrom, 1962) and the Sierra Madre Oriental physiography in the far north (Segerstrom, 1962, Fig 3.3). The high basins of the Trans Mexican Volcanic Belt are commonly separated by hills and mountain ranges that can reach above 3,000 m a.s.l. Within the region of the study area, there are three major mountain ranges, the Sierra Nevada volcanic range to the southeast, the Sierra de Pachuca volcanic range to the northwest, and the Sierra de Las Cruces to the southwest (Fig 3.2).

3.5: Vegetation

The vegetation varies with altitude, climate and slope exposure. Where the average annual precipitation values are above 700 mm natural forest grows on north and south-facing slopes, usually at elevation. Precipitation values are between 500 – 700 mm restrict forest growth to north-facing slopes (Segerstrom, 1962). Below 500 mm, natural forest growth only occurs along streams and rivers (Segerstrom, 1962). On low slopes, and within uncultivated areas of the valley floor where the average annual rainfall is deficient (<400 mm) abundant desert flora dominate (Segerstrom, 1962). Native vegetation has been heavily disrupted by agricultural practice that was initially dry but has now become irrigation fed, with most of the water coming from the Agua Negra and the Rio Salado (see below).

3.6: Drainage

The drainage area of the Tequixquiac Basin is around 294 km^2, with relief reaching between 2350 – 3168 m.a.s.l sloping towards the basin floor, at its lowest, 2197 m.a.s.l. (Fig 1.1). The catchment mainly has a dendritic drainage pattern and low drainage density (less than 2 km of stream length within a 2 km^2 portion of the 294 km^2 area of the drainage basin) (Topographic (1: 50 000) map of Zumpango De Ocampo (E14A19 INEGI)) (Fig). The basin is hydrologically open and drained by the Rio Salado River to the northeast (Fig 1.2). Further north, the Salado River merges with the Tula River (Jiménez & Chávaz, 2004) which later merges with the San Juan and Hondo (Jiménez & Asano, 2008). The Tequixquiac Basin forms part the Basin of Mexico 's extensive drainage system via a 30.5 km tunnel and canal system, the Gran Canal del Desagüe along which the Agua Negra flows, that drains wastewater from the Basin of Mexico (Fig 1.2) along Barranca Acatlan (Fig 1.3 & Chapter 6).

3.6.1: Barranca and catchment draining

Small barrancas (gullies), between 2 – 6 km long, drain the upper and lower catchment (INEGI, 1997) (see Chapter 6). Morphologically barrancas have flat-bottoms and steep, near-vertical walls or cut banks and are essentially geo-fluvial/alluvial features that form in older unconsolidated sediments (see Chapter 6 and Heine & Schönhals, 1973; Borejsza & Frederick, 2010). Lateral confinement means vertical downcutting and backfilling are the primary responses to changes in discharge volumes and sediment load (Schumm, 1977 & 1999; Elliott et al. 1999; Waters & Haynes, 2001; Borejsza & Frederick, 2010). Barrancas are commonplace in arid and semi-arid environments where streams are ephemeral and fluvial systems alternate between two disequilibrium modes: stream channel erosion and incision (entrenchment) and infilling and back-filling (aggradation) (Bull, 1997). A knickpoint forms at some point along the shallow channel drainage pathway on a sloped surface. With repeated intermittent run-off or through-flow, head-cutting erosion occurs, causing the head of the barranca to migrate upslope which, through time and repetition, creates the barranca. With each rainfall and storm event runoff, erosion and the transport of materials expand the barranca in length and sometimes depth (Schumm, 1977 & 1999). Aggradation and erosion often occur together when the supply of sediment exceeds the capacity and availability of water to remove it from the barranca. In the Tequixquiac Basin barrancas have formed because of the large volume of underlying, unconsolidated easily erodible Quaternary clastic material (Borejsza & Frederick, 2010) and the positive topography created by the southern hydrological divide (see Chapter 8, Figs 8.14 – 8.16).

3.6.2: Natural springs

Today several active springs drain into the Tequixquiac Basin (see Appendix 10). Spring lines tend to develop where groundwater held in unconfined or artesian aquifers finds a route to the surface via, for example, fracture and fault systems. Springs can also be a product of perched aquifers where an impervious hydrostratigraphic unit (e.g. clay, basalt or granite) can hold infiltrated surface water and throughflow at elevation. The impermeable hydro-stratigraphic unit prevents groundwater from moving vertically downwards to join the main aquifer below the water table. Deep stream and river incision and barranca formation can expose a perched aquifer giving the stored water an exit at a perched point which appears to be the case in the study area.

