Circular features in the Trans-Mexican Volcanic Belt

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Abstract

One hundred and ninety-one circular or elliptical features have been located on Landsat imagery of the Trans-Mexican Volcanic Belt (TMVB). The origin of most of these features is unknown. Nine have been recognized as collapse calderas (clearly visible on Landsat imagery) and studied in detail, while an equally small number have been tentatively identified as such but not thoroughly investigated. On the basis of the identification of at least five of the nine calderas through their detection on Landsat images, it is proposed that the present inventory is a reliable base to extend the census of the TMVB confirmed calderas, now clearly too small for a population of roughly 8000 volcanic centers, many of which emitted large volumes of felsic pyroclastic products.

Keywords: Mexico; Calderas; Remote sensing; Trans-Mexican Volcanic Belt

1. Introduction

The Trans-Mexican Volcanic Belt (TMVB) is a volcanic province 20–150 km wide and about 1000 km long, stretching in a roughly east–west direction from Puerto Vallarta to Veracruz at the Pacific Ocean and Gulf of Mexico coasts, respectively (Demant, 1978; Robin, 1982; Verma, 1987, and references cited therein). In spite of the large extension of the province covered by felsic pyroclastic products, only nine of the approximately 8000 volcanic centers identified (Robin, 1982) in the TMVB have been classified as collapse calderas. Several authors (Nelson and Carmichael, 1984; Negendank et al., 1985) have located other volcano-tectonic features within the TMVB, but no systematic attempt has ever been made to identify calderas across the entire volcanic belt.

Such work is considered of paramount importance by the present authors, because many geothermal energy and volcanic hazards are associated with calderas. In 1991, two of us (F.A. and S.P.V.) searched Landsat images for semicircular features in the central part of the TMVB. Fieldwork led to the identification of Mazahua caldera (Fig. 1; Anguita et al., 1991), and served as a test case for the present work.

2. The inventory

The entire TMVB is covered by 13 Landsat MSS series images, numbers 28, 29, 34, 35, 41, 42, 49, 50, 58, 59, 67, 75, and 76 in the collection available from

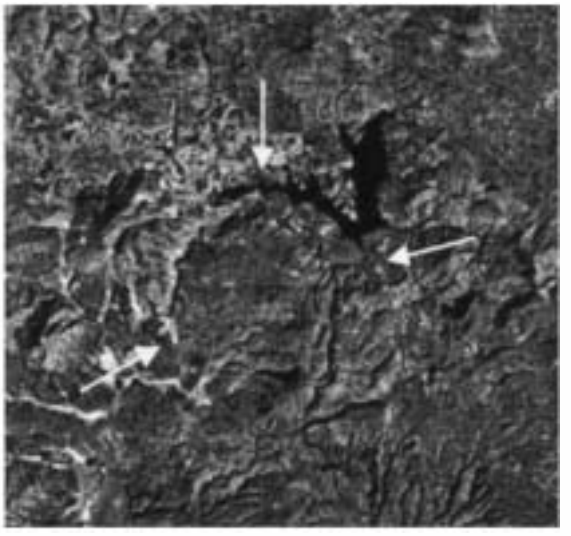

Fig. 1. The Mazahua caldera (approximately 8 km diameter), identified first on the basis of this Landsat image (image 41, coordinates 19°37′N, 100°00′W; feature #105 in Table 1; reliability: Fair) and then confirmed from field work. North is up. Arrows highlight the caldera rim.

Instituto Nacional de Estadistica, Geografía e Informática, (INEGI, the official mapping institution in Mexico). The bulk of our work was the identification of circular and elliptical features on those images (Fig. 2). These features were then located on 'spaciomaps' (georeferenced color Landsat image mosaics) published by INEGI and by SAHOP (the Secretaría de Asentamientos Humanos y Obras Públicas), and assigned a number, geographical data and descriptive features, such as morphology, diameter, and apparent relations to tectonic lineaments. We then assigned each feature a reliability index. The label 'Good' indicates a clearly distinguishable feature on both Landsat images and spaciomaps. 'Fair' indicates a feature seen on only one of the two images sets. 'Poor' features are not clearly expressed on either image set. Our inventory, includes 191 features, listed in order of decreasing longitude. We classify the features as circular (~65%), semicircular (~15%), elliptical (~19%), and semielliptical (~1%) subsets. We attribute the 'half' features to faulting.

Our inventory (Table 1) may have overlooked some caldera-like features, and some features identified by us may not be calderas. Field work is needed.

