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ABSTRACT
A new geological map at 1:50,000 scale of La Reforma Caldera Complex has been produced applying modern survey methodologies to volcanic areas. This map aims to represent a reliable and objective tool to understand the geological evolution of the region. La Reforma Caldera Complex is a Pleistocene nested caldera located in the central part of the Baja California peninsula, Mexico. The twelve formations defined within the Quaternary volcanic record were grouped into three phases (pre-caldera, caldera, and post-caldera). The pre-caldera phase (>1.35 Ma) is characterized by scattered eruptions, mostly occurred in submarine environment. The caldera phase (1.35–0.96 Ma) groups several distinct explosive and effusive eruptions that formed the present-day caldera depression. The post-caldera phase includes scattered effusive eruptions (ended at 0.28 Ma) and resurgence, characterized by several hundred meters of uplift of the central block within the caldera depression.

1. Introduction and previous studies

Geological maps have to be objective and detailed because they represent a fundamental tool to understand the geological evolution of a given area, and, when mapping is conducted at relatively high scale, they provide a sound basis for detailed studies aimed at assessment of natural hazards, and exploitation of geothermal potential and/or ore deposits. For this reason, within the project CEMIE GEO (Centro Mexicano de Innovación en Energía Geotérmica), which involves different sites in Mexican Quaternary volcanic districts, we surveyed La Reforma Caldera Complex area and produced a new geological map at 1:50,000 scale Main Map.

La Reforma Caldera Complex is located in the central part of the Baja California peninsula, 35 km to the NW of the town of Santa Rosalía (Demant, 1984). Along with the Aguajito Caldera (Garduño-Monroy, Vargas-Ledezma, & Campos-Enriquez, 1993) and the Tres Virgenes volcanic complex (Avellán et al., 2018), La Reforma Caldera complex represents a manifestation of the Quaternary volcanism in the central part of the Baja California (Figure 1). The first geological contributions in the region focused on the Plio-Pleistocene sedimentary rocks of the Santa Rosalía Basin (Ortlieb, 1978; Ortlieb & Colleta, 1984; Wilson, 1948; Wilson & Rocha, 1955) because of the exploitation of copper and manganese minerals. Wilson and Rocha (1955) provided a detail geological map of the Santa Rosalía area, but did not include La Reforma range, located to the northwest. Schmidt (1975) published the first geological map of the Sierra La Reforma that was interpreted as a complex system of uplifted tectonic blocks. One of these blocks was made of crystalline granodioritic rocks dated by the Author at 91.2 ± 2.1 Ma by K-Ar method. Demant and Ortlieb (1981) recognized the Sierra La Reforma as a resurgent caldera, and Demant (1984) presented a regional geological map of Santa Rosalía with a mineral and petrological characterization that included La Reforma Caldera. In 1982, the National Power Company (Comisión Federal de Electricidad = CFE) began geological and geophysical

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prospecting in the Tres Vírgenes area (southwest of La Reforma) for geothermal exploration (e.g. Lira, González, & Arellano, 1997; Lira, Ramirez, Herrera, & Vargas, 1983) followed by its exploitation in 1986. The CFE survey involved other prospecting areas as El Aguajito (Garduño-Monroy et al., 1993) and set the basis for new studies of Tres Vírgenes (Capra, Macías, Espindola, & Siebe, 1998; Sawlan et al., 1981; Schmitt, Stockli, & Hausback, 2006; Schmitt, Stockli, Niedermann, Lobera, & Hausback, 2010) with the updated geology of the Tres Vírgenes volcanic complex (Avellán et al., 2018; Macías et al., 2012). Schmitt et al. (2006) dated the age of La Reforma (1.3 Ma) and Aguajito ignimbrites (1.2 Ma) with the U-Pb method in zircon, with the aim of understanding the general evolution of the Quaternary volcanic centres northwest of Santa Rosalia.

Despite these efforts, no detailed studies of La Reforma were carried out to produce a comprehensive volcanological map and evolution of the caldera. The CEMIE GEO project, a Mexican initiative to carry out modern geothermal studies, allowed to perform new investigations of La Reforma caldera, aimed at understanding its geothermal potential.

Here, we present the first contribution of this project with the revised geology and stratigraphy of La Reforma caldera complex that was assisted by 40Ar/39Ar and U-Pb geochronology (Table 1) from previous studies and new data from the PhD work of García-Sánchez (2019). This new map will set the basis for modern studies in the area, which will be helpful to future prospecting for ore deposits and geothermal potential areas, as well as paleogeographic reconstructions of marine depositional systems and mineralization.