3.6.3: Artificial drainage

The Rio Salado, Nochistongo and Tula Rivers today are almost exclusively carrying wastewater away from Mexico City (Jiménez & Asano, 2008). In the Tequixquiac Basin wastewater arrives through the Gran Canal de Desagüe which is drained by the Agua Negra River through Barranca Acatlan into the Rio Salado River (Fig 1.2). This water is then channelled and used for irrigation practices. Because of the wastewater drainage system and usage, the BGS (British Geological Survey, 1998) and The National Water Commission (1998) conducted a study in the Tula Valley North of the Tequixquiac Basin (Fig 1.2). They found that estimated aquifer recharge for one irrigation district in the Tula region was $25m^3/s$, 13 times the natural recharge rate (Jiménez & Chávez, 2004). The additional groundwater was found to have come from wastewater infiltrating down into the groundwater system recharging the aquifer with contaminated water pumped from the Basin of Mexico.

3.7: Geological setting

Geologically Mexico is composed of several crustal blocks that reached their current position after the Carboniferous (Dickinson & Lawton, 2009). During the Cretaceous (145 - 65 Ma) marine sediments (Fig 3.3) were deposited in epicontinental seas that centrally split North America and covered most of Central and Eastern Mexico. These deposits today form the elevated Mexican plateau that sits between different Sierras to the south, east and west (Fig 3.2). The southern end of the plateau is generally above 2000 m.a.s.l and dominated by volcanic deposits (Fig 3.2). Towards the North, there is an erosional trend and relief declines to below 2000 m.a.s.l (Alaniz & Nieto, 2007). During the Eocene (56 – 35 Ma) the Laramide Orogeny caused folding and faulting of the eastern continental shelf creating the Sierra Madre Oriental (SMO) which flanks the eastern side of the Mexican plateau. The orogeny elevated the eastern edge of Mexico, at its highest point, to around 3700 m.a.s.l and established a regional tectonic system of grabens centred in the Basin of Mexico spanning east-west across the country (see Fig 2.2 a) (Favolden, 1989). During the Cenozoic (65 Ma – to the present), due to subduction-related volcanism, two major volcanic arcs formed in Mexico; the NNW trending the Sierra Madre Occidental and the E-W trending Trans Mexican Volcanic Belt (Fig 3.2). The Sierra Madre Occidental occupies the western edge of Mexico today stretching north from the Pacific Coast where it overlaps with the Trans Mexican Volcanic Belton the same latitude as Mexico City (Ferrari et al. 2000) (see Fig 3.2). The Trans Mexican Volcanic Belt represents the most recent episode of magmatic activity that has been on-going since the Jurassic period related to subduction along the Middle American Trench (Szynkaruk et al. 2004; Ferrari et al. 2012; Fig 2.2). The Tequixquiac Basin and southwestern and central Hidalgo regions represent areas of transition between the Trans Mexican Volcanic Belt and the start of surface expressions of the Cretaceous limestone basement in the north (Fig 3.1). In the Basin of Mexico, because of deformation and subsidence, the limestone basement is approximately 2240m below the present basin floor (Fig 3.) (Fig 8.14).

