Received: 14 November 2022 | Revised: 26 January 2023 | Accepted: 28 January 2023

DOI: 10.1002/ldr.4623

RESEARCH ARTICLE

WILEY

A geoheritage valuation to prevent environmental degradation of a new volcanic landscape in the Canary Islands

Nicolás Ferrer[1] | Juana Vegas[2] | Inés Galindo[3] | Gonzalo Lozano[4]

[1]Instituto de Oceanografía y Cambio Global, Universidad de Las Palmas de Gran Canarias (IOCAG-ULPGC), Parque Científico Tecnológico Marino de Taliarte, Telde, Spain

[2]Instituto Geológico y Minero de España, Consejo Superior de Investigaciones Científicas (IGME-CSIC), Madrid, Spain

[3]Instituto Geológico y Minero de España, Consejo Superior de Investigaciones Científicas (IGME-CSIC), Las Palmas de Gran Canaria España, Spain

[4]Instituto Geológico y Minero de España, Consejo Superior de Investigaciones Científicas (IGME-CSIC), Tres Cantos, Spain

Correspondence

Nicolás Ferrer, Instituto de Oceanografía y Cambio Global, Universidad de Las Palmas de Gran Canarias (IOCAG-ULPGC), Parque Científico Tecnológico Marino de Taliarte, Telde 35214, Spain.
Email: nicolas.fvg@ulpgc.es

Funding information

OAPN, Grant/Award Number: IVRIPARC 2779/2021; Spanish Ministry of Science and Innovation, Grant/Award Numbers: RD 1078/2021, IGME-CSIC; European Social Fund, Grant/Award Numbers: CATALINA RUIZ 2021 SI-1776, APCR2021010018/6431001

Abstract

On 19 September 2021, a new monogenetic volcano (Tajogaite) erupted on the Island of La Palma (Canary Islands, Spain). After 85 days of Strombolian style eruption, with emissions of volcanic material, a pyroclastic cone 200 m high and 800 m in its basal diameter was formed. Successive lava flows descended the western slopes and reached the Atlantic Ocean on 29 September. On descending the coastal cliffs and entering the sea, the lava flows formed two lava deltas on the submarine island shelf, backed by fossilized coastal cliffs. This geological event has raised a new challenge: the environmental conservation of new volcanic landscapes in island territories with high anthropogenic pressure on land uses. This work uses comparative and numerical methods in geoheritage to support their conservation from a scientific basis. In a first phase, a cartographic inventory was made of all the volcanic formations similar to the new volcano in the geological framework of the Canary Islands. In a second phase, their representativeness (A), rarity (R), diversity (D), integrity (I), and observability (O) were quantitatively measured by means of dimensional estimators. The results obtained show that the new volcano presents a geological value of the first order in the context of the Canary Islands, which is one of the most prominent oceanic archipelago worldwide. Its value is based above all on its high conservation state with respect to the similar volcanoes in the Canary Islands. The high mismatch found between the intrinsic geological value and the environmental protection of this area, justifies the development and application of urgent basic guidelines for its protection, as well as the promotion of geotourism as opposed to alternative land uses.

KEYWORDS

Canary Islands, geoconservation, geoheritage, La Palma, Tajogaite, volcanic eruption

1 | INTRODUCTION

The eruption of the Tajogaite Volcano on the Island of La Palma (Canary Islands) lasted 85 days, from 19 September 2021. It was a typical monogenetic strombolian style eruption, with abundant emission of pyroclasts and fluid lava flows, that gives rise to the construction of many oceanic islands throughout its geological history (Carracedo & Troll, 2016). Continuous emissions of volcanic material formed a pyroclastic cone about 200 meters high and 800 meters in diameter. More than 150 million cubic meters of lava were emitted from the eruptive vents (Civico et al., 2022) and flowed down the slopes until reaching the west coast on 29 September. The lava flows plunged down coastal cliffs, advanced along the submarine island shelf and formed two spectacular lava deltas of 0.75 and 0.05 km^2 backed by fossilized coastal escarpments (Figure 1). As a result of the 2021 eruption, the Canary Islands now exhibit a spectacular new volcanic landscape, which lacks protection under any conservation legislation, in a territorial framework where anthropogenic pressure on land uses is extremely high. Valuing the new volcanic landscape in terms of geoheritage can support its urgent conservation, preventing it from being quickly and easily taken over by urbanization and other non-conservationist human activities.

The techniques for geoheritage identification and valuation procedures, that were born as a scientific discipline in the 1970s, aims at providing foundations for the environmental protection of relevant geological sites and landscapes, that is, for geoconservation (e.g., Bostick et al., 1975; Duque et al., 1979; Elizaga et al., 1980). Due to their remarkable geological features and their scientific and social attractiveness, the are many precedents of geoheritage studies in volcanic territories (e.g., Galindo et al., 2019; Guilbaud et al., 2021; Megerle, 2020; Németh et al., 2017; Różycka & Migoń, 2018; Szepesi et al., 2017). In particular, the Canary Islands, which constitute one of the most prominent oceanic volcanic chains in the world, have been declared as a geological framework of international relevance (García-

FIGURE 1 Field photographs taken by the research team during the different development phases of the new Tajogaite volcanic formation (La Palma Island). (a). Main cone, September 2021. (b). Emission of ʻa'ā lava flows from the main cone, October 2021. (c). Field of ʻa'ā lava flows in the distal part, before the cliff. (d). Cratering of the main cone, December 2021. (e). Secondary crater, December 2021. (f). Lava delta on the west coast of the Island of La Palma. [Colour figure can be viewed at wileyonlinelibrary.com]

Cortés, 2008; García-Cortés et al., 2001) and have already been the subject of several works of geosites selection and assessment (e.g., Becerra-Ramírez et al., 2020; Dóniz-Páez et al., 2011; Dóniz-Páez et al., 2020; Galindo et al., 2019, 2022). For their scientific value, most of the recent monogenic eruptions on the island of La Palma have been included in the Spanish Geosites Inventory (IELIG project, IGME-CSIC, http://info.igme.es/ielig/), within the regional framework of 'Historical and Prehistoric Volcanism' (Vegas et al., 2019). However, Tajogaite Volcano provides a unique opportunity to carry out for the first time a geoheritage valuation of a newly created volcanic landscape.