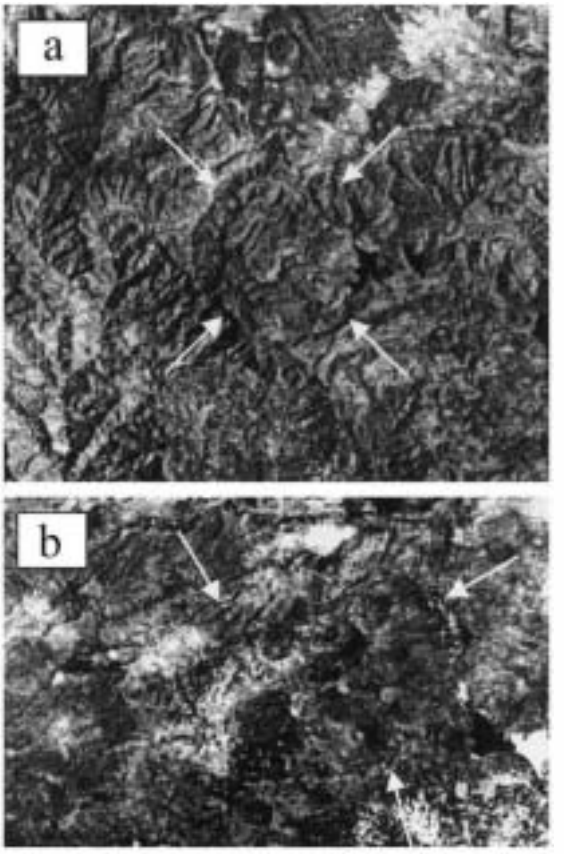

Fig. 2. Examples of circular (a, Landsat image 58, coordinates 19°18.3′N, 101°32.8′W, about 7 km diameter, feature #62 in Table 1; reliability: Good) and elliptical (b, Landsat image 49, coordinates 20°01′N, 101°36.5′W; about 20 × 30 km diameter; feature #159 in Table 1; reliability: Poor) features. North is up. Arrows point the borders of the features.

3. The circular features in the tectonic framework of the TMVB

The tectonics of the TMVB has been studied by Nelson and Carmichael (1984); Lugo et al. (1985); Luhr et al. (1985); Negendank et al. (1985); Nelson and Sánchez-Rubio (1986); Pasquarè et al. (1987); Johnson and Harrison (1990); Allan et al. (1991); Ferrari et al. (1991); Wallawender and Hanan (1992); Moore et al. (1994); Suter et al. (1995); Ramírez-Herrera (1996); and Campos-Enríquez et al. (1999). As shown in Fig. 3, a number of the faults detected by these authors transect many of the features of our census.

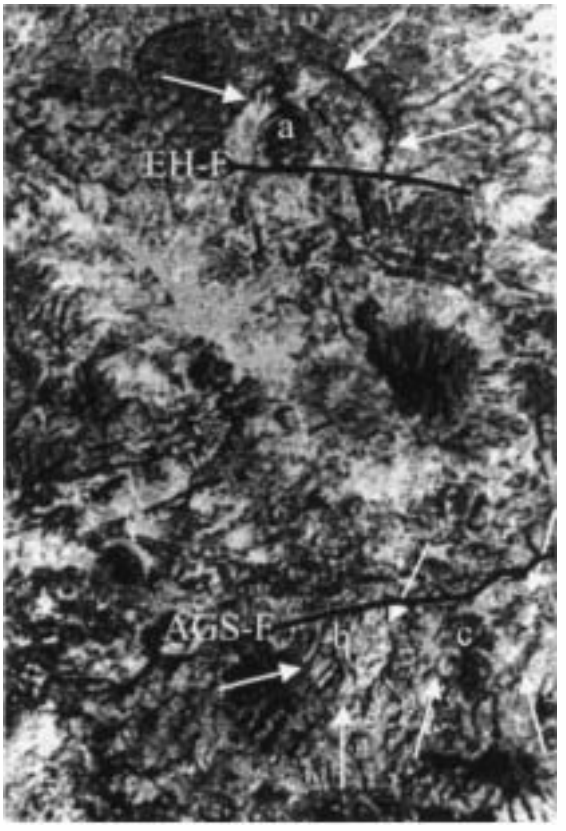

Fig. 3. Examples of features apparently connected with satellite lineations. a, the Amealco caldera (about 10 km diameter, Landsat image 49, coordinates 20°08′N, 100°09′W; feature #100 in Table 1; reliability: Good, cut by the Epitcaio Huerta fault identified EH-F); and b, c, two other semicircular features cut by a fault (identified AGS-F) belonging to the Acambay graben system. North is up. Arrows point the borders of the features.

Fig. 4 is a tectonic sketch map of the TMVB, to which the circular features have been added. From this superposition it becomes clear that the highest concentration of circular features (15%) occurs at the intersection of two important tectonic systems of central Mexico: the east–west Chapala-Tula tectonic lineament (7–7′ in Fig. 4) and a N160°W lineament, the Querétaro-Taxco feature system (6–6′ in Fig. 4). Probably it is not a coincidence that three of the nine recognized calderas in the TVMB (Los Azufres, Amealco, and Mazahua) are located on this tectonic crossing. Other concentrations of circular features occur at equally significant tectonic intersections: for instance, La Primavera caldera is located (together with eight other circular features) on the crossing of the main arm of the TMVB with the Colima graben. Twenty of the features form likewise a belt at about 102°W longitude, where the Pénjamo north–south graben crosses the TMVB (4–4′ in Fig. 4). On the contrary, there is a clear gap where the Tzitzio anticline (Ferrari et al., 1991) crosses the Belt, thus suggesting a possible association of at least some of the features with extensional stress fields. The absence of features in the vicinity of the Lake Cuitzeo could be related to the compression caused on this area by the Michoacan block.