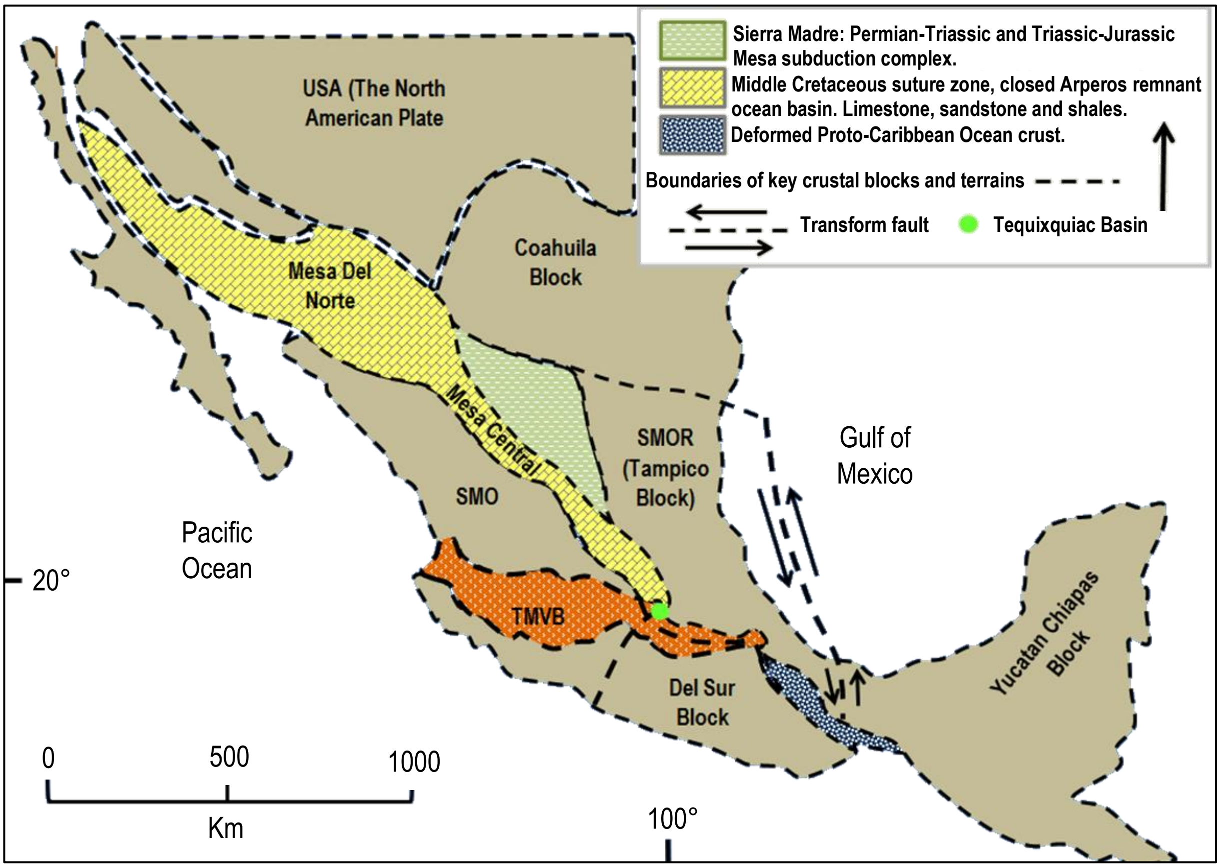


Figure 3.2: Simplified expression of the key crustal blocks and terranes that make-up Mexico (modified from Dickinson & Lawton, 2009). The Trans Mexican Volcanic Belt (TMVB) represents the most recent episode of long running and continual magmatic activity occurring in stages since the Jurassic Period (Ferrari et al. 2012). SMO: Sierra Madre Occidental. SMOR: Sierra Madre Oriental.

3.8: Surface geology in the study area

3.8.1: Introduction

Geological mapping in the south and central Hidalgo region and the northern Basin of Mexico was carried out by Segerstrom, (1952, 1956; 1962) and Mooser, (1975). These works involved extensive geological investigations of predominantly pre-Quaternary deposits and their resulting geological maps (Segerstrom, 1952, 1956; Mooser, 1975). The formations and units summarised below were mapped and defined by Segerstrom, (1952, 1956; 1962) and Mooser, (1975) and for full descriptions, refer to these works.

3.8.2: Cretaceous limestone system

3.8.2.1: El Doctor Limestone

Map Keycode: Ked (Fig 3.3).

Mid Cretaceous light to medium grey, relatively pure, medium to fine-grained marine limestone that has a range of textures. Chert lenses, dolomite, shale, limestone breccias, calcarenite and calcirudite interbeds, and gastropods and less common are corals, oysters and pelecypods also occur. Deposits directly overlie the lower Las Trancas or the Santuario formations. The maximum reported thickness is up to ca. 750 – 900 m. The El Doctor Limestone was deposited in shallow epicontinental marine environments suggested by biostromes, conglomerates, and thick limestone beds. Thin chert interbeds indicate increased water depth. In the study area, deposits occur in the northwest and south-east of Apaxco de Ocampo (Fig 3.3).

3.8.2.2: Cuautla Formation

Map key code: Kc (Fig 3.3).

Mid to the upper Cretaceous thick beds of calcarenite with biostromes and rudists that range in thickness up to 2 m with occasional thin lenses of chert. Some sections have a limestone conglomerate at the base, and volcanic rocks and terrestrial sediments underlie others. Reported maximum thickness is up to ca. 750 m and beds overlie the El Doctor Formation disconformably. The Cuautla Formation was deposited in a relatively narrow marine zone with the deposits lensing out towards the edges. These deposits occur in the study area to the northwest of Apaxco de Ocampo (Fig 3.3).

3.8.3: Cenozoic volcanic system

3.8.3.1: El Morro Formation (fanglomerate)

Map key code: Tem (Fig 3.3).

Eocene-Oligocene indurated limestone conglomerate consisting of various locally available (within 7 km) rock types (fine-grained – boulder size) deposited in alluvial fans. The matrix, if present, is reddish-grey and conglomerate units can be interbedded with siltstone, sandstone, andesite and basalt lava and tuffs depending on the section. Sorting is usually poor, tabular fragments are unoriented, and bedding is poorly defined although very occasionally sandstone lenses can be cross-bedded. The maximum formation thickness has been reported up to 400 m, and the lower contact represents an angular unconformity with the underlying marine beds.

The El Morro Formation is terrestrially formed and related to rapid sediment deposition from steep-sided highlands into the subsiding basins (Simons & Maps, 1956). In the study area, deposits occur in an isolated pocket to the southeast and northwest of Apaxco de Ocampo (Fig 3.3).