In order to quantify the relevance of a geological site or landscape, the so-called parametric methods have been developed (Bruschi & Cendrero, 2005). These methods recognize two distinct evaluative dimensions in the value of geological features: the intrinsic value (also called 'scientific') and the social value (e.g., Bruschi & Cendrero, 2005; Dingwall et al., 2005; Carcavilla et al., 2007; De Lima et al., 2010; Fassoulas et al., 2012; Brilha, 2016, 2018). In parametric methods, the intrinsic and social dimensions are estimated by means of a series of criteria (parameters) that may differ significantly between authors. García-Cortés et al. (2019) make a compromise synthesis of the main published proposals, determining that the most significant parameters of the intrinsic value are (1) representativeness, (2) rarity, (3) integrity, (4) degree of scientific knowledge, (5) type-locality, and (6) diversity.

The aim of this work is to evaluate the geoheritage relevance of the Tajogaite Volcano as an example of scientific basis for conservation and promotion of a newly created geological landscape in a volcanic island territory of high anthropic pressure. To do this, a new effective methodological procedure, based on a relational approach and measurable parameters free of subjectivity, is tested.

2 | STUDY AREA

The Canary Islands form a volcanic archipelago made up of eight main islands and three major islets, located on the African tectonic plate, around 28° north latitude and 15° west longitude (Figure 2). The archipelago forms an east–west sub-alignment of islands with a main decreasing age trend to west (Lanzarote = 15.5 Ma, Fuerteventura = 20.6 Ma, Gran Canaria = 14.5 Ma, Tenerife = 7.5 Ma, La Gomera = 12.5, La Palma = 2.0 Ma, El Hierro = 1.1 Ma). Volcanism in the Canary Islands has been studied since the 19th century and, specifically on the island of La Palma, the pioneering works are those of Von Buch (1825), Lyell (1865), and Hausen (1969). The first firm reports on the origin of magmatism of the Canary Islands are recent (Hoernle et al., 1991; Hoernle et al., 1995; Hoernle & Schmincke, 1993). Although the evidence of an age succession has led to the interpretation of the archipelago as a hotspot, with structural and geodynamic peculiarities that explain the 'imperfect' spatio-temporal arrangement of the islands and their long survival periods (Acosta et al., 2003; Carracedo, 1999; Carracedo et al., 1998, 1999, 2001; Schmincke & Sumita, 1998), this model

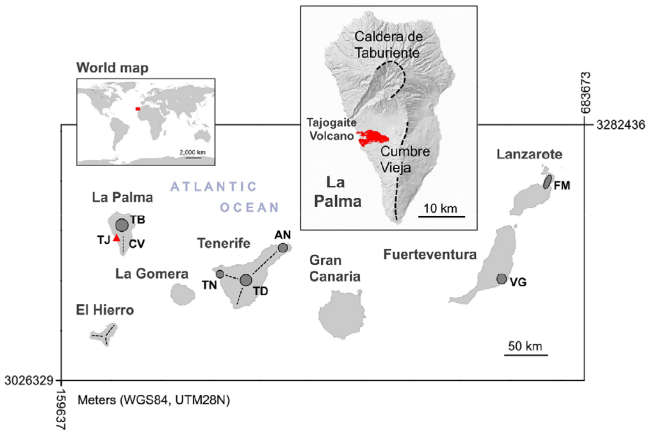

FIGURE 2 Study area. Location of the geological domain of the Canary Islands on the world map and location of the eruption of the new volcano on the Island of La Palma. Names cited in the text: AN, Anaga massif; CV, Cumbre Vieja ridge; FM, Famara massif; TB, Taburiente Caldera; TD, Teide-Pico Viejo stratovolcano; TJ, Tajogaite Volcano; TN, Teno massif; VG, Vigan massif. Dosset lines. The dashed lines represent volcanic ridges. [Colour figure can be viewed at wileyonlinelibrary.com]

remains controversial (Anguita & Hernán, 2000; Blanco-Montenegro et al., 2018). The hotspot model explains the origin of certain intraplate island chains from the movement of a lithospheric plate over a stationary mantle plume that generates new islands in the opposite direction of its movement (Langenheim & Clague, 1987; Wilson, 1963).

The new Tajogaite Volcano occupies an area of ~12.25 km^2 on the central-western sector of the island of La Palma, at an altitude between 0 and 1050 m asl (Figure 2). La Palma is a young island, less than 1.8 Ma, located at the western end of the archipelago, 400 km from the African coast. It has an inverted triangle shape, with a perimeter of almost 200 km, an area of 708 km^2, and 2426 m altitude at its highest point. The northern half of the island consists of an inactive Pleistocene subcircular shield volcano (Taburiente Edifice). To the south there is a growing volcanic rift called Cumbre Vieja, formed during the Upper Pleistocene and Holocene (Acosta et al., 2003; Carracedo et al., 2001; Hoernle & Carracedo, 2009). Cumbre Vieja is currently in a state of constructive activity and is one of the most volcanically active areas in the Canary Islands. Seven eruptions have been recorded in historical times (Hernandez-Pacheco & Valls, 1982).

In socioeconomic terms, the Canary Islands have the largest population (2,172,944 people) and territory (7492 km^2) in the Macaronesian region (Instituto Canario de Estadística [ISTAC], 2021). It has the highest population density in the region along with the islands of Madeira (almost three times higher than the islands of Cape Verde or the Azores) and also higher economic development than that of the surrounding region. It has the highest GDP in the region (39,163 million euros in 2020) and, together with Madeira, also the highest GDP per capita. The economy is heavily tertiarized and specialized in tourism, which has led to a dense occupation of coastal areas since the 1960s. The high anthropogenic pressure on the natural environment faces the archipelago with the challenge of generating sustainable development models that make economic growth compatible with ecosystems conservation.

3 | DATA SOURCES AND METHODS

The assessment of the intrinsic value of the Tajogaite Volcano shows a relational and numerical method in three steps.

For a rigorous comparative approach, the first step consisted of identifying and mapping all the formations similar to Tajogaite Volcano in the geological domain of the Canary Islands. To do this, the defining components or basic units of the Tajogaite Volcano was firstly established (Figure 3):

(U_1) One or more emission centers forming pyroclastic cones or felsic domes.

(U_2) One or more lava fields developed as longitudinal sloping flows, descending along coastal cliffs to the sea.

(U_3) One or more fan-shaped lava platforms (lava deltas) formed by the advance of lava flows over the submarine island shelf (locally called 'low islands' or *fajanas*).