2. Methods

The geological map, here presented at 1:50,000 scale, has been surveyed at 1:25,000 scale in a logistically difficult area due to the absence of any roads and access feasible only by the coastline and a few mountain pathways (Figure 2).

The fieldwork was preceded by critical review of existing literature for the studied area, along with analyses of satellite images (including ESRI and Google images) and of a 25 m pixel-sized digital elevation model (DEM) and its derived morphological features (slope aspect, shaded relief, 3D visualization, etc.).

The geological survey, carried out during 5 field campaigns (from 2014 to 2017), has been realized using INEGI topographic map and iGIS® software on iPad mini equipped with Google Earth images. Geological survey was carried out on lithostratigraphic basis, which allowed for the definition of various formations. Indeed, lithostratigraphic units are the only ones easily recognizable in the field because of their lithology and stratigraphic position (Groppelli & Martí-Molist, 2013; Groppelli & Viereck-Goette, 2010; Martí, Groppelli, & da Silveira, 2018; Salvador,
In addition to the stratigraphic position, we used abrupt change in lithology, presence of palaeosols, or intercalation of marine sediment to define formations.

For the pre-Quaternary basement units (Figure 3), we adopted the published regional stratigraphic framework (Bryan, Orozco-Esquivel, Ferrari, & Lopez-Martinez, 2014; Conly, Brenan, Bellon, & Scott, 2005; Ferrari, Orozco-Esquivel, Bryan, López-Martínez, & Silva-Fragoso, 2018; Hausback, 1984; Kimbrough et al., 2001; McLean, 1988; Sawlan & Smith, 1984; Schmidt, 1975; Umhoefer, Dorsey, Willsey, Mayer, & Renne, 2001). For the Quaternary volcanics, we have defined twelve formations (Table 2). The youngest one (Cueva del Diablo formation) includes lithostratigraphic units of lower rank, members, as the lithological properties allow distinguishing them from the adjacent part of the formation (Salvador, 1994). Moreover, six different lithosomes (Pasquarè et al., 1992; Wheeler & Mallory, 1953) provide additional details to the stratigraphic succession of the Cueva del Diablo formation, based on their morphology, vent location and product distribution (Table 3).

In order to summarize the volcanic succession, we have identified three main phases (pre-caldera, caldera and post-caldera) on the basis of the relationships of the deposits with the caldera evolution. Moreover, we have grouped all the pre-Quaternary rocks into a ‘sedimentary and igneous basement’ unit.

During field mapping, we have collected samples for petrographic and geochemical analyses and age determination of rocks. Petrographic data allowed for a better characterization of the lithostratigraphic units, whereas radiometric data allowed constraining formations and lithosomes, thus helping reconstruct the evolutionary phases of La Reforma caldera.

All the field data have been stored in a geodatabase, using iGIS software in the field and then ArcGis® platform during the preparation of the geological map.

The colour scale chosen for representation of lithostratigraphic units on the map follows the three evolutionary phases: pre- (brown shaded), syn- (red shaded) and post- (green shaded) caldera phases. A scale of light blue was used to represent the sedimentary and igneous basement units, whereas blue colour was used for the Cretaceous basement (granitoids) in order to highlight its location. This was important in order to highlight the resurgence of the central part of the caldera. Regarding symbols, we have marked crater rims, pit crater rims, caldera rim, bedding attitude, marine terraces and faults. Dykes have been marked by lines too. Insets at 1:20,000 scale highlight the detailed stratigraphic succession in two deep fluvial valleys to the west and south-west.