3.8.3.2: The Pachuca Group *(*Segerstrom, 1963) also known as the El Peńon Formation (Ledesma-Goerreror, 1987).

Map key code: Tpv (Fig 3.3).

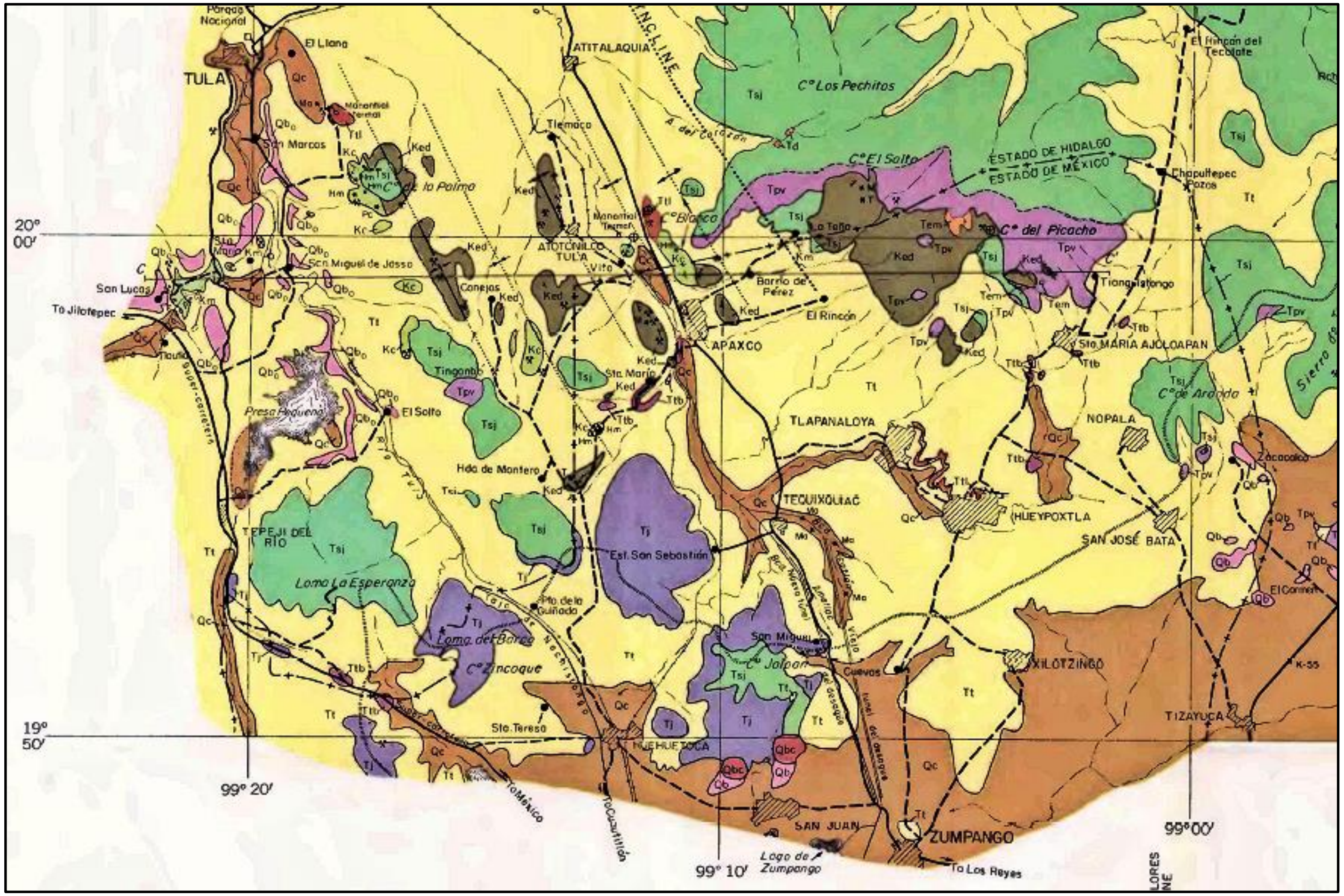
Eocene-Miocene volcanic rocks that range in composition from basalt to rhyolite deposited by volcanic flows. The Pachuca Group is complexly faulted, indurated, hydrothermally altered, and mineralised. Clastic rocks within this group range from fine-grained tuff to coarse tuff breccias. Conglomerates also occur consisting of eroded volcanic rock, and occasionally lacustrine deposits, including shale. Fossil plants are present in some sections. Maximum thickness reach ca. 2000 m although this varies considerably because of lensing at the edges. Sections that overlie the El Morro Formation do so conformably. Other sections that overlie older rocks have a marked unconformity with the underlying beds. Within the group disconformities are variable and the youngest formation can overlie the oldest or any variation in-between. The Pachuca Group, for the most part, closes the eastern margin of the study area around the Tlapanaloya and Apaxco de Ocampo regions (Fig 3.3).