Once the basic units had been established, we proceeded to inventory the formations that comply with them. Hereafter, they will be called Tj formations. The recognition was made integrating the local knowledge of the team with digital orthophotos of 25 cm pix^{-1} (GRAFCAN, Government of the Canary Islands, https://www.idecanarias.es/), digital terrain models of 5 m pix^{-1} (IGN, Government of Spain, https://centrodedescargas.cnig.es/) and geological maps of the Canary Islands of scale 1:50.000 (IGME-CSIC, https://info.igme.es/cartografiadigital/) in the ArcGIS software package.

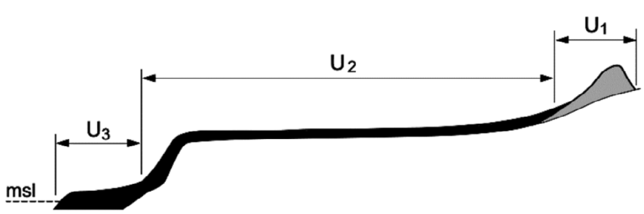

FIGURE 3 Basic units of the Tj formations: U_1 (pyroclastic cone), U_2 (lava field), and U_3 (lava delta); used for the comparative analysis of the new volcanic formation (Tajogaite Volcano) with similar volcanic formations of the Canary Islands Geological Domain.

Once the inventory was obtained, the second step consisted of selecting the parameters for the intrinsic value assessment of the formations. For this, the methodological bases of the Spanish Inventory of Geosites (IELIG project, acronym in Spanish) (García-Cortés et al., 2019) and its guidelines in the Canary Islands (Vegas et al., 2019) were followed, assessing the intrinsic value through representativeness (A), rarity (R), integrity (C), observability (O), and diversity (D). We omitted degree of scientific knowledge (K) due the recent formation of the volcano and type locality character (T) because the main analyzed interest of the new formation is geomorphological. These parameters have been re-conceptualized and numerically estimated to remove as much of the subjectivity of the team as possible and to eliminate any necessary correlation between them, thus ensuring their independence as distinct and objective evaluators (Table 1). The following operations have been computed in a GIS environment of analysis (ArcGIS) to estimate the valuation parameters:

(1) Representativeness (A), understood as the ability of the site to serve as an example or model of the geological features, events, and processes of a given domain (De Lima et al., 2010; Ellis et al., 1996; García-Cortés et al., 2019; Joyce, 2010), has been identified with the formation development (Sharples, 2002) and approximated through the surface extent, understood to be equivalent to the magnitude of the volcanic causative process.

$$A_{Tj} = P_{(s)} \quad (1)$$

Where: A_{Tj} is the representativeness of a Tj formation and *P* is the percentile of the formation within the inventoried set of *s* values, or surface area of the Tj formation.

(2) Rarity (R), understood as scarcity or specificity of the geological feature, has been identified with the inverse value of abundance, and calculated through a spatial proxy, taking as a reference, first, the abundance of Tj formations within each island:

$$R1_{Tj} = P_{(1\text{-}s/S)}$$

Where: $R1_{Tj,1}$ is the rarity of a Tj formation at the island level; *P* is the percentile of the formation within the inventoried set of *s/S* values, *s* is the total surface area of the Tj formations on the island, and *S* is the total surface area of the island. And, second, considering the local density of Tj formations within the island through the quadratic kernel function of Silverman (1986):

TABLE 1 Re-conceptualization of assessment parameters, selection of physical-based numerical proxies, and normalization of units by percentiles.

Evaluation parameter	→	Conceptualization	→	Measurable physical proxy selection	→	Units	→	Normalization
Representativeness	→	Development grade/magnitude	→	Total surface	→	km^2	→	Percentile
Rareness	→	Inverse of abundance	→	Spatial density	→	N/km^2	→	Percentile
Diversity	→	Richness and evenness	→	Shannon entropy	→	Bits	→	Percentile
Integrity	→	Conservation state	→	Non-antropized surface	→	%	→	Percentile
Observability	→	Surface visibility	→	Non-vegetated surface	→	%	→	Percentile

$$R2_{Tj} = P_{(Ds)} \quad (3)$$

Where: $R2_{Tj}$ is the local rarity of a Tj formation; P is the percentile of the formation within the inventoried set of Ds values, or Silverman's kernel density.

(3) Diversity (D), understood as the variety of elements of geological interest, has been given a combined idea of richness (estimated by the number of different U_1-U_2-U_3 units) and evenness (the balance degree in the spatial representation of each unit), and has been approximated by Shannon's entropy index (Shannon & Weaver, 1949):

$$D_{Tj} = P_{(H')} \quad (4)$$

Where: D_{Tj} is the diversity of a Tj formation; P is the percentile of the formation within the set of inventoried H′ values, or Shannon index value.

(4) Integrity (I), understood as the conservation state of the geological feature, has been identified with the degree of anthropic occupation and approximated by calculating the surface area not occupied by human infrastructures:

$$C_{Tj} = P_{(C\%)} \quad (5)$$

Where: D_{Tj} is the integrity of a Tj formation; P is the percentile within the inventoried set of C% values, or percentage of human infrastructures free-area.

(5) Observability (O), understood as the ease with which the volcanic formation can be accessed and observed in its full dimension, has been identified with the surface visibility according to the type of dominant vegetation cover:

$$O_{Tj} = P_{(O\%)} \quad (6)$$

Where: O_{Tj} is the integrity of a Tj formation; P is the percentile within the inventoried set of O% values, or percentage of visible surface.

To calculate observability, a mean surface visibility has been assigned to the vegetation cover classes of the Vegetation Map of the Canary Islands scale 1:2.000 (Del Arco et al., 2006) (Table 2). This mean value has been weighted to the surface extent of each vegetation cover and then averaged within each Tj formation to estimate the total visibility.

In the last step, the parameter's values were normalized using percentiles to rank the inventoried formations and to standardize both the statistical values distribution and the variety of units used in each of them. The combination of the partial values of parameters has been tested under the criteria of (i) simple mean, (ii) weighted mean, where A = 35%, R = 20%, C = 15%, O = 15%, and D = 15% (adapted from García-Cortés et al., 2019); and (iii) maximum value; giving rise to three comparable geoheritage rankings. Once the rankings were obtained, the final geoheritage value [0,1] was crossed with the degree of protection of each formation, understood as the proportion of surface area protected by legal figures in the Canary Islands Network for Protected Natural Areas and/or the Natura 2000 Network. The difference between both magnitudes has been used to interpret the possible mismatch between heritage value and environmental protection in each formation.