In addition to the legend, we have included the following elements into the map: (1) an inset showing the geographic location of the mapped area, (2) a stratigraphic scheme to illustrate the relationships among

| Sample   | Coordinates | Lithostratigraphic unit | Altitude (m) | Method       | Material dated | Age (Ma) | Error 1σ | Notes |
|----------|-------------|-------------------------|--------------|--------------|----------------|-----------|----------|-------|
| RF-102   | 358009      | Plutonic rocks          | 160          | Zircons      | Plutonic rocks | 97.8 ± 1.5|          |       |
| RF-5A    | 360207      | Cueva Amarilla ignimbrite| 250          | Zircons      | Cueva Amarilla ignimbrite | 19.25 ± 0.08|          |       |
| RF-47    | 367168      | Cueva Amarilla ignimbrite| 319          | Zircons      | Cueva Amarilla ignimbrite | 2.4 ± 1.5 |          |       |
| RF-53F   | 354423      | Carrizo ignimbrite     | 250          | Zircons      | Carrizo ignimbrite | 1.89 ± 0.27|          |       |
| RF-26D   | 365319      | Contrabando formation  | 319          | Zircons      | Contrabando formation | 1.47 ± 0.08|          |       |
| RF-51    | 369626      | Punta Candeleros formation | 1          | Zircons      | Punta Candeleros formation | 1.42 ± 0.05|          |       |
| RF-65    | 358751      | Punta Candeleros formation | 6          | Zircons      | Punta Candeleros formation | 1.35 ± 0.02|          |       |
| RF-18    | 355645      | Los Balcones ignimbrite| 250          | Zircons      | Los Balcones ignimbrite | 1.27 ± 0.02|          |       |
| RF-88    | 363593      | Los Balcones ignimbrite| 719          | Zircons      | Los Balcones ignimbrite | 1.29 ± 0.06|          |       |
| RF-12    | 357200      | Mesa del Yaqui formation| 367          | Zircons      | Mesa del Yaqui formation | 1.18 ± 0.06|          |       |
| BH00R41  | –           | Aguajito ignimbrite (Schmitt et al., 2006) | –           | U/Pb         | U/Pb | 1.17 ± 0.07|          |       |
| RF-122   | 366559      | Punta Arena ignimbrite | 14           | Zircons      | Punta Arena ignimbrite | 0.96 ± 0.21|          |       |
| RF-26I   | 365319      | Cueva del Diablo formation | 26          | Zircons      | Cueva del Diablo formation | 0.46 ± 0.08|          |       |
| RF-41A   | 368029      | Cueva del Diablo formation | 26          | Zircons      | Cueva del Diablo formation | 0.28 ± 0.05|          |       |
Figure 2. Geological map on a shaded topography (INEGI data). Numbers refer to the lithostratigraphic units described in Table 2, except (16) Recent alluvial deposits.
Table 2. Description of the lithostratigraphic units (group, formation and member) identified within La Reforma caldera complex.