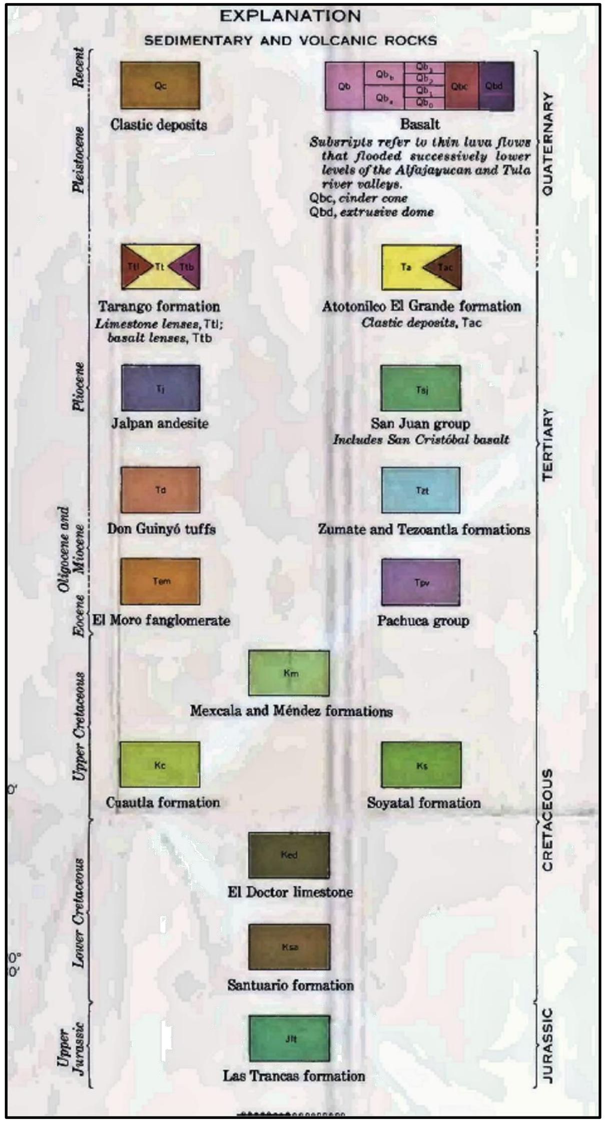
3.8.3.3: San Juan Group and the Jalpan Andesite

Map key code: Tsj (San Juan Group). Tj (Jalpan andesite) (Fig 3.3)

Middle to late Pliocene basaltic and andesite flows, water-laid tuffs, and a volcanic conglomerate composed of pebbles and cobbles of older andesite and rhyolite up to 400 thick. West and northwest of the Zumpango region the lithofacies change from basalt to hornblende andesite (Jalpan andesite) in the lower part of the section. Eroded cinder cones, basalt bombs, and composite cones are also associated with this group. Across the region volcanic eruptions and products associated with this group were quiet, probably occurring along fissures. The water-laid tuffs suggest lacustrine depositional environments and conglomerates fluvial and alluvial depositional environments. Basalt and andesite flows lie disconformably over older volcanic rocks, the Las Trancas formation, and the El Doctor limestone depending on the site. The San Juan Group occurs in the far south-west of the study area and to the southeast and southwest. The Jalpan Andesite occupies the western edge of the study area and forms the mesas that close the basin to the west (Fig 3.3).

Figure 3.3: Geological map of the study area (Sub-section of the geological map taken from Segerstrom, 1952, 1956, 1962)