TABLE 2 Mean surface visibility according to the vegetation covers of the Vegetation Map of the Canary Islands 1: 2000 (Del Arco et al., 2006).

Vegetation cover type	Mean cover (%)	Mean visibility (%)
Scarce or null vegetación	0	100
Rupicolous vegetation	5	95
Grasslands	15	85
Thickets	35	65
Planted forests and woodlands	85	15
Natural forests and woodlands	90	10
Antropic areas	100	0

4 | RESULTS

4.1 | Inventory of similar formations

Twenty-seven volcanic formations similar to Tajogaite Volcano (the Tj formations) have been identified and mapped in the geological domain of the Canary Islands. They are preferentially distributed over the most volcanic active western province of the archipelago, being absent in the islands of La Gomera and Gran Canaria. Twelve have been identified on La Palma, nine on Tenerife, three on El Hierro, two on Lanzarote, and one on Fuerteventura (Figure 4). In total, the identified Tj formations extend over 179.2 km^2. This means that they occupy a small extension of the surface area of the geological domain of the Canary Islands (2.4%), so their rarity is significantly high in this context (determinable at a value of 97.6%).

The occurrence of monogenetic eruptions that lead to pyroclastic cones and lava fields that enter the sea in a fan-shaped form, is typical of islands with high recent volcanic activity. For this reason, they mainly appear on young islands in the early (El Hierro, La Palma) or central (Tenerife) phases of their volcanic growth; or on older islands with strong post-erosive magmatic reactivation activity (Lanzarote, Fuerteventura). The presence and extension of U_3-units (lava deltas) in Tj formations depends on the advance of marine erosion on the coastal front along time and the eustatic moment of the eruption (Quaternary sea-level). They are therefore no older than the Upper Pleistocene.

On La Palma, a greater number of Tj formations have been counted. Twelve in total, labelled in decreasing order of age as LP_1, LP_2, LP_{3a}, LP_{3b}, LP_4, LP_5, LP_{6a}, LP_{6b}, LP_7, LP_8, LP_9, and LP_{10} (Tajogaite Volcano). They develop along the Cumbre Vieja ridge, in the central-southern part of the island (Figure 2). The emission centers emerge

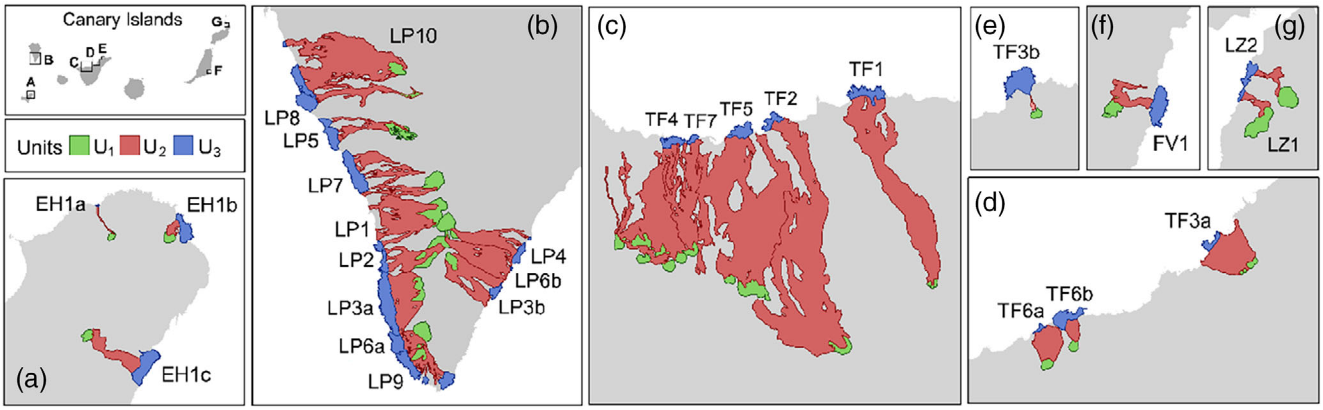

FIGURE 4 Inventory of the 27 Tj formations found in the geological domain of the Canary Islands, with differentiation of the defining units (U_1-U_2-U_3) and the expression of their identifying code according to island and order of age. LP10 is the code given to the case study (Tajogaite Volcano in La Palma). The location of maps (a), (b), (c), (d), (e), and (g) can be found on the general map of the Canary Islands, top left. [Colour figure can be viewed at wileyonlinelibrary.com]

preferentially near the ridge axis (N-S) between 500 and 1500 m altitude, and the lava fields flow to the sea along its western and eastern flanks. The nature of the rocks is predominantly basaltic. Most of these formations are from Holocene and eight of them are historical (e.g., San Juan and Teneguía volcanoes). The lava flows fall down coastal cliffs up to 100 m high, carved over Upper Pleistocene basaltic piles. In contact with the sea, they form emerging coastal platforms with an average width of ~500 m. These platforms show, on the western coast, a great lateral continuity due to eruptions coalescence.

On Tenerife, the second highest concentration of Tj formations has been found. Nine in total, labeled as TF_1, TF_2, TF_{3a}, TF_{3b}, TF_4, TF_5, TF_{6a}, TF_{6b}, and TF_7. They are located on the northern island face. In the oldest cases, they are associated with peripheral Salic eruptive episodes of the Teide-Pico Viejo stratovolcano (Figure 2). The rest develop from the structural convergence point in the center of the island, mainly toward the NE rift axis (from the Teide-Pico Viejo Complex to the Anaga Massif) and toward the NW ridge axis (from the Teide-Pico Viejo complex to the Teno massif) (Figure 2). Their rocks are predominantly basaltic in nature and the ages range from Upper Pleistocene, in the oldest formations, to the most recent eruptions in historical times, such as in Garachico (1706) and the Chinyero Volcano (1909).

