Chapter 1. Introduction

1.1. Aims of the study

The transition of magmatism from the Sierra Madre Occidental to the TMVB has been intensively discussed within the last decades (e.g. Mooser, 1972; Demant, 1978; Cantagrel and Robin, 1979; Nixon et al., 1987). Recent studies have shown that the TMVB as a distinctive geologic province dates back to the Middle to Late Miocene, as a result of counterclockwise rotation of the magmatic arc of the Sierra Madre Occidental (Ferrari et al., 1999). Little is known about the initial activity of the early arc because the main focus of previous works was on younger volcanism (Márquez el al., 1999; Siebe et al., 2004; García-Palomo et al., 2002; Verma, 2000; Riggs and Carrasco-Núnez, 2004). The remnants of the ancestral TMVB are found close to the present volcanic front of the central sector of the arc as stated by several authors, such as in the Sierra de Mil Cumbres and Sierra de Angangueo volcanic complexes in the State of Michoacán (Pasquaré et al., 1991; Capra et al., 1997) and in the Malinalco area (State of México), where lavas were dated at 19.5 Ma (Ferrari et al., 2003) and 21 Ma (García-Palomo et al., 2000). These rocks are considered to be part of the initial Early Miocene activity of the Transmexican Volcanic Belt (Gómez-Tuena et al., 2007). Another evidence of early volcanic activity of the TMVB is the Tepoztlán Formation which has been neglected in studies on the initial phase of the Transmexican Volcanic Belt so far.

The aims of this study are the development of a stratigraphic framework for the Tepoztlán Formation, to correlate single stratigraphic sections within the formation and to get to know more about its relationship to surrounding formations. Furthermore, it is the task to reconstruct the depositional environment and its change in time and space as well as the identification of possible eruption centres. Prior to this study, direct radiometric ages and palaeomagnetic studies were missing and little was known about the depositional evolution of the Tepoztlán Formation. Palynological studies are applied to produce new results about the palaeoclimate by means of the coexistence approach (Mosbrugger and Utescher, 1997) and the vegetational evolution in Central Mexico during the Lower Miocene. The palynological studies are also supposed to offer a basis for a broader application of the coexistence approach and thus, present new continental sediment archives for the palaeoclimate reconstruction. Finally, the aim of this study is to merge all these new results to an integrated model of the Early Miocene evolution of the central TMVB.

1.2. Previous work

The Tepoztlán Formation was first mentioned by Ordónez (1938) although the name was given much later by Fries (1960) and De Cserna et al. (1988), describing it briefly as “massive lahars rich in subrounded porphyritic andesite clasts intercalated with fluvial deposits”. Furthermore, Fries assigned it to be of early Miocene age and supposed an origin from the volcanic series of Mt. Xochitepec. Later, De Cserna and Fries (1981) suggested an origin from the volcanic centre of Zempoala in the State of México.

Haro-Estrop (1985) made a first attempt to establish a stratigraphical framework for the Tepoztlán Formation, dividing the formation into three different units related to the dominating depositional processes: a volcanic-laharic unit, a fluvial-laharic unit and a laharic-volcanic unit. Despite those earlier works, it took several years until the first geological map of the Tepoztlán area was provided by Avila-Bravo (1998). In the same year García-Palomo (1998) came up with a rough estimate of the age of the Tepoztlán Formation. K/Ar-geochronology of a basaltic andesite which underlies the formation at San Nicolás near Malinalco revealed an age of 21.6 ± 1.0 Ma, a lava flow of the Basal Mafic Sequence on top of the formation revealed an age of 7.5 ± 0.4 Ma, thus confirming the formerly assumed depositional age within the Miocene (García-Palomo et al., 2000). In the following years, emphasis was set on smaller mapping projects in an attempt to document the distribution of the Tepoztlán Formation within the states of Morelos and Estado de México (Hechler, 2002; Lenhardt, 2002; Michelsen and Tunon-Vettermann, 2004; Bär and Schwab, 2005; Lehmann, 2009; Faridfar, 2009; Cizmesija, in prep.). Furthermore, first palynological (Lenhardt, 2003) and sedimentological (Trauth, 2007) studies were carried out.