| Formation                        | Acronym | Description                                                                 | Location                                                                 | Geochemistry                          | Interpretation and notes                                                                 |
|----------------------------------|---------|------------------------------------------------------------------------------|--------------------------------------------------------------------------|---------------------------------------|------------------------------------------------------------------------------------------|
| **Post-caldera phase**           |         |                                                                              |                                                                          |                                       |                                                                                          |
| Cueva del Diablo formation       | 15      | Scoria cones and domes sometimes associated with limited lava flows (Figures 4(c) and 5(c)). Lava flows are usually thin (2–5 m) and alternated to scoriae. Dikes and small sub-intrusive bodies are also present (Figure 6(a) and b)). | Western side of the caldera depression | Mainly basaltic-andesitic and andesitic lavas. Locally rhyolitic lavas | This formation includes all the deposits formed after the caldera phase. The volcanic activity is scattered and low volume respect the previous phase. Inside the caldera depression usually the centres are located along the ring faults. It is possible to identify several lithosomes (see Table 3). The deposits form alluvial fans within the western part of the caldera depression probably due to the dismantling of the resurgent block. |
| Arroyo Grande member              | 15b     | Sands to gravel deposits made of lavas and plutonic rocks with interbedded three thin (<1 m) white fallout deposits (Figure 6(c)). The deposits are matrix supported, partially loose, and coarsely stratified (0.5–1 m) with parallel and lenticular shapes. The total thickness is up to 50 m. | Western side of the caldera depression | White pumices are trachydacitic, while the grey ones are dacitic. | This ignimbrite represents the last event caldera-forming partially filling the paleo-depression formed during the previous caldera collapses. It was deposited in subaqueous environment and affected locally by hydrothermal circulation. Age: 0.96 ± 0.21 Ma. |
| **Caldera phase**                 |         |                                                                              |                                                                          |                                       |                                                                                          |
| Punta Arena ignimbrite            | 14      | White loose pyroclastic deposit, made of grey and white pumices, lava and scoria lithics (red and grey) in abundant ash matrix. Matrix is generally whitish to yellowish in colour, but it becomes light-green when hydrothermally modified (Figure 5(c) and d)). It is locally fairly well-consolidated due to hydrothermal alteration. Locally abundant shells (mainly bivalves) are present, mixed into the deposit. Lag breccias made of abundant heterolithologic lithic blocks are present around Cerro la Reforma. The thickness varies from few meters to more than 200 m because of the irregular paleo-topography at the time of deposition. | Western side of the caldera depression | Rhyolite                               | This ignimbrite represents one of the main volcanic events of the close Aguajito Volcanic Complex. Age: 1.17 ± 0.07 Ma (Schmitt et al., 2006). |
| Aguajito ignimbrite               | 13      | Not welded, light-brown pyroclastic deposit with white pumice and loose crystals of pl at the bottom, overlain by light-pink to light-purple, lithic-rich ignimbrite. Welded at top, with brown flammers, lithics (granite, lavas), ash-rich matrix, and loose crystals of pl, amphib and px. The total thickness is up to 40 m. | Western side of the caldera depression | Rhyolite                               | This ignimbrite represents one of the main volcanic events of the close Aguajito Volcanic Complex. Age: 1.17 ± 0.07 Ma (Schmitt et al., 2006). |
| Mesa El Yaqui formation           | 12      | Blocky lava flow succession, dark-grey in colour, associated with few scoria layers. Aphyric to porphyritic lavas with phenocrysts of pl, ol, px and Fe-Ti oxides. The thickness varies from 3 to 20 m. | Western side of the caldera depression | Rhyolite                               | This formation represents an effusive period during the caldera-forming phase, when most of the caldera depression was already formed. Age: 1.18 ± 0.46 Ma. |
| La Rebeca ignimbrite              | 11      | Pyroclastic deposits consisting of basal welded, reddish bed overlain by various welded brownish to dark-grey deposits (Figure 5(b)). Welded deposits contain black flamma pumice and accidental lithics (lavas). Loose crystals of pl and px occur in ashy matrix. The thickness is up to 40 m. | Western side of the caldera depression | Rhyolite                               | This ignimbrite represents one of the main events caldera-forming and responsible of most present caldera morphology. Age: 1.29 ± 0.02 Ma. |
| Cerro La Reforma formation        | 10      | Succession of thick lava flows (up to 10 m) associated with minor pyroclastic deposits (Figure 5(d)). The formation comprises also lava domes along caldera rims (in map n. 10a). Lava flows are porphyritic with phenocrysts of pl, px and Fe-Ti oxides. Xenocrysts of qtz and sedimentary xenoliths are also present. The thickness is more than 400 m because the base is always not visible. | Western side of the caldera depression | Rhyolite                               | This formation represents the first lava flow filling of the caldera depression, later tilted during the resurgence. Age: 1.27 ± 0.02 Ma. |
| Los Balcones ignimbrite           | 9       | Grey welded pyroclastic deposit made of light-grey pumice and dark grey flamma, with abundant lithics (grey, black and white lavas) (Figures 4(c) and 5(a) and b)). Abundant loose crystals of pl and minor px in greyish ash-rich matrix. The thickness is up to 30 m. | Western side of the caldera depression | Rhyolite                               | This ignimbrite represents the first known event caldera-forming. Age: 1.35 ± 0.02 Ma. |

(Continued)
### Pre-caldera phase

#### Punta Candeleros formation

- **Acronym**: 8
- **Description**: Hyaloclastites, pillow lavas and lava domes with columnar jointing (Figure 4(a) and b)). Lava texture varies from aphyric to porphyritic with phenocrysts of pl and px.
- **Location**: This formation crops out widely in the NW and SE sectors of the caldera depression, both inside and outside.
- **Geochemistry**: Lava composition varies from basaltic-andesite to andesite with minor trachy-dacite.
- **Interpretation and notes**: The formation includes effusive episodes, mainly submarine, affecting the area immediately before the onset of the caldera phase. Age: 1.42 ± 0.05 Ma (pillow lavas); 1.36 ± 0.06 Ma (lava dome).

#### Contrabando formation

- **Acronym**: 7
- **Description**: Stratified, light-yellow pyroclastic deposit made of white and grey pumices (Figure 4(a)). Loose crystals of pl and px occur in reddish ash-rich matrix.
- **Location**: This formation crops out only in the SE area along the external slopes of the caldera depression.
- **Geochemistry**: Rhyolite
- **Interpretation and notes**: The formation represents one of the scattered explosive events affecting the area before the caldera phase. Age: 1.47 ± 0.08 Ma.