4. Discussion

One possible origin of the circular and elliptical features is the collapse of a volcanic construct. Other possibilities include circular intrusions, tectonic

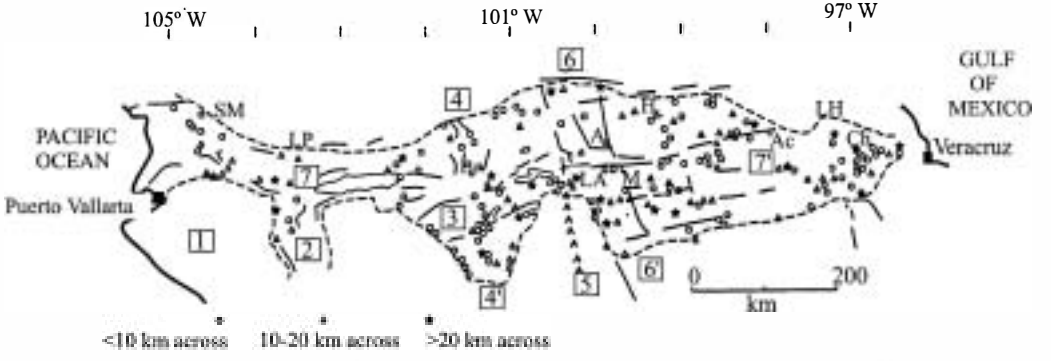

Fig. 4. Tectonic sketch map of the TMVB, with the locations of detected features shown with symbols: circles (58%) for features less than 10 km across, triangles (29%) for features between 10 and 20 km across, and stars (13%) for features larger than 20 km across. Verified calderas are: SM, Santa María del Oro; LP, La Primavera; LA, Los Azufres; A, Amealco; M, Mazahua; H, Huichapan; Ac, Acoculco; LH, Los Humeros; Ch, Chiconquiaco. Major tectonic elements are: 1, Jalisco block; 2, Colima graben; 3, Michoacan block; 4–4′, Pénjamo graben; 5, Tzitzio anticline; 6–6′, Querétaro-Taxco fracture zone; 7–7′, Chapala-Tula fracture zone.

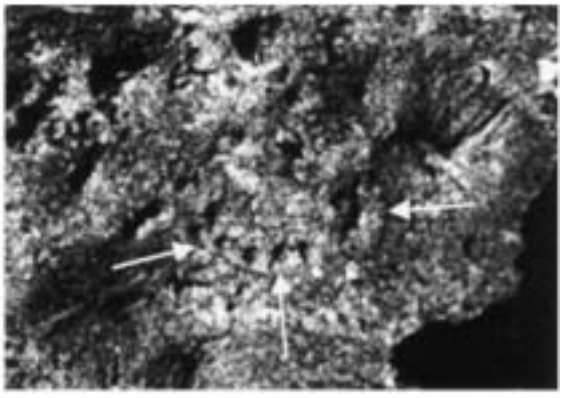

Fig. 5. This elliptical feature (about 5 × 9 km diameter, Landsat image 58, coordinates 19°38.8′N, 101°44.2′W; feature #52 in Table 1; reliability: Fair) is partially circled by lava domes, possible evidence for its relation with a once active magma chamber. North is up. Arrows point the border of the feature.

subsidence, and the influence of the Sierra Madre Occidental old tectonovolcanic structures on the younger TMVB constructs. Although our satellite image reconnaissance alone does not define the origin of the features, some evidence favors the caldera collapse hypothesis. Such is the presence of monogenetic emission centers (domes?) circling some of the features possibly representing ring-fractures (Fig. 5), or of volcanic (resurgent?) constructs centered on some others (Fig. 6).

We contend that our inventory is a simple but useful tool to help design field campaigns for locating calderas. This procedure has been successfully used in several cases (Los Humeros by Pérez-Reynoso, 1978; Santa Maria del Oro by Nelson and Carmichael, 1984; Chiconquiaco by Negendank et al., 1985; Los Azufres by Pradal and Robin, 1985; Mazahua by Anguita et