1.3. Geological and environmental setting

The TMVB is a continental magmatic arc that is constituted by nearly 8000 volcanic structures (e.g. Gómez-Tuena et al., 2007). It is related to the subduction of the Cocos and Rivera plates under the North American plate along the Central American Trench which was established during the Middle-Late Miocene (Ferrari et al., 2000b). The TMVB is about 1000 km long and ranges from 80 to 230 km in width. In contrast to other subduction-related volcanic belts, running parallel to a deep-sea trench, the TMVB is orientated in E-W direction, forming an angle of about 16° with the Middle America Trench (Gómez-Tuena et al., 2007). The belt consists of a large number of Tertiary and Quaternary cinder cones, maars, domes, and stratovolcanoes with predominantly calc-alkaline chemical and mineralogical composition (Siebe and Macías, 2004).

The study area (18°54´-19°01´N lat, 98°57´-99°32´W long.), approximately 1000 km^2, is located along the southern edge of the TMVB in the states of Morelos and Estado de Mexico

(Fig. 1), where Tertiary volcaniclastic series of the Tepoztlán Formation are covered by Quaternary lavas and scoria of monogenetic volcanoes of the Chichinautzin volcanic field. Within this area, the Tepoztlán Formation crop out in an area of 180 km2 and has an overall maximum thickness of 800 m. The volume of the deposited material, still remaining after erosion, was calculated to 130 km^3 with the help of GIS. The formation is widespread around the villages of Malinalco and Chalma in Mexico State and Tepoztlán and Tlayacapan in Morelos; sparse outcrops are located east of Tlayacapan and southeast of the Nevado de Toluca (Capra and Macías, 2000; García-Palomo et al., 2002).

A variety of Eocene-Oligocene (Balsas Group) and older rocks, mostly Cretaceous limestones, underlie the formation. It is covered by lava flows of Pliocene to Holocene age. Close to Malinalco the Tepoztlán Formation crops out between the San Nicolás Basaltic Andesite and the overlying Basal Mafic Sequence (García-Palomo et al., 2000). In Tepoztlán and the eastern vicinities it unconformably overlies the Balsas Group and is covered by the Chichinautzin Formation.

The entire succession comprises pyroclastic deposits (fall, surge and flow deposits), deposits from lahars (debris flow and hyperconcentrated flow deposits) and coarse to fine fluvial and lacustrine deposits (conglomerates, sandstones and mudstones). Only few lava flows and dykes are present. Bedding within the Tepoztlán Formation is generally flat-lying or gently dipping with up to 10° to N/ NNE. The succession is disrupted by normal faults and sub-volcanic intrusions. Displacements at faults are frequently about half a meter and rarely exceed a few meters.

The modern subtropical climatic conditions within the State of Morelos are characterised by hot, humid summers and dry winters under influence of the Mexican or North American monsoon (Adams and Comrie, 1997). The Mexican monsoon is experienced with a pronounced increase in rainfall from an extremely dry June to a rainy July. These summer rains typically last until mid-September when a drier regime is re-established over the region (Douglas et al., 1993). The mean annual temperature is 20°C, and the mean temperatures in August and in January are 24°C and 19.3°C, respectively (historical weather data from 1981-2008; meteorological station of Cuernavaca, altitude 1628 m). Precipitation is relatively low, 770 mm on average. Most of the annual precipitation occurs in summer (June-September).
Tepoztlán itself is located at an elevation of 1700 m above sea level. With an altitude of 2114 m, Mt. Tepozteco (Cerro del Tepozteco) is the highest peak within the study area. To the north, the TMVB rises up to the Valley of Mexico at an elevation of 2240 m. In the south of the study area, the landscape is characterised by wide plains and gentle hills built of Cretaceous carbonates.

The modern vegetation of the Tepoztlán area is characterised by grassland in the plains and the “tundra vulkanika” (Fries, 1960) on top of the extensive lava fields in the north, represented by lichens and shrubs. In between, on the slopes of the Tepoztlán Formation, mixed deciduous forests and coniferous forests (with *Pinus montezumae* as dominant species) are found. The closest place to the study area for a comparison with the Tepoztlán flora to Holocene to Recent palynological studies is Lake Zempoala (2800 m altitude, 19°03'N, 99°81'W). Here, the forests are dominated by *Quercus*, *Pinus* and *Abies* (Miranda and Hernández-X, 1963). The lower montane forest belt (1800 – 2800 m) includes mesophyllous forest with *Carpinus caroliniana*, *Garrya laurifolia*, *Tilia houghii* and *Acalypha phleoides* (Luna et al., 1989). However, the same altitudinal interval on exposed mountain ridges and on drier slopes becomes a mixed forest (2400 – 2800 m) where *Quercus laurina*, *Arbutus xalapensis* and *Pinus montezumae* coexist with species of *Salix* and *Viburnum*. In the upper montane forest belt (2800 – 3700 m) two forest types can be recognized at different altitudinal intervals. From 2800 to 3550 m *Abies religiosa*-dominated forest occurs, with *Roldana angulifolia* and *Thuidium delicatulum* in the understorey (Miranda and Hernández-X, 1963). From 3550 to 3700 m *Pinus hartwegii*-dominated forest with *Festuca tolucensis* and *Festuca amplissima* is common (Lauer, 1978).