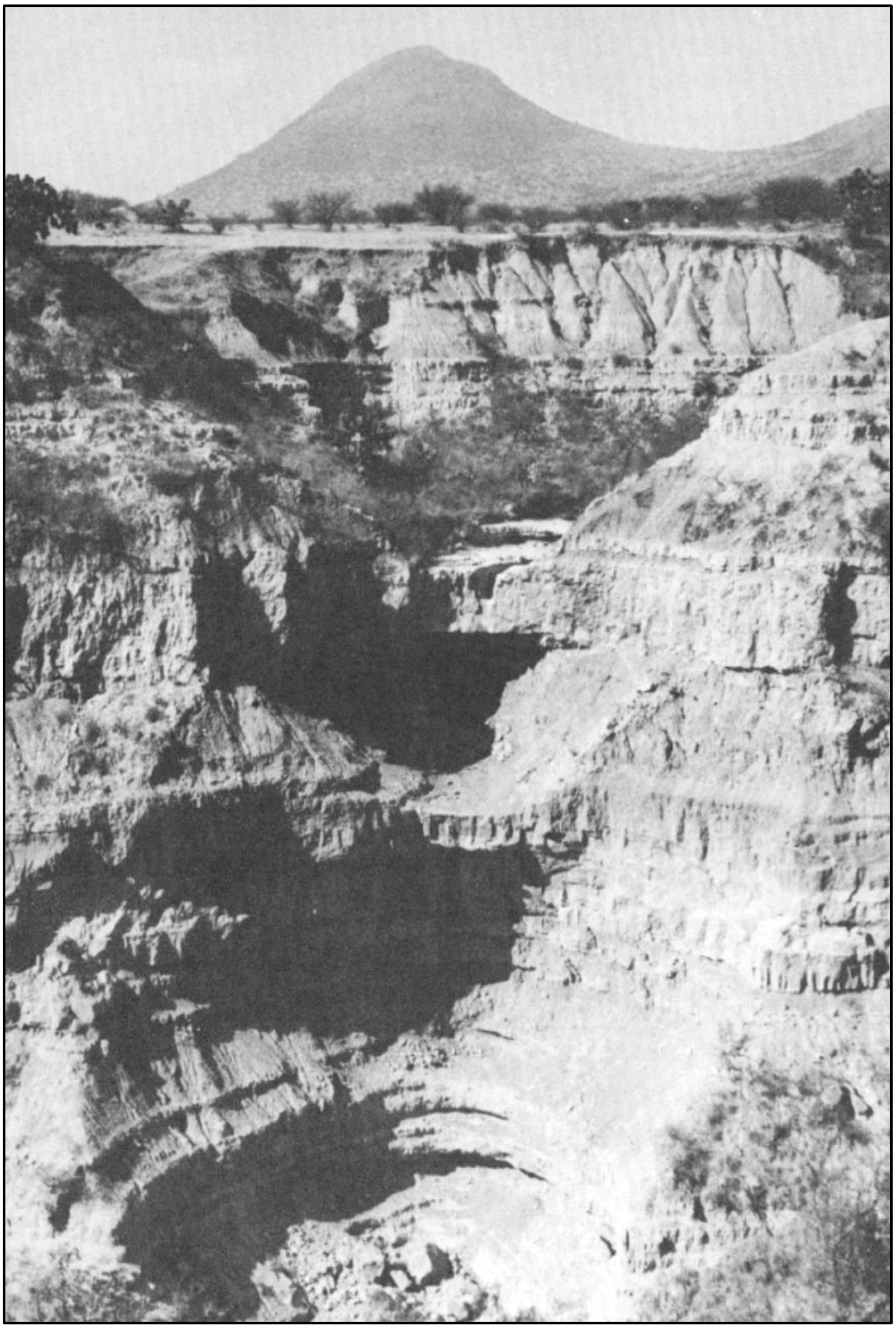


Figure 3.4: The Tarango Formation, over 150 m of exposed lacustrine muds, tephras and limestones that were exposed when the drainage channel was cut through San Mateo Hill (Site TB17) for the Nochistongo in the southwestern study area (see Chapter 6) (image taken from Segerstrom, 1962).

3.8.4: Late Pliocene – early Pleistocene system

3.8.4.1: The Trango and Atotonilco El Grande Formations

Map key code: Tt (Tarango Formation), Ttl (Tarango limestone lenses), and Ttb (Tarango basalt lenses) (Fig 3.3).

Pliocene to early Pleistocene formations thought to have been actively forming around the same time. The Tarango Formation, at type localities, consists of lacustrine deposits, mudflows, lahars and coalescing alluvial fans and in some sections, limestone lenses up 12 m thick, but with limited lateral extent (< km^2). The Atotonilco El Grande Formation is like the Tarango Formation but has a high proportion of basalt lavas and basalt agglomerate related to eruptive vents in some areas. Formation thicknesses are > 150 m up to 600 m and sediments collected within lacustrine, fluvial, alluvial and lava flow depositional environments. Poorly preserved fossils associated with the Atotonilco El Grande Formation include Mastodon, horse molars and bones that are usually associated with clastic sediments interbedded with basaltic lava flows.

In the north (i.e. Huehuetoca) and northeast, these formations form low passes between the study area and the Pachuca sub-basin respectively. The low pass sits around ca. 2280 m a.s.l, ca 40 m above the lowest lake in the Basin of Mexico (Lake Texcoco). Early drainage works cut a path for the Tajo de Nochistongo (southwest of the study area; Fig 3.3) through the low pass in the north-western Basin of Mexico which exposed ca. 30 – 40 m of the Tarango Formation. The sequence includes water-lain yellow/brown silt, three beds (each ca. 3 m + thick) of sand-sized pumice and beds are horizontal and un-faulted. Between the study are and the Zumpango region of the Basin of Mexico (Fig 3.1), which is a higher pass than Tajo de Nochistongo, two further drainage channels were cut east of Zumpango to Tequixquiac. The western drainage cut is 12 km long and passes through > 150 m of the Tarango Formation, with occasional gravel beds with andesite cobbles.