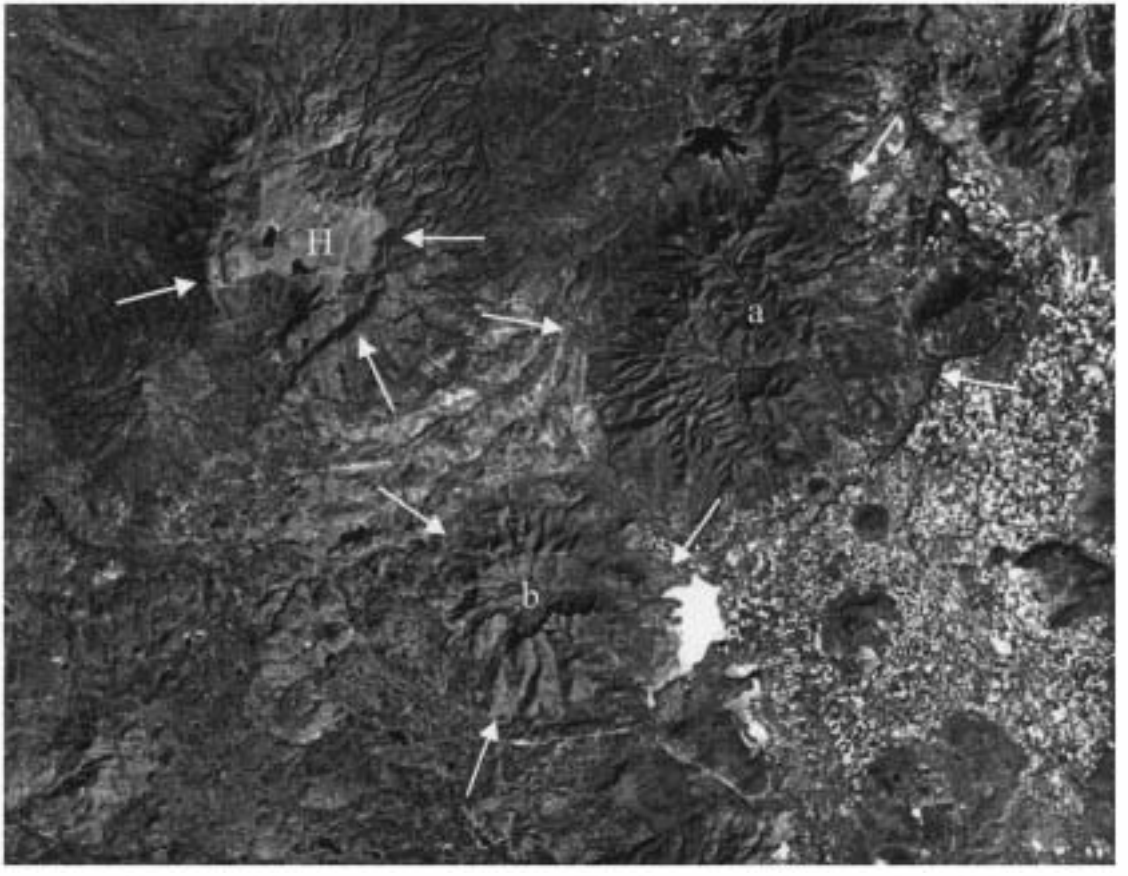

Fig. 6. The centers of the features a, b, (Landsat image41, respective coordinates 20°11′N, 99°26′W; feature #122 in Table 1; reliability: Good, and 20°17′N, 99°13′W; feature #129 in Table 1; reliability: Good) appear occupied by volcanic constructs, possible resurgent edifices. H is the Huichapan caldera (about 8 × 10 km diameter). North is up. Arrows point the borders of the features.

Table 1
Inventory of circular features in the Trans-Mexican Volcanic Belt

Feature	Landsat image	Coordinates		Diameter (km)	Morphology	Lineaments	Political State	Closest village	INEGI map no.[a]	Feature reliability[b]
		Long. (W)	Lat. (N)							
1	75	104°51′	21°31′	5	Circular	NW–SE	Nayarit	Bellavista	F13-D21	Good
2	75	104°43′	21°19′	3 × 5	Elliptical	–	Nayarit	San Pedro Lagunillas	F13-D31	Good
3	75	104°42′	21°16′	5	Circular	–	Nayarit	San Pedro Lagunillas	F13-D31	Fair
4	75	104°42′	21°00′	9	Circular	E–W; NE–SW	Nayarit	Talpa de Allende	F13-D41, D61	Good
5	76	104°40′	20°43′	16	Semicircular	E–W	Jalisco	San Sebastián	F13-D51	Good
6	75	104°40′	21°02′	12	Semicircular	E–W	Nayarit	Lizeta	F13-D41, D61	Fair
7	76	104°40′	20°41′	20 × 25	Elliptical	NW–SE	Jalisco	Zacatongo Natividad	F13-D61, D62	Good
8	75	104°39′	21°13′	4	Circular	–	Nayarit	San Pedro Lagunillas	F13-D42	Good
9	75	104°34′	21°22′	7	Circular	NW–SE	Nayarit	Santa Ma. del Oro	F13-D42	Fair
10	76	104°31′	20°42′	15	Circular	NW–SE	Jalisco	Zacatongo	F13-D42	Good
11	76	104°26′	20°45′	10	Semicircular	NW–SE	Jalisco	Zacatongo Natividad	F13-D42	Good
12	75	104°22′	21°04′	5 × 6	Elliptical	NW–SE	Nayarit	Ixtlán del Río	F13-D42, D43, D52, D53	Good
13	67	104°21′	20°46′	12	Circular	NW–SE	Nayarit	Amatlán de Cañas	F13-D52, D53	Fair
14	67	104°06′	20°31′	12	Circular	NW–SE	Jalisco	Ameca	F13-D63, D64, D73, D74	Fair
15	67	104°00′	19°51′	13	Circular	N–S	Jalisco	Tapalpa	F13-D83, D84, E13-B13, B14	Fair
16	67	103°58′	20°07′	20	Circular	NE–SW; N–S	Jalisco	Tecolotlán	F13-D84	Fair
17	67	103°52′	20°27′	22	Circular	NW–SE; N–S	Jalisco	El Cabezón	F13-D71	Fair
18	67	103°48′	20°01′	8	Circular	NW–SE	Jalisco	Juanacatlán	F13-D84	Poor
19	67	103°46′	19°53′	8 × 10	Elliptical	–	Jalisco	Tapalpa	F13-B14	Poor
20	67	103°44′	20°57′	14	Circular	–	Jalisco	Tala (Presa de la Vega)	F13-D64	Fair
21	67	103°44′	20°23′	12	Circular	WNW–ESE	Jalisco	Villa Corona	F13-D74	Fair
22	67	103°40′	20°13′	8	Semicircular	NW–SE; E–W	Jalisco	Barranca de Sta. Clara	F13-D84, D85, D74, D75	Fair
23	67	103°33′	20°38′	18	Circular	–	Jalisco	Guadalajara	F13-D54, D55	Fair
24	58	102°50′	20°22′	10	Circular	–	Jalisco	Ocotlán	F13-D77	Good
25	58	102°43′	19°58′	6	Circular	NW–SE; E–W	Michoacán	Los Olivos	E13-B17	Good
26	58	102°42′	20°02′	4	Circular	E–W	Michoacán	Julquilpan de Juárez	F13-D87	Good
27	58	102°38′	20°16′	7	Circular	–	Jalisco	Jamay	F13-D78	Fair
28	58	102°36′	20°26′	17 × 25	Elliptical	E–W	Jalisco	Portezuelo	F13-D78	Good
29	58	102°25′	20°17′	5	Semicircular	NW–SE	Michoacán	Yurecuaro	F13-D78	Good
30	58	102°26′	19°37′	5	Circular	NE–SW; E–W	Michoacán	Los Reyes de Salgado	F13-B28, B29	Good
31	58	102°22′	19°35′	7	Circular	NE–SW; E–W	Michoacán	Los Reyes de Salgado	F13-B28, B29	Fair
32	58	102°21′	20°12′	8	Circular	ENE–WSW	Jalisco	El Aguacaliente	F13-D88	Good
33	59	102°14′	19°25′	9	Circular	WNW–ESE	Michoacán	Nuevo Parangaricutiro	E13-B39	Fair
34	59	102°06′	19°14′	6	Circular	NW–SE; E–W	Michoacán	Gabriel Zamora	E13-B49	Fair
35	59	102°05′	19°10′	6	Circular	NW–SE	Michoacán	Gabriel Zamora	E13-B49	Good
36	59	102°04′	19°07′	6	Circular	NW–SE	Michoacán	El Gueco	E13-B49	Fair
37	58	102°01′	20°40′	7	Circular	N–S; NE–SW	Jalisco	Josefina de Allende	F13-D69, F14-C61	Good
38	50	102°00′	19°17′	42	Circular	NE–SW; NW–SE	Michoacán	Taretan	E14-A31, A41, E13-B49, B39	Fair
39	58	101°59′	20°44′	15 × 19	Elliptical	NE–SW; ENE–WSW	Jalisco	Jesús Maria	F13-D69, F14-C61	Fair