The remaining Tj formations have been identified on El Hierro, Lanzarote, and Fuerteventura. Those from El Hierro, labeled $EH1_a$, $EH1_b$, and $EH1_c$, are coeval and correspond to recent eruptions in the north of the island. They correspond to Holocene, non-historic emissions from the last episodes of island growth in the NE–SW rift (Figure 2). From a compositional point of view, basalts and basanites predominate, both in the lava flows and in the cinder cones. In Lanzarote and Fuerteventura, the Tj formations come from post-erosive volcanic reactivation phases, specific of the oldest islands of the Canary Island chain (Lanzarote ~16 Mya, Fuerteventura ~20.2 Mya). The two formations identified on Lanzarote (La Corona Volcano, LZ_1, and Los Helechos Volcano, LZ_2) arise from new emission centers in the Miocene Famara massif in the north of the island (Figure 2). The basaltic lava flows descend toward the sea along the Famara palaeo-cliff, with short courses and terminal lava deltas of limited extension. Finally, the formation found in Fuerteventura (Jacomar Volcano and inlet, FV_1) corresponds, as in the case of Lanzarote, to a recent eruption of reactivation phase, basaltic in nature, which occurred in the geological context of the Miocene volcanic massif of Vigán, on the central-eastern coast of the island (Figure 2).

4.2 | Geoheritage value assessment

The surface area measure identifies the magnitude of the geological process and the resulting landform features with their significance of representativeness (A). The overall mean value found in the 27 Tj formations is 6.6 km^2, with a standard deviation of 7.25 km^2, a minimum of 0.24 km^2 in EH_{1a}, and a maximum of 27.9 km^2 in TF_2. The upper half of the surface area distribution is occupied by the formations of the Tenerife and La Palma islands, where volcanic processes are of greater magnitude (Figure 5). The Tajogaite Volcano (LP_{10}) presents 12.2 km^2, thus occupying the 85.2 percentile of the representativeness parameter ($A_{LP10} = 0.85$), significantly above the median of the whole inventory of Tj formations in the Canary Islands (Table 3).

The Tj formations are rarer on islands where they are less abundant in the geographical space (they occupy less surface area). No Tj formations have been found in La Gomera and Gran Canaria. In the rest of the Canary Islands, the grater rarity (R) are found on the oldest less-active islands of Fuerteventura ($R_1 = 0.99$) and Lanzarote ($R_1 = 0.99$), and the least Rarity (R) on La Palma ($R_1 = 0.75$), the youngest and most volcanically active island together with El Hierro. In turn, the local density predictor (the Silverman's kernel density) determines that the greatest spatial rarity inside of La Palma corresponds to the Tajogaite Volcano (LP10,), since it occupies a marginal position in the north–south succession of Tj formations on the island (Figure 5). Thus, the rarity (R) of LP_{10} is located at the 44.4th percentile ($R_{LP10} = 0.44$), being approximately at the median of the whole inventory of Tj formations in the Canary Islands (Table 3).

The diversity (D) of the Tj formations takes into account the number of elements of units U_1, U_2, and U_3, as well as the spatial balance

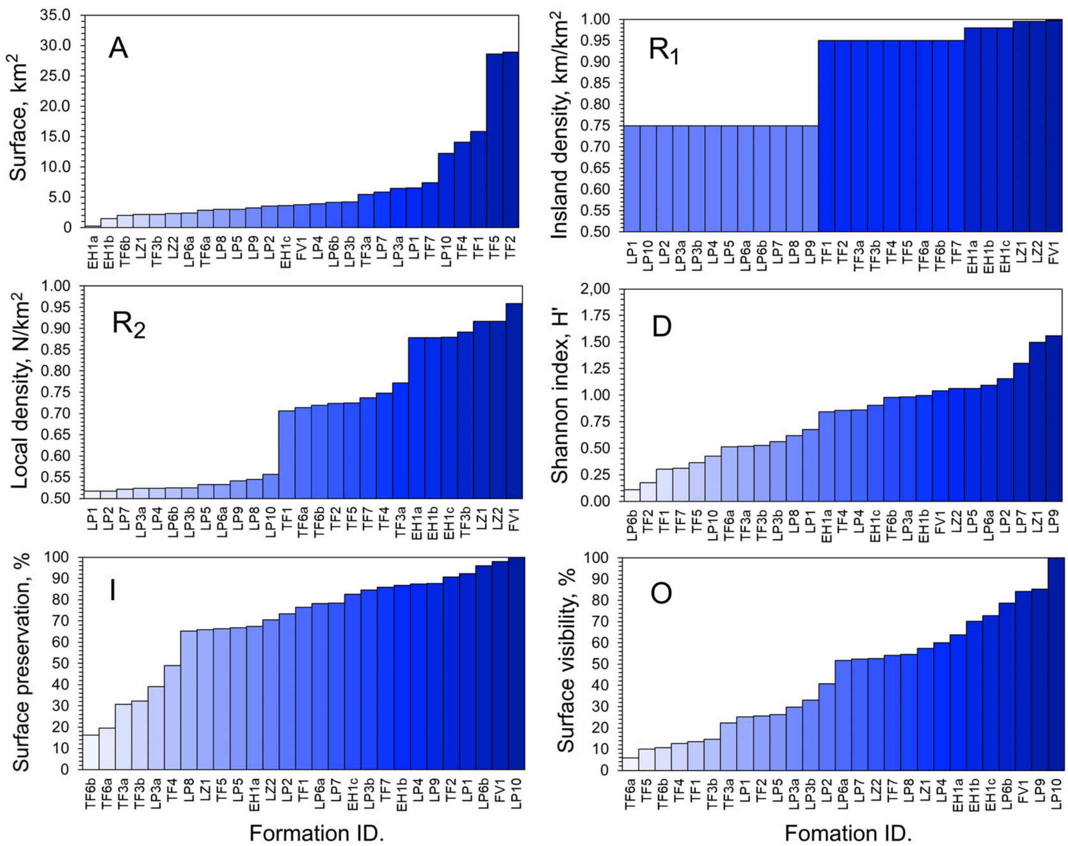

FIGURE 5 Dimensional values of the Tj formations of the Canary Islands in representativeness (A), rarity (R_1, R_2), diversity (D), integrity (I), and observability (O). LP_{10} (Tajogaite Volcano) shows a maximum value on integrity (I) and observability (O), and a significant high value in representativeness (A). [Colour figure can be viewed at wileyonlinelibrary.com]

of these units, that is, the size ratio between the units. In this way, the Shannon index (H′) range from a maximum of 1.56 in LP_9 to a minimum of 0.11 in LP_{6b}, with an average of 0.79. On the island of Tenerife, the Tj formations show the lowest mean diversity, since the overall area occupied by the U_3- units is too small and it is misbalanced with respect to the rest of the units (Figure 5). The H′ value of the new volcanic formation LP_{10} is 0.43, which places it at the 22.2 percentile of diversity ($D_{LP10} = 0.22$), significantly below the median of the Tj formations inventory in the Canary Islands (Table 3).