3.8.5: The Quaternary system

Figure 3.3 only identifies basalt cinder cones from the Quaternary system. All other formations are grouped and only shown if the collective Quaternary system is thicker than 3 m. The Tacubaya, Younger Becerra, Older Becerra and Totolzingo Formations discussed below were identified by Furlong, (1925), Maldonado & Aveleyra, (1949), De Terra, (1949), Hibbard, (1955) and Aveleyra, (1955) (see Chapter 1 & Table 1.1).

3.8.5.1: Basalt

Map code: Volcanic cinder cones (Qdc). Basalt lava flows (Qb) (Fig 3.3).

Pleistocene age un-weathered basaltic cinder cones and basalt lava flows that follow the course of the Tula River. Variations include; black olivine basalt flow with olivine phenocrysts (2 – 3 mm) deposited under fluid flow conditions and cinder cones that are black ash and lapilli weathered to a yellow-brown soil. Close to the vents well cemented red scoriaceous rock is common (tezontle). Flow deposits are up to 10 m thick. Volcanic cinder cones (Qdc) and basalt lava flows (Qb) in various stages of erosion are found in the Zumpango region along the southwest margin of the study area (Fig 3.3).

3.8.5.2: Tacubaya Formation

Map code: Qa (Fig 3.3).

Pleistocene hard brown ochre clay coated in carbonate. Calcrete, or inter-formational caliche layers I and II (Table 1.1), are also common. Calcrete occurrence is related to the limestone bedrock, the height of the water table, erosion and the availability of unconsolidated sediment. The Tacubaya Formation is recorded in Barranca Acatlan, Barranca La Botica and Barranca El Salto (see Chapters 1 & 8)

3.8.5.3: Older Becerra Formation

Map code: Qc (Fig 3.3)

Pleistocene clastic deposits and soils including silt, clay, sand and ash deposited in lake systems, alluvium, and fanglomerates, talus and other locally sourced material deposited over short distances, predominantly from the surrounding sierras. Bentonite topped pink clays that grade into gravelly sands and yellow grey silts. Furlong (1925) previously identified two distinct Pleistocene gravel horizons and faunas (later named the Upper and Lower Breccia Formations). The Older Becerra Formation lies disconformably above the Tacubaya Formation and is recorded in Barranca Acatlan, Barranca La Botica and Barranca El Salto and other Barranca that feed into these (see Chapters 1 & 8).

3.8.5.3: Younger Becerra Formation

Map code: Qa (Fig 3.3)

Later Pleistocene fossil fauna rich gravel units with well-rounded and angular clasts overlain by greyish cross-bedded sand and gravel layers that grade to yellow-cream silts deposited in sediment gravity flow events. Calcrete is also common, and deposits contain Glyptodon, Gopher, Rodent, Wolf, Arctodus (bear), Mammoth, Horse, Camel, Bison, Shrub-Ox fossil bones (Hibbard, 1955). The younger Baccara Formation lies disconformably over the Older Becerra Formation. Positive topography is thought to have been created by up-lift related to fault movement. Changing climatic conditions are thought to have helped to destabilise slopes by reducing vegetation cover with entrainment and resedimenting occurring during short-lived flood events or under more sustained hydrological conditions.

3.8.5.3: Totolzingo Formation

Map code: Qa

Terminal Pleistocene Holocene dark silt and sand with caliche layers.

3.9: Central eastern Mexico fault systems

Recent crustal deformation in Central Mexico is mainly caused by faulting, rifting, transtension and shear (Johnson & Harrison, 1990). There are numerous fault systems concentrated across Central Mexico created by the fragmented nature of Mexico's continental crust (Figs 2.2 & 3.2). Crustal division means that at least three of the southern continental blocks (the Guerrero Block to the east, the central Michoacan-Oaxaca Block and the western Jalisco Block; Fig 2.2) are moving independently of each other and the North America Plate (Johnson & Harrison, 1990). The central and eastern parts of the Trans Mexican Volcanic Belt are predominantly influenced by the E-W trending Chapala - Tula fault system, the NNW – SSE Querétaro – Taxco fault system and to a lesser extent the Tepic - Chapala, and the Chapala – Oaxaca fault systems that run along the western edge of Mexico (Fig 2.2) (Johnson & Harrison, 1990).