#### Carrizo ignimbrite (not mappable)

- **Acronym**: ND
- **Description**: Red welded pyroclastic deposit containing yellow and grey pumices and abundant lithics (green or grey lavas and black scoriae) (Figures 4(c) and 5(a)). Abundant loose crystals of pl in reddish ash-rich matrix.
- **Location**: This ignimbrite crops out only in limited areas along deep valleys all around the caldera depression.
- **Geochemistry**: This formation is not mappable at the present scale. Age: 1.89 ± 0.27 Ma.

#### Cueva Amarilla ignimbrite

- **Acronym**: 6
- **Description**: Greenish grey pyroclastic deposit with white pumice at bottom and black scoriae at top (Figure 4(a and c)). Loose crystals of pl and px occur in yellow ash-rich matrix.
- **Location**: This ignimbrite crops out only in the S and N sector along the external slopes of the caldera depression.
- **Geochemistry**: ND
- **Interpretation and notes**: The formation represents one of the scattered explosive events affecting the area before the caldera phase. The source area is unknown due the scarce outcrops. Age: 2.4 ± 1.5 Ma.

#### Mesa de Enmedio ignimbrite

- **Acronym**: 5
- **Description**: Light-grey pyroclastic deposit made of pumices (10–50 cm long). Loose crystals of pl and px occur in yellow ash matrix.
- **Location**: This formation crops out only close to the Punta Arena
- **Geochemistry**: ND
- **Interpretation and notes**: The formation represents one of the scattered explosive events affecting the area before the caldera phase. The source area is unknown due the scarce outcrops. Age: 1.89 ± 0.27 Ma.

#### Sedimentary Formation of the Santa Rosalia basin

- **Acronym**: 4
- **Description**: Siltstones, sandstones and isolated conglomerates (Figure 4(c)), with interlayered several volcanic deposits (ignimbrites, pillow lavas, hyaloclastites, and reworked volcanics, see # 5, 6, 7, and 8). Brownish siltstones (up to 30 m thick) at base, overlain by fossiliferous sandstones and conglomerates (5–20 m thick). Fossils mainly consist of bivalves (Pectinidae) and well-preserved oysters and sea urchins.
- **Location**: This formation crops out mainly along the coast and deep valleys south of the caldera depression. Inside the caldera, it crops out in the resurgent block and locally at the base of the caldera inner walls.
- **Geochemistry**: Sedimentary and igneous basement
- **Interpretation and notes**: This formation, known also as Formación sedimentaria de la cuenca de Santa Rosalia, Auct. (Ortleib & Colleta, 1984; Wilson, 1948), represents the marine tectonic depression due to the opening of the California Gulf. Age: Pliocene-Middle Pleistocene (Ortleib & Colleta, 1984).

#### Sedimentary and igneous basement

#### Santa Lucia formation

- **Acronym**: 3
- **Description**: Lava flows and domes, associated with dikes. Lavas with aphyric to porphyritic texture and phenocrysts of pl and px and amphibole. The formation, interlayered with the Comondú Group (see n. 2), is up to 80 m thick.
- **Location**: This formation crops out only in the south margin of the map.
- **Geochemistry**: Lava are andesitic to basaltic in composition.
- **Interpretation and notes**: Andesite-dominated arc lava suites erupted when the Gulf region was affected by oblique-subduction of the Farallon-Guadalupe plate under the North America plate along the western margin of Baja California (Conly et al., 2005). Age: 19.25 ± 0.08 Ma.

#### Comondú Group

- **Acronym**: 2
- **Description**: Red sandstones, siltstones and conglomerates interlayered with lavas (Santa Lucia Formation, see n. 3) (Figure 3(b)). The thickness is up to 100 m, but the base is always not visible.
- **Location**: This group crops out only in the south margin of the map and some deep valleys.
- **Geochemistry**: These rocks crop out inside the caldera depression (western margin of the resurgent block) and outside along Yaqui canyon.
- **Interpretation and notes**: Also known as Batholites Peninsulares, (Gastil, 1975; McLean, 1988; Schmidt, 1975) these rocks represent a voluminous batholith intruded into the Early Cretaceous supra-crustal volcanic and sedimentary sequence. Intrusions occur as small sheet and diapirs or as a combination of large nested intrusive centres and smaller isolated intrusions (Kimbrough et al., 2001). Age: 97.8 ± 1.5 Ma.
3. Evolution of La Reforma caldera complex