Table 1 (*continued*)

Feature	Landsat image	Coordinates		Diameter (km)	Morphology	Lineaments	Political State	Closest village	INEGI map no.[a]	Feature reliability[b]
		Long. (W)	Lat. (N)							
40	58	101°58′	20°24′	6 × 8	Elliptical	ENE–WSW	Guanajuato	Pénjamo	F14-C71	Good
41	58	101°55′	19°31′	14	Circular	E–W	Michoacán	Ziracuaretiro	E14-A21, A31	Fair
42	50	101°51′	19°12′	8	Circular	NE–SW	Michoacán	Ario Rosales	E14-A41	Fair
43	50	101°50′	19°24′	6 × 8	Elliptical	NE–SW	Michoacán	Ziracuaretiro	E14-A31	Fair
44	58	101°49′	19°28′	4 × 5	Elliptical	NE–SW	Michoacán	Ziracuaretiro	E14-A31	Fair
45	50	101°49′	19°27′	6 × 10	Elliptical	NE–SW	Michoacán	Ziracuaretiro	E14-A31	Fair
46	58	101°47′	20°11′	3	Circular	–	Michoaán	Angamacutiro	F14-C81	Fair
47	58	101°47′	20°09′	4	Circular	–	Michoacán	Angamacutiro	F14-C81	Poor
48	58	101°47′	19°51′	5	Elliptical	NE–SW	Michoacán	Zacapú	E14-A11	Fair
49	58	101°47′	19°33′	6	Circular	NE–SW	Michoacán	Tingambato	E14-A21	Fair
50	59	101°47′	19°07′	6	Circular	–	Michoacán	Ario Rosales	E14-A41	Fair
51	50	101°45′	19°34′	6	Circular	NE–SW	Michoacán	Erongaricuaro	E14-A21	Fair
52	58	101°44′	19°39′	5 × 9	Elliptical	E–W	Michoacán	Erongaricuaro	E14-A21	Fair
53	58	101°43′	20°34′	6	Circular	NE–SW	Guanajuato	Pénjamo	F14-C61	Fair
54	58	101°43′	20°10′	7	Circular	–	Michoacán	Angamacutiro	F14-C81	Fair
55	49	101°43′	19°42′	7	Semicircular	E–W	Michoacán	Naranja de Tapia	E14-A21	Fair
56	58	101°41′	20°22′	7	Semicircular	WNW–ESE	Guanajuato	Pénjamo	F14-C71	Poor
57	58	101°41′	19°30′	7 × 5	Elliptical	E–W	Michoacán	Pátzcuaro	E14-A31, A21	Poor
58	59	101°39′	19°04′	12	Circular	N–S; NE–SW	Michoacán	La Huacana	E14-A42	Good
59	49	101°37′	20°01′	20 × 30	Elliptical	E–W	Michoacán	Villa Morelos	F14-C82	Poor
60	58	101°37′	19°54′	10	Semicircular	E–W	Michoacán	Villa de Jiménez	E14-A12	Fair
61	50	101°34′	19°06′	15	Circular	NE–SW; N–S	Michoacán	Puruarán	E14-A42	Good
62	58	101°33′	19°18′	7	Circular	NE–SW	Michoacán	Coeneo	E14-A32	Good
63	50	101°33′	19°04′	7	Circular	NE–SW; N–S	Michoacán	Puruarán	E14-A42	Good
64	50	101°30′	19°14′	15	Semicircular	NE–SW	Michoacán	Tacámbaro	E14-A42	Fair
65	49	101°28′	19°46′15	15	Circular	NE–SW	Michoacán	Quiroga	E14-A12	Poor
66	49	101°22′	20°42′	5	Circular	NE–SW; E–W	Guanajuato	Irapuato	F14-C62	Fair
67	49	101°22′	19°07′	15	Circular	NE–SW	Michoacán	Capula	E14-A42	Poor
68	50	101°21′	19°06′	30	Circular	NE–SW; N–S	Michoacán	Morelia	E14-A42	Fair
69	49	101°20′	20°45′	3	Circular	NE–SW; E–W	Guanajuato	Irapuato	F14-C52, C53, C62, C63	Fair
70	49	101°17′	19°33′	4	Circular	ENE–WSW; NNW–SSE	Michoacán	Acuitzio	E14-A23	Fair
71	49	101°11′	19°37′	7	Semicircular	ENE–WSW	Michoacán	Morelia	E14-A23	Poor
72	49	101°10′	20°45′	3 × 5	Elliptical	E–W	Guanajuato	La Ordeña	F14-C53, C63	Fair
73	49	101°08′	19°55′	27 × 35	Elliptical	E–W	Michoacán	Cuitzeo	E14-A13	Fair
74	49	100°55′	20°41′	10	Semicircular	NW–SE	Guanajuato	Salamanca	F14-C64	Fair
75	49	100°54′	20°48′	5	Circular	NE–SW	Guanajuato	La Ordeña	F14-C54	Fair
76	49	100°53′	19°51′	5	Circular	ENE–WSW	Michoacán	Queréndaro	E14-A14	Poor
77	49	100°50′	19°45′	8	Semicircular	ENE–WSW; NW–SE	Michoacán	Queréndaro	E14-A14	Fair