3.9.1: Faulting associated with the Basin of Mexico

The Basin of Mexico is an Eocene/Oligocene tectonic depression over 2km deep (Ferrari et al. 2003; Aívarez & Nieto, 2007) which has sixteen NE – SW lateral displacement and/or normal faults that have been active since the Miocene (see Fig 8.14 and Mooser, 1975; Marín-Córdova et al. 1986; De Cserna et al. 1988; Marín-Córdova et al. 2004). Marín-Córdova et al. (2004) propose the existence of a NW 35º – SE distensive fault axis, related to the NW 35º – SE and the NE – SW faults, that joins Popocatepetl Volcano (southeast), the Tequixquiac - Huehuetoca zone (northwest), the lowest portion of the Basin of Mexico including Lake Texcoco and the Peñon de Los Baños zones (see Chapter 8). Faulting is proposed to be caused by deformation forcing blocks to pull apart in NW-SE directions creating new deformation in the Basin of Mexico (Marín-Córdova et al. 2004 (see Chapter 8). The southern Basin of Mexico is bordered by the Chapala-Tula Fault System (Fig 2.2) and the Taxco-Queretaro Fault system (see Fig 2.2) which is thought to control the monogenetic volcanism of the Sierra Chichinautzin (Garcia-Palomo et al. 2000; Ferrari et al. 2003; Aíarez & Nieto, 2005; Gómez et al. 2007).

3.9.5: Faulting associated with the Mezquital Valley

The Mezquital Valley (Hidalgo, Fig 1.1) lies immediately north of the study area (Fig 1.1) and has been characterised as a Miocene fault-bounded graben/lacustrine basin comprising a single tectonic depression (Campos & Sànchez 2000; Gómez et al. 2007; see Fig 8.14). Within the Mezquital Valley master faults place Cretaceous Limestone against Late Miocene – Early Pliocene alluvial and lake deposits thought to belong to the Tarango Formation (Tt, Fig 3.3 & 3.4) dated to be between 7.1 – 4.6 Ma (Kowallis et al. 1998; Suter et al. 2001).

The Cardonal fault limits the northern end of the Mezquital Valley and cuts rock dated to 4.6 Ma vertically displacing the Tarango Formation sediments by 300m. This implies that the fault system has been inactive since the early Pliocene and two recent earthquakes (magnitude (Mw) 5) indicate the fault is still active (Suter et al. 1991, 1996 & 2001; Quintanar et al. 2004). Towards the southern margin of the Mezquital Valley, there are two E-W trending normal faults moving at a rate of 0. 02 mm/yr (Suter et al. 2001).

3.10: Faults influencing the Tequixquiac Basin

From a regional perspective Figure, 2.2 shows most major faults systems found across Central Mexico do not have any direct influence on the Tequixquiac Basin other than the Chapala-Tula Fault system. The Chapala-Tula Fault system flanks the Tequixquiac Basin along its western edge (see Figs 2.2) and may have influenced rates of deformation and subsidence in the study area. A northwest-southeast distensive axis linking Popocatepetl Volcano to the Tequixquiac – Huehuetoca zone is currently causing new deformation and subsidence in the region of Tequixquiac and possibly has done for a significant portion of its past. Faulting associated with northern horst of the Cuautitlan graben in the Basin of Mexico may influence the Tequixquiac Basin along its southern margin due to its position immediately north of this end of the graben system in the Basin of Mexico (Fig 8.14). From a local perspective, the North and North-eastern margins of the Tequixquiac Basin are lined by faulted Cretaceous limestone that separates the study area from the Mezquital Vally (Fig 3.3). The Pliocene - Quaternary Mesa Grande lava flow and volcanic cone (Fig 3.3) closes the Tequixquiac Basin to the west and may have been controlled by a fault, fracture and structural weakness along the western side of the Tequixquiac Basin.

3.11: Summary and conclusion

Here the physiography of the study area has been outlined and indicates that the Tequixquiac Basin is a hydrologically independent, temperate semi-arid basin. This chapter has also demonstrated that the study area has a complicated geological history (see Figs 3.3, 8.9, 8.1). Around the Tequixquiac region folding and faulting associated with the Laramide Orogeny and its position at the northern edge of the graben system in the Basin of Mexico (see Chapter 8) has caused Quaternary volcanic and clastic deposits, and Cretaceous limestone to sit adjacent to each other. To the north, northeast and northwest, the Tequixquiac Basin is limited, in parts, by exposures of basement limestone that are lifted in structural blocks limited by faults (Marín-Córdova et al. 2004). Pliocene/Pleistocene basaltic and andesitic lava flows and volcanic cones close the basin to the West. In the northeast, Eocene-Oligocene andesitic and rhyolitic volcanic sierras reach 3168 m.a.s.l and stretch 11km to the east towards the Sierra Madre Oriental. Low hills (c.2300 – 2400 m.a.s.l) limiting the southern Tequixquiac Basin comprise an early Pliocene volcanic material overlain by Quaternary alluvial deposits (Durazo & Farvolden, 1989, Mooser, 1975). The Tequixquiac Basin, along with the Tula, Nochistongo and the Mezquital basins, are filled with Pliocene (possibly as old as Miocene and as young as Pleistocene) lake clays combined with soils, pumice and tuffs derived from tephra fallout that collectively form the Tarango Formation (Mooser, 1975) (see Figs 3.3, 8.9, 8.1).

Chapter 4 follows and outlines the methods used by this research to achieve the aims and objective discussed in chapter 1.