The geological map (Figure 2) highlights how La Reforma caldera complex developed over a basement made of igneous (granitoids) rocks (Peninsular Ranges Batholith, Gastil, 1975), volcaniclastic and sedimentary rocks (Comondú Group, Bryan et al., 2014; Hausback, 1984; López, Garcia, & Arellano, 1995; Sawlan, 1991; Sawlan & Smith, 1984; Umhoefer et al., 2001) with interbedded lava flows, ignimbrites, and domes (Santa Lucia formation, Garduño-Monroy et al., 1993).

Table 3. Description of the lithosomes recognized inside the Cueva del Diablo formation (Post-caldera phase).

| Lithosomal unit                  | Acronym | Description                                                                 | Interpretation and notes                                                                 |
|----------------------------------|---------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Punta Prieta scoria cones        | L6      | Scoria cones associated with a thin lava flow (max. 5 m thick) extending eastward up to the sea. No evidences of marine terraces. | Small scoria cones that produced limited lava flows cropping out in the eastern sector of La Reforma Caldera. These represent the most recent volcanic event of La Reforma caldera complex. Age: 0.28 ± 0.05 Ma. |
| Cerro Colorado scoria cone       | L5      | Low-volume products aligned pit craters and scoria cones, except for the easternmost lava flow that extends up to the coastline. No evidences of marine terraces. The easternmost lava flow field is a complex 'aa' morphology with superimposed flows reaching a maximum thickness of 50 m. | NE-SW striking aligned pit craters and scoria cones, cropping out outside the caldera depression (south). The easternmost cone is associated with a large lava flow extending up to the coastline. Age: 0.46 ± 0.08 Ma. |
| Punta El Gato stratocone         | L4      | Scoria cone associated with a short lava flow. The lava flow surface is smoothed by erosion. Lava flow thickness is up to 10 m. | Short lava flow cropping out outside the caldera depression (north). |
| Punta Gorda stratocone           | L3      | Eroded scoria cone associated with a lava flow extending up to the coastline. The lava flow surface is smoothed by erosion. Lava flow thickness is up to 10 m. No evidences of marine terraces. | Lava flow cropping out outside the caldera depression (north) and extending up to the coastline. |
| Morro de las Palmas dome         | L2      | Small-volume rhyolitic domes cropping out along the northern side of La Palma river. Presence of thick lava flows, with a maximum thickness of 40 m. | Rhyolitic domes cropping out outside the caldera depression (north) forming a small dome field. |
| Las Minitas dome                 | L1      | Domes associated with thick (more than 20 m) tabular lava flows displaying columnar joints. | Thick tabular lava flows and domes covering the Punta Arena Ignimbrite and cropping out inside the caldera depression (north). |

Figure 3. View of representative outcrops from the sedimentary and igneous basement of La Reforma caldera complex. (a) Granitoid basement from central part of La Reforma caldera complex; (b) Reddish fluvial conglomerate (Comondú Group).

The pre-caldera volcanic activity developed in a shallow water, marine basin, as suggested by the occurrence of siltstones and fossiliferous sandstones (Sedimentary Formation of the Santa Rosalia basin) interbedded with volcanic units. The pre-caldera activity is characterized by both explosive and effusive eruptions, with emplacement of pyroclastic density currents (PDCs; Mesa de Enmedio and Cueva Amarilla ignimbrites), volcaniclastics (Contrabando formation), pillow lavas and domes (Punta Candeleros formation). Only one subaerial ignimbrite is exposed at El Carrizo canyon, SW of the caldera rim (Carrizo ignimbrite). The pre-caldera activity probably built up a stratovolcano, whose remnants are today exposed on the SE and NE parts of the caldera complex, and along the sea cliffs in the Punta Gorda area.