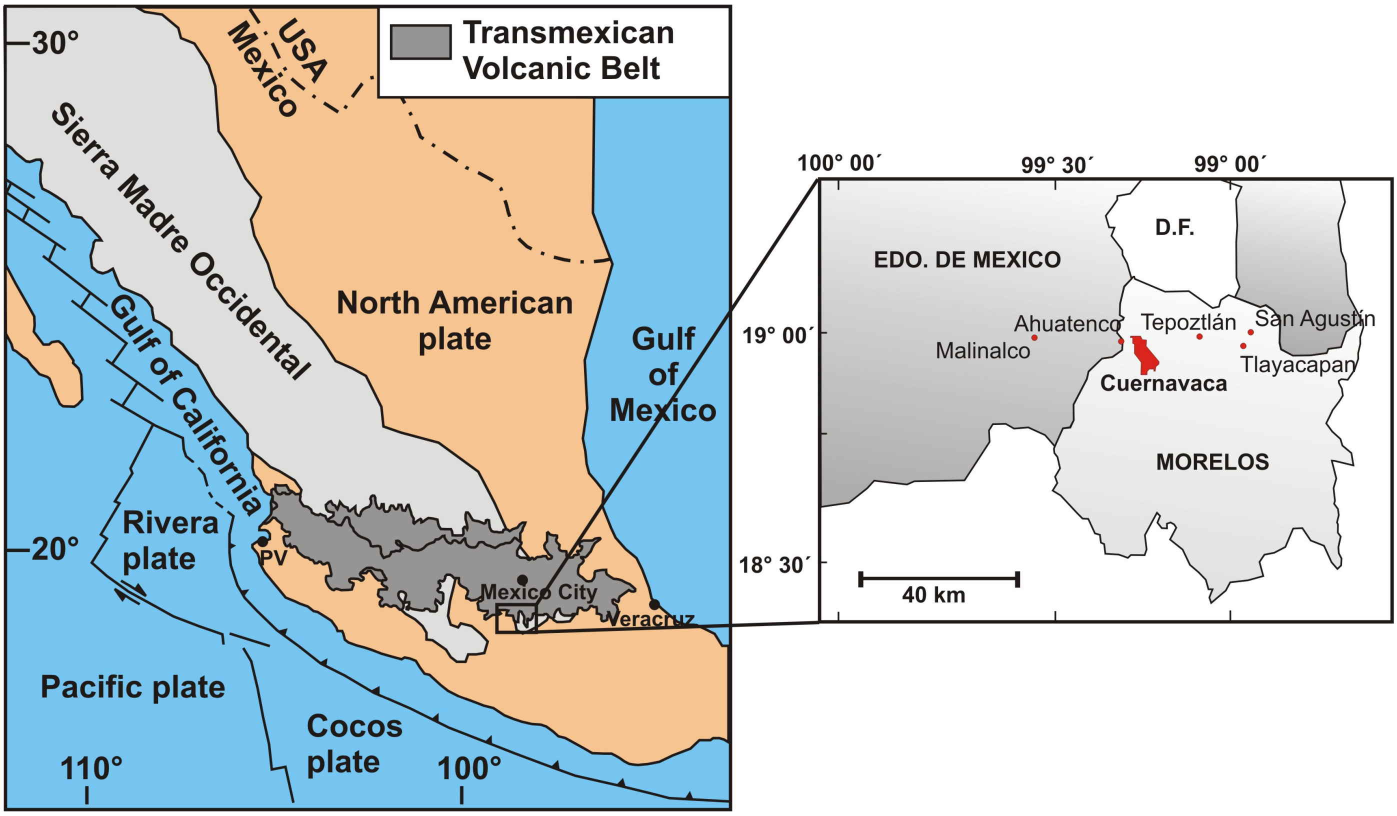

Figure 1. Location of the study area.