The integrity (I), as a state of conservation of Tj formations estimated through the proportion of surface free of human occupation, shows a mean value of 69.9%, with a minimum of 16.4% in TF_{6b} and a maximum of 100% in LP_{10} (Figures 5 and 6). Therefore, LP_{10} (Tajogaite Volcano) is at the 100th percentile of integrity ($I_{LP10} = 1.0$) within the set of Tj formations in the Canary Islands. The island with the lowest mean integrity in its Tj formations is Tenerife (51.9%), where the greatest demographic and land use pressure occurs in the context of the archipelago.

The observability (O), as a proportion of the visible surface in each formation, is strongly linked to vegetation development, which in turn is closely linked to the age of the landform features and the local climate. For this reason, the island with the lowest average observability in its Tj formations is again Tenerife (18.5%). The parameter observability (O) shows an average value for the whole inventory of 44.7.9%, with a minimum of 5.8% in TF_{6a} and a maximum of 100% in LP_{10} (Figure 5). Therefore, as in the integrity parameter (I), LP_{10} (Tajogaite Volcano), is located in the 100th percentile of observability ($O_{LP10} = 1.0$) within the inventory of Tj formations in the Canary Islands (Table 3).

The arithmetic combination of the percentiles of the parameters A, R, D, I, and O for the 27 Tj formations has allowed us to estimate the global geomorphological heritage value for the Tajogaite Volcano in the context of recent volcanism in the Canary Islands (Figures 7 and 8a). Thus, the simple mean combination of A, R, D, I, and O, ranks Tajogaite in the third place of 27 in the set of Tj formations (behind FV_1, Jacomar, and LP_9, Teneguía Volcano). The combination by weighted mean ranks Tajogaite in the second place of 27 in the set of Tj formations, only behind FV_1 (Jacomar). And the combination by maximum value, ranks Tajogaite in the first place of 27 in the set of Tj formations, a position shared with FV_1, (Jacomar), LP_9 (Teneguía Volcano), and TF_2 (Roque Blanco). Jacomar (FV_1) and Teneguía (LP_9) maintain high integrity and observability values, as does Tajogaite, being also extremely unique in its context, in the case of Jacomar, and diverse, in the case of Teneguía. Roque Blanco (TF_2) is particularly relevant due to the magnitude factor when only the maximum values are observed.

By cross-referencing the heritage valuation obtained with the degree of environmental protection of the territory in which each Tj formation is located (% protected land), an approximation of its

TABLE 3 Rank position of the Tajogaite Volcano (LP_{10}, bold values) in the assessment parameters of representativeness (A), rarity (R). diversity (D), integrity (I), and observability (O) within the set of Tj formations in the geological domain of the Canary Islands.

Representativeness		Rareness		Diversity		Integrity		Observability	
ID	-th percentile	ID	-th percentile	ID	-th percentile	ID	-th percentile	ID	-th percentile
TF_2	100.0	FV_1	100.0	LP_9	100.0	**LP_{10}**	**100.0**	**LP_{10}**	**100.0**
TF_5	96.3	LZ_2	96.3	LZ_1	96.3	FV_1	96.3	LP_9	96.3
TF_1	92.6	LZ_1	92.6	LP_7	92.6	LP_{6b}	92.6	FV_1	92.6
TF_4	88.9	EH_{1c}	88.9	LP_2	88.9	LP_1	88.9	LP_{6b}	88.9
LP_{10}	**85.2**	EH_{1b}	85.2	LP_{6a}	85.2	TF_2	85.2	EH_{1c}	85.2
TF_7	81.5	EH_{1a}	81.5	LP_5	81.5	LP_9	81.5	EH_{1b}	81.5
LP_1	77.8	TF_{3b}	77.8	LZ_2	77.8	LP_4	77.8	EH_{1a}	77.8
LP_{3a}	74.1	TF_{3a}	74.1	FV_1	74.1	EH_{1b}	74.1	LP_4	74.1
LP_7	70.4	TF_4	70.4	EH_{1b}	70.4	TF_7	70.4	LZ_1	70.4
TF_{3a}	66.7	TF_7	66.7	LP_{3a}	66.7	LP_{3b}	66.7	LP_8	66.7
LP_{3b}	63.0	TF_5	63.0	TF_{6b}	63.0	EH_{1c}	63.0	TF_7	63.0
LP_{6b}	59.3	TF_2	59.3	EH_{1c}	59.3	LP_7	59.3	LZ_2	59.3
LP_4	55.6	TF_{6b}	55.6	LP_4	55.6	LP_{6a}	55.6	LP_7	55.6
FV_1	51.9	TF_{6a}	51.9	TF_4	51.9	TF_1	51.9	LP_{6a}	51.9
EH_{1c}	48.1	TF_1	48.1	EH_{1a}	48.1	LP_2	48.1	LP_2	48.1
LP_2	44.4	**LP_{10}**	**44.4**	LP_1	44.4	LZ_2	44.4	LP_{3b}	44.4
LP_9	40.7	LP_8	40.7	LP_8	40.7	EH_{1a}	40.7	LP_{3a}	40.7
LP_5	37.0	LP_9	37.0	LP_{3b}	37.0	LP_5	37.0	LP_5	37.0
LP_8	33.3	LP_{6a}	33.3	TF_{3b}	33.3	TF_5	33.3	TF_2	33.3
TF_{6a}	29.6	LP_5	29.6	TF_{3a}	29.6	LZ_1	29.6	LP_1	29.6
LP_{6a}	25.9	LP_{3b}	25.9	TF_{6a}	25.9	LP_8	25.9	TF_{3a}	25.9
LZ_2	22.2	LP_{6b}	22.2	**LP_{10}**	**22.2**	TF_4	22.2	TF_{3b}	22.2
TF_{3b}	18.5	LP_4	18.5	TF_5	18.5	LP_{3a}	18.5	TF_1	18.5
LZ_1	14.8	LP_{3a}	14.8	TF_7	14.8	TF_{3b}	14.8	TF_4	14.8
TF_{6b}	11.1	LP_7	11.1	TF_1	11.1	TF_{3a}	11.1	TF_{6b}	11.1
EH_{1b}	7.4	LP_2	7.4	TF_2	7.4	TF_{6a}	7.4	TF_5	7.4
EH_{1a}	3.7	LP_1	3.7	LP_{6b}	3.7	TF_{6b}	3.7	TF_{6a}	3.7