The onset of La Reforma caldera started with the eruption of Los Balcones ignimbrite, nowadays not
exposed within the caldera, but only visible in the Arroyo Grande and El Carrizo canyons, to the SW of the caldera rim, and La Palma canyon to the north. The caldera depression was filled by lava flows alternating with scoriae, with a thickness of more than 400 m (Cerro La Reforma formation). La Reforma ignimbrite marks the second caldera-forming eruption, which enlarged the initial caldera depression. The deposits of La Reforma ignimbrite are extensively exposed outside the caldera rims to the S and SW, whereas they crop out sporadically within the caldera in the northern, eastern and southern parts. The eruptive activity resumed with the emplacement of widespread, thin lava flows, probably erupted along fissures parallel to the caldera-forming ring faults, and composing the Mesa El Yaqui formation. The geographical distribution of these lava flows (bordering almost all the caldera rims), suggests they were accompanied by resurgence of the central block of the caldera, which prevented most of the intrusion of feeding dykes within the caldera depression. After the emplacement of Mesa El Yaqui formation, La Reforma stratigraphic succession is characterized by the occurrence of Aguajito ignimbrite, likely deriving from the nearby Aguajito volcanic complex (Garduño-Monroy et al., 1993; Schmitt et al., 2006). The Aguajito ignimbrite deposits are well exposed to the west, but they have been never reported within La Reforma caldera. The Punta Arena ignimbrite is the last eruption of the caldera phase, and it extensively crops out only within the caldera, where it fills up topographic depressions with thickness of up to 200 m. Thin horizontal stratification and the occurrence of marine shells within the deposits testify for the subaqueous deposition of this formation.

The Cueva del Diablo formation contains the post-caldera deposits (Table 3), dominated by the evidence of effusive activity along the ring faults and faults bordering the central resurgent block (Las Minitas dome, Morro de las Palmas dome, Punta Gorda stratocone, Punta El Gato stratocone, Punta Prieta scoria cones). Only a few eruptive centres occur outside the caldera rims, and are located along NE-SW tectonic alignments (Cerro Colorado scoria cone). It is during this phase that the resurgence culminated to the present-day status, with the exposure of the plutonic rocks of the Peninsular Ranges Batholith in the SW part of the resurgent block. The uplift of the central part of the resurgent block determined the closure of the drainages to the E, with the formation of a small sedimentary basin in the western part of the caldera. This morphological barrier was likely responsible for the deposition of the volcaniclastic sediments of the Arroyo Grande member.

The magmatic driven resurgence of the central block of the caldera was accompanied by a regional uplift of the entire complex, in the order of more than 100 m, as testified by several marine terraces visible on the marine cliffs to the east (Figure 7). This regional uplift has been also responsible of the emersion of the whole caldera complex, as it is visible today.

4. Conclusions

The new geological map of La Reforma caldera complex represents an accurate and updated basis for understanding the geological evolution of this part of
Figure 5. View of representative outcrops from the caldera phase of La Reforma caldera complex. (a) Los Balcones greyish ignimbrite on top of the Carrizo reddish ignimbrite in the Yaqui canyon area; (b) La Reforma ignimbrite (grey and red basal facies) on top of the Los Balcones ignimbrite; (c) Punta Arena ignimbrite, locally displaying yellowish and greenish hydrothermal alteration topped by post-caldera lava flows in the Cerro La Cueva del Diablo area; (d) View of Cerro La Reforma formation.

Figure 6. View of representative outcrops from the post-caldera phase of La Reforma caldera complex. (a) Intrusion with cooling joints from the Cueva Del Diablo formation; (b) View of the Arroyo Grande member in the Arroyo Grande canyon area; (c) Layered intrusion.
Baja California (Figure 2). The map has relevance for the comprehension of the Pleistocene volcanism in the area as it provides new insights into the inception of volcanism in this part of the peninsula. The content of the map includes a new stratigraphic reconstruction of La Reforma pre-caldera, syn-caldera, and post-caldera activity and their timing. This information will provide support to understand the evolution of the Santa Rosalia Basin and the interaction between marine sedimentation and submarine and subaerial volcanism. The geological map of La Reforma caldera complex also represents an invaluable contribution towards the knowledge of the territory and the exploitation of natural resources.

**Software**

Geological boundaries, structural features and polygons were digitized from field paper maps using ArcGIS ESRI (10.2.1 for Desktop, 10.2.1.3497 version), often with the aid of Google Earth Pro. The regional setting scheme (on the upper left corner of the map page) was constructed and edited by using CorelDraw X6. The 3D scene (on the bottom of the map page) was edited using ArcScene (ArcGIS 10.2.1). The map was produced by using ArcGIS ESRI and the final editing page was performed in Adobe Illustrator 6.0.

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