Table 1 (*continued*)

Feature	Landsat image	Coordinates		Diameter (km)	Morphology	Lineaments	Political State	Closest village	INEGI map no.[a]	Feature reliability[b]
		Long. (W)	Lat. (N)							
78	49	100°49′	19°51′	6	Circular	ENE–WSW	Michoacán	Zinapécuaro	E14-A14	Poor
79	49	100°48′	20°43′	5	Circular	–	Guanajuato	Commonfort	F14-C64	Fair
80	49	100°47′	19°46′	7	Circular	ENE–WSW	Michoacán	Queréndaro	E14-A14	Fair
81	49	100°45′	20°50′	20	Circular	NW–SE; N–S	Guanajuato	Calderón	F14-C55	Fair
82	49	100°43′	19°39′	10	Circular	WNW–ESE; E–W	Michoacán	Mil Cumbres	E14-A24	Good
83	49	100°39′	19°49′	10	Semicircular	ENE–WSW	Michoacán	Ciudad Hidalgo	E14-A25	Fair
84	49	100°39′	19°45′	11	Semicircular	ENE–WSW	Michoacán	Ciudad Hidalgo	E14-A24	Poor
85	49	100°39′	19°49′	45	Circular	E–W	Michoacán	Mararatío	E14-A15	Good
86	49	100°37′	20°29′	9	Semicircular	NW–SE	Guanajuato	Apaseo El Alto	F14-C75	Fair
87	49	100°35′	20°50′	14	Circular	ENE–WSW; NW-SE	Guanajuato	El Potrero	F14–C55	Fair
88	42	100°28′	19°21′	5	Circular	E-W	Michoacán	La Florida	E14–A35	Fair
89	42	100°27′	19°24′	5	Circular	E–W	Michoacán	Jungapeo	E14-A35	Fair
90	49	100°26′	20°04′	7 × 10	Elliptical	E–W	Guanajuato	Puroaguita	F14-C85	Poor
91	49	100°26′	19°31′	8	Circular	E–W	Michoacán	San Felipe de Alza	E14-A25	Fair
92	42	100°23′	19°00′	16	Circular	N–S	Michoacán	Nanchititla	E14-A45, A46, A55, A56	Fair
93	49	100°21′	20°27′	5	Semicircular	NE–SW; NW–SE	Querétaro	El Milagro	F14-C75	Fair
94	42	100°21′	19°30′	17 × 25	Elliptical	N–S	Michoacán	Zitácuaro	E14-A34, A35, A24, A25	Fair
95	42	100°20′	19°18′	20	Circular	N–S	México	Ixtapán del Oro	E14-A35, A36, A45, A46	Fair
96	42	100°17′	19°28′	17	Circular	N–S; E–W	Michoacán	Zitácuaro	E14-A35	Good
97	42	100°13′	19°14′	15	Circular	NE–SW	México	Ixtapán del Oro	E14-A36, A46	Fair
98	41	100°12′	19°51′	8	Semicircular	E–W	Michoacán	Tlalpujahuillo	E14-A16	Fair
99	42	100°10′	18°51′	11 × 13	Elliptical	ENE–WSW	México	Ixtapán de la Panocha	E14-A56	Fair
100	49	100°09′	20°08′	10	Semicircular	E–W	Querétaro	Amealco	F14-C86	Good
101	41	100°08′	19°50′	9	Semicircular	E–W	Michoacán	Tlalpujahuillo	E14-A16	Fair
102	42	100°08′	19°30′	16	Circular	E–W; N–S	México	Loma de Juarez	E14-A16, A17, A26, A27	Good
103	49	100°07′	20°13′	32 × 42	Elliptical	NE–SW; NW–SE	Querétaro	Colón	F14-C86	Good
104	42	100°00′	19°28′	13	Circular	N–S	México	Villa Victoria	E14-A36, A37	Good
105	41	100°00′	19°37′	8	Circular	N–S; E–W	México	San Felipe del Progreso	E14-A26, A27, A16, A17	Fair
106	41	99°58′	19°55′	4	Semicircular	E–W	México	Temascalcingo	E14-A17	Fair
107	41	99°54′	20°25′	7	Circular	E–W	Querétaro	San Juan del Rio	F14-C77	Poor
108	41	99°45′	20°26′	7	Circular	N–S; E–W; NE–SW	Hidalgo	La Cruz	F14-C77	Fair
109	41	99°42′	19°33′	2	Semicircular	E–W	México	Sta. Cruz de Tepexpan	E14-A27	Fair
110	41	99°41′	19°39′	15	Circular	E–W	México	Dolores Amarillas	E14-A27	Fair
111	42	99°41′	19°24′	16	Circular	NE–SW; NW–SE	México	Almoloya de Juárez	E14-A37	Fair
112	42	99°38′	19°19′	32	Circular	NW–SE	México	Toluca	E14-A38	Fair
113	41	99°35′	20°18′	7	Circular	E–W	Hidalgo	Nopala	F14-C88	Fair
114	41	99°35′	19°30′	9	Semicircular	N–S; E–W	México	Zanja Vieja	E14-A28	Fair
115	41	99°35′	19°25′	10	Circular	N–S; E–W	México	Sta. Ana Jilotzingo	E14-A38	Fair
116	42	99°32′	19°14′	35	Circular	ENE–WSW	México	Toluca + Tianguistanco	E14-A48	Fair