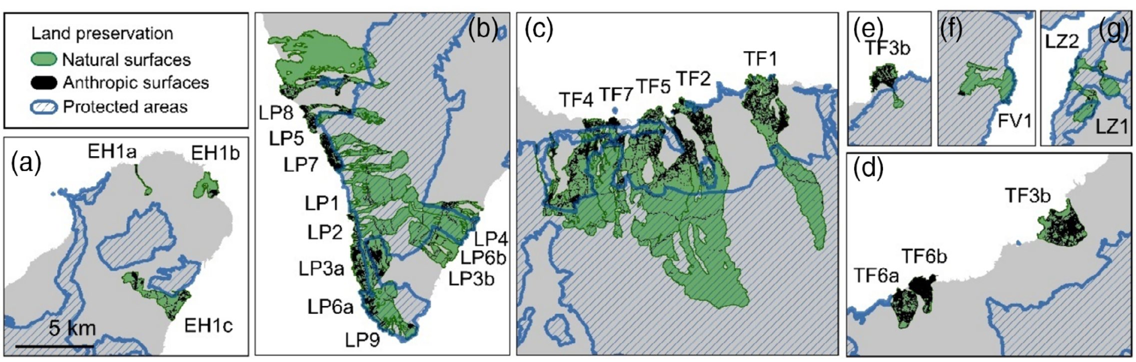

FIGURE 6 Land preservation in the Tj formations of the Canary Islands. Human occupation reaches 83.6% of the land in one Tj formation of Tenerife (TF_{6b}) and is minimal in Tajogaite Volcano (LP_{10}), which shows the maximum value on integrity. The distribution of protected areas (Canary Islands Network for Protected Natural Areas and Natura 2000 Network) is clearly related to less human occupation in the most populated islands. Map locations: (a) North of El Hierro; (b) South of La Palma; (c) North of Tenerife; (d,e) Northeast of Tenerife; (f) East of Fuerteventura; (g) North of Lanzarote. [Colour figure can be viewed at wileyonlinelibrary.com]

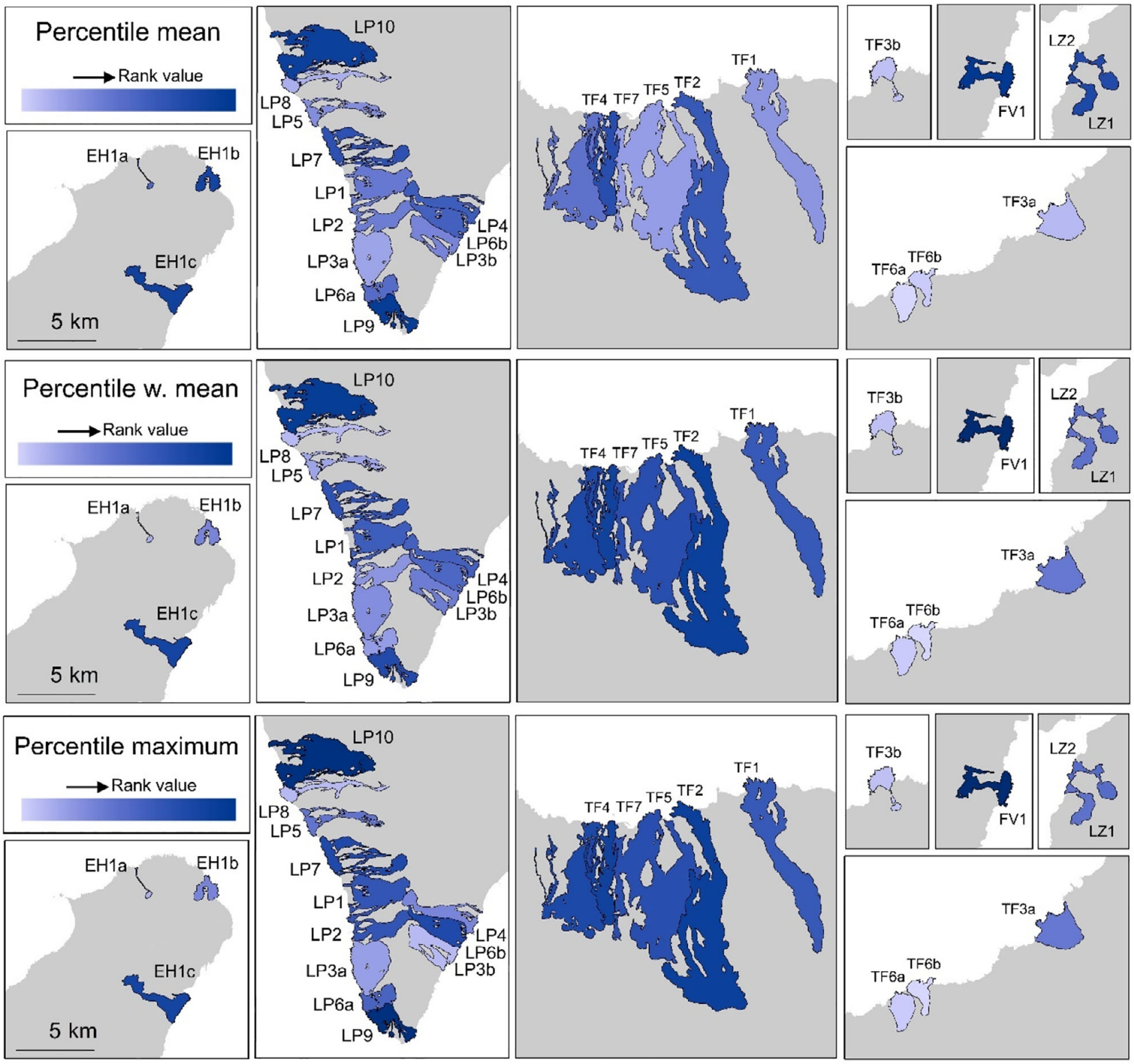

FIGURE 7 Ranking of the geoheritage value of the Tj formations in the Canary Islands, according to the mean, weighted mean, and maximum values of the representativeness (A), rarity (R). diversity (D), integrity (I), and observability (O). [Colour figure can be viewed at wileyonlinelibrary.com]