Table 1 (*continued*)

Feature	Landsat image	Coordinates		Diameter (km)	Morphology	Lineaments	Political State	Closest village	INEGI map no.[a]	Feature reliability[b]
		Long. (W)	Lat. (N)							
117	41	99°31′	20°21′	8 × 10	Elliptical	–	Hidalgo	Huichapan	F14-C88	Good
118	41	99°31′	19°46′	4	Circular	N–S; E–W	México	San Fco. de la Tablas	E14-A18	Fair
119	41	99°30′	19°52′	3	Semicircular	N–S; E–W	México	Barajas	E14-A18	Fair
120	41	99°30′	19°35′	12	Circular	N–S; E–W; NW–SE	México	Jiquilpingo	E14-A28	Good
121	41	99°29′	20°03′	11	Circular	NE–SW; NW–SE	México	San Agustín Buenavista	F14-C88	Fair
122	41	99°26′	20°11′	4 × 6	Elliptical	E–W	Hidalgo	Tepetitlán	F14-C88	Good
123	41	99°24′	20°03′	3	Circular	NE–SW	Hidalgo	Tula de Allende	F14-C88	Fair
124	41	99°23′	19°28′	8	Elliptical	N–S; E–W	México	Villa Alpina	E14-A38	Fair
125	42	99°20′	18°59′	7	Circular	NE–SW; N–S	México	Ocuilán	E14-A58, A59	Fair
126	42	99°17′	18°53′	18	Circular	N–S	Morelos	Cuemavaca	E14-A59	Fair
127	42	99°17′	19°22′	15	Circular	NNW–SSE; E–W	D.F.	San Miguel Ajusco	E14-A39	Fair
128	41	99°15′	20°28′	3		Semielliptical	N–S; E–W	Hidalgo	Ixmiquilpan	F14-C79
Fair										
129	41	99°13′	20°17′	17 × 18	Elliptical	ENE–WSW; NW–SE	Hidalgo	Progreso	F14-C89	Good
130	41	99°11′	19°45′	4	Semicircular	N–S; E–W	México	El Sitio	E14-B11	Poor
131	41	99°10′	20°19′	5	Semicircular	E–W; ENE–WSW	Hidalgo	Progreso	F14-C89	Fair
132	42	99°09′	19°15′	5	Circular	E–W	D.F.	Topilejo	E14-A48, A38, A49, A39	Fair
133	42	99°03′	19°18′	10 × 15	Elliptical	E–W	D.F.	Xochimilco	E14-A49	Fair
134	34	99°03′	19°48′	9	Circular	–	México	San Pedro dela Laguna	E14-A19	Fair
135	41	99°00′	20°02′	10	Semicircular	NNW–SSE; NE–SW	Hidalgo	Ajacuba	–	Fair
136	34	98°57′	19°52′	4	Circular	N–S	México	Santa Lucia	E14-B11	Fair
137	35	98°57′	19°17′	3	Circular	NE–SW	D.F	Sta. María Nativitas	E14-B31	Good
138	35	98°57′	19°26′	14	Circular	NE–SW	D.F.	Sta. María Nativitas	E14-B31	Fair
139	34	98°53′	19°47′	6	Circular	NW–SE	México	Santa Lucía	E14-B11	Poor
140	41	98°53′	20°25′	8	Circular	NW–SE; E–W	Hidalgo	Santiago de Anaya	E14-A81	Good
141	35	98°52′	19°04′	8	Circular	E–W	México	Juenitepec de Mariano	E14-B41	Good
142	41	98°50′	20°24′	8	Circular	NW–SE; E–W	Hidalgo	Santiago de Anaya	F14-A81	Good
143	41	98°50′	20°23′	7	Circular	NW–SE; E–W	Hidalgo	Santiago de Anaya	F14-A81	Fair
144	35	98°49′	19°04′	6	Circular	E–W	México	Nepantla	E14-B41	Good
145	41	98°49′	19°45′	2.5	Circular	NNW–SSW; E–W	México	Teacalco	E14-B11	Fair
146	34	98°49′	19°57′	10	Circular	–	Hidalgo	Zapatlán de Juárez	E14-B11	Poor
147	34	98°48′	19°50′	6	Semicircular	WNW–ESE	México	Teopancala	E14-B11	Fair
148	34	98°46′	19°41′	12	Circular	NE–SW	México	Teotihuacán	E14-B11	Poor
149	35	98°46′	19°01′	9	Circular	E–W	México	Tepetlixpa	E14-B41	Fair
150	34	98°46′	20°03′	11	Circular	–	Hidalgo	Huiquilpan	F14-D81	Poor
151	34	98°40′	20°02′	13 × 20	Elliptical	–	Hidalgo	Epazoyucán	–	Fair
152	34	98°36′	20°15′	14	Circular	NW–SE	Hidalgo	Atotonilco el Grande	–	Fair
153	34	98°34′	20°00′	5	Circular	–	Hidalgo	Zempoala	–	Fair
154	34	98°34′	20°01′	5	Circular	–	Hidalgo	Epazoyucán	–	Fair

Table 1 (*continued*)

Feature	Landsat image	Coordinates		Diameter (km)	Morphology	Lineaments	Political State	Closest village	INEGI map no.[a]	Feature reliability[b]
		Long. (W)	Lat. (N)							
155	34	98°26′	20°06′	5	Circular	NE–SW	Hidalgo	Acatlán	–	Poor
156	34	98°25′	20°56′	6	Semicircular	E–W	Hidalgo	Singuilucan	–	Fair
157	34	98°20′	19°04′	18 × 22	Elliptical	NE–SW	Hidalgo	Tulancingo	–	Fair
158	34	98°12′	18°58′	10 × 12	Elliptical	E–W	Puebla	Puebla	–	Fair
159	34	98°10′	19°34′	16	Circular	–	Tlaxcala	Tlaxco	–	Poor
160	34	98°09′	19°58′	5 × 9	Elliptical	–	Puebla	Acoculco	–	Poor
161	34	98°03′	19°33′	20	Circular	NW–SE; NE–SW	Tlaxcala	Atotonilco	–	Fair
162	34	97°59′	19°31′	3	Circular	ENE–WSW	Tlaxcala	Terrenate	–	Fair
163	35	97°45′	19°19′	12 × 15	Elliptical	E–W	Tlaxcala	Xicoténcatl	–	Fair
164	29	97°44′	19°00′	5	Circular	N–S	Puebla	Acatcingo	–	Poor
165	35	97°40′	19°13′	12	Circular	–	Puebla	Rafael Lara Grajales	–	Fair
166	35	97°35′	19°17′	15	Circular	–	Puebla	Oriental	–	Fair
167	29	97°34′	19°33′	5	Circular	N–S	Puebla	Rafael Lara Grajales	–	Good
168	29	97°33′	19°08′	9	Circular	N–S	Puebla	San Salvador el Seco	–	Good
169	28	97°28′	19°23′	4	Circular	N–S	Puebla	Cerro Pinto	–	Good
170	28	97°26′	19°40′	17	Circular	WNW–ESE	Puebla	Tezuitlán	–	Good
171	29	97°26′	19°15′	8 × 10	Elliptical	N–S	Puebla	Emilio Portes Gil	–	Good
172	28	97°23′	19°40′	50	Circular	–	Puebla	Tezuitlán	–	Good
173	29	97°23′	19°14′	7 × 9	Elliptical	N–S	Puebla	Zacatepec	–	Good
174	29	97°18′	19°27′	8	Circular	NE–SW	Veracruz	San Antonio Limón	–	Good
175	29	97°15′	19°15′	3	Circular	N–S	Veracruz	Cerro de las Cumbres	–	Good
176	29	97°10′	19°20′	9 × 12	Elliptical	–	Veracruz	Perote	–	Poor
177	29	97°09′	19°09′	5 × 7	Elliptical	NW–SE	Veracruz	Perote	–	Poor
178	29	97°08′	19°19′	6	Semicircular	NW–SE; NE–SW	Puebla	Chichiquitán	–	Good
179	29	97°08′	19°04′	16 × 25	Elliptical	NW–SE; NE–SW; E–W	Veracruz	Coscomatepec	–	Good
180	29	97°06′	19°21′	5	Semicircular	NW–SE	Veracruz	Ayahualulco	–	Good
181	29	97°05′	19°33′	20	Circular	WNW–ESE	Veracruz	Perote	–	Good
182	29	97°05′	19°28′	7	Elliptical	NW–SE	Veracruz	Coatitlán	–	Good
183	29	97°03′	19°17′	10	Circular	NW–SE; NE–SW	Puebla	Chichiquitán	–	Good
184	29	97°02′	19°26′	3	Circular	NW–SE	Veracruz	Coatitlán	–	Good
185	29	97°56′	19°24′	8	Circular	NW–SE	Veracruz	Coatitlán	–	Good
186	29	96°52′	19°33′	4 × 5	Elliptical	E–W	Veracruz	Jalapa Enríquez	–	Fair
187	29	96°51′	19°28′	9	Circular	NW–SE	Veracruz	Jalapa Enríquez	–	Poor
188	29	96°48′	19°29′	9	Circular	WNW–ESE	Veracruz	Jalapa Enríquez	–	Poor
189	29	96°41′	19°25′	17	Circular	WNW–ESE	Veracruz	Cosautlán de Carvajal	–	Poor
190	29	96°40′	19°23′	45	Circular	WNW–ESE	Veracruz	Actopán	–	Fair
191	29	96°38′	19°24′	4	Circular	E–W	Veracruz	Idolos	–	Good

[a] –, INEGI 1:50,000 map not available.

[b] Feature reliability: 'Good' means that the feature is clearly visible (e.g. Fig. 2a); 'Poor' is reserved for dubious features (e.g. Fig. 2b).

al., 1991; see Fig. 4 for locations of these calderas). The other known calderas are also clearly visible on Landsat imagery. A comprehensive evaluation of potential geothermal resources and volcanic hazards within the Trans-Mexican Volcanic Belt could benefit from our approach.

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