possible protection deficit has been obtained (Figure 8b). If the simple mean value of A, R, D, I, and O is used as a global valuation, the resulting values indicate that the protection deficit could affect approximately 35% of the inventoried Tj formations, with this deficit being significant (≥0.5) in the three formations of El Hierro (EH_{1a}, EH_{1b}, EH_{1c}), and maximum in the new Tajogaite Volcano of La Palma (LP_{10}). If the weighted mean of A, R, D, I, and O is used as an overall assessment criterion, the observed protection deficit could amount to approximately 50% of the inventoried Tj formations, again being significant (≥0.5) in those of El Hierro (EH_{1a}, EH_{1b}, EH_{1c}), together with TF_{3a}, and maximum in the new Tajogaite Volcano of La Palma (LP_{10}). And if, finally, the global criterion of maximum value in A, R, D, I, and O is used, the protection deficit could reach approximately 75% of the inventoried Tj formations, being significant (≥0.5) in TF_{6a}, TF_{3b}, TF_{6b}, TF_{3a}, EH_{1a}, EH_{1b}, EH_{1c}, and, again, maximum in the new Tajogaite Volcano of La Palma (LP_{10}).

5 | DISCUSSION

5.1 | Methodological adaptations to an emergency scenario

This work does not use conventional methods in geoheritage valuations based on semi-quantitative scoring scales and the Expert Judgment (e.g., Brilha, 2016, 2018; Bruschi & Cendrero, 2005; De Lima

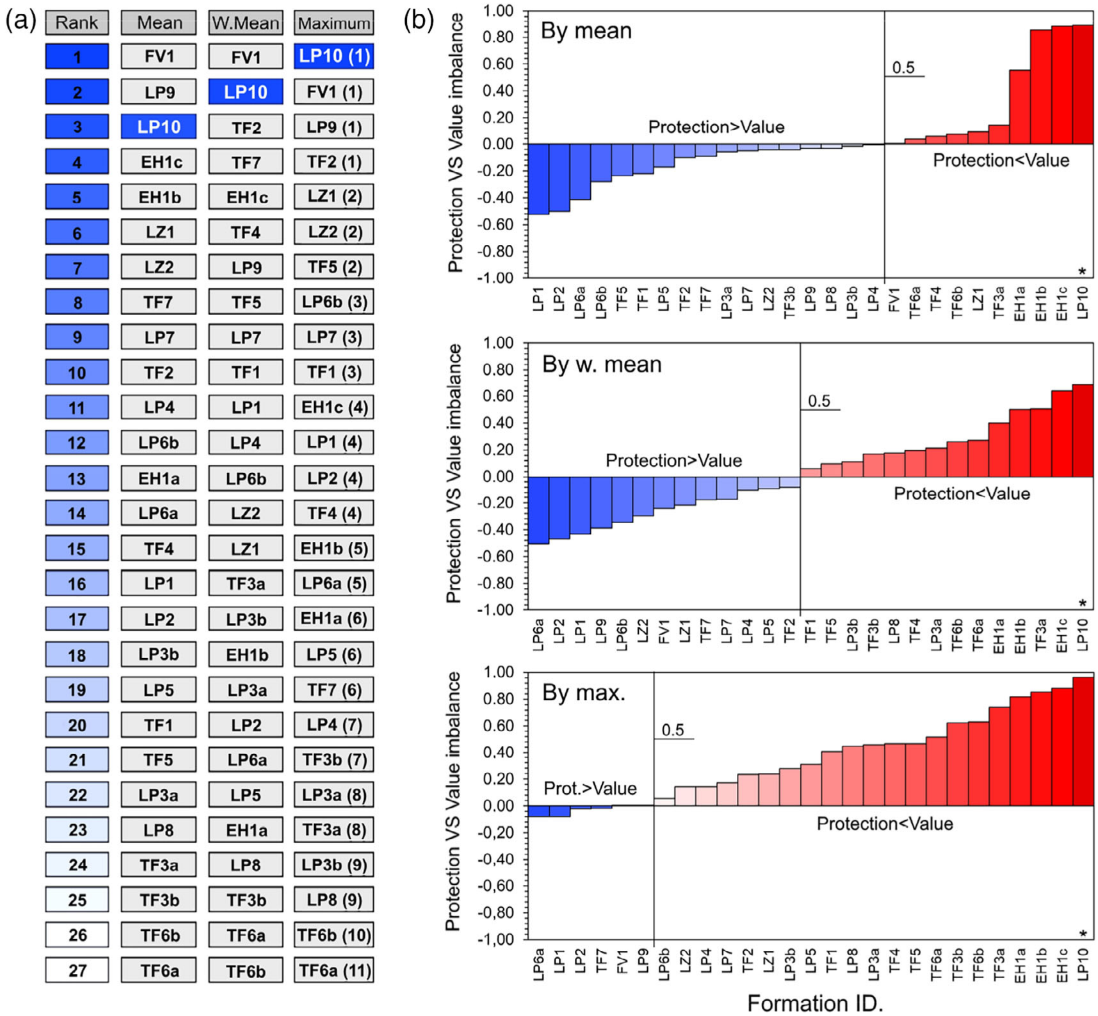

FIGURE 8 (a) Final ranking of the Tj formations geoheritage value from the combination of representativeness (A), rarity (R), diversity (D), integrity (I), and observability (O). (b) Mismatch between the Tj formations geoheritage value and their environmental protection under the regional and national legal figures (the Canary Islands Network for Protected Natural Areas) and European level (Natura 2000 Network). [Colour figure can be viewed at wileyonlinelibrary.com]

et al., 2010; Dingwall et al., 2005; Fassoulas et al., 2012; García-Cortés et al., 2019; JNCC, 1977; Reynolds, 2001). Instead, it uses a quantitative perspective based on physical dimensions, free of subjectivity, within a spatial comparative framework of known geographical boundaries. The method relates the element analyzed (in this case, the Tajogaite Volcano) with the set of elements of the same type existing in its geological domain (in this case, Canary Islands) (Figures 2, 3).

In order to arrive at the measurements, firstly, a re-conceptualization has been made on the broad meaning of the criteria, which allows a univocal, individualized, and non-overlapping recognition of each one of them (Table 1). Secondly, a numerical approximation has been sought, based on physical dimensions, which can effectively describe the concept (Tables 1, 2). The re-conceptualization may imply a reduction and omission of nuances of meaning, implied in the subjectivity inherent to the Expert Judgment, but we believe that it may have methodological potential when complementing conventional evaluation processes, as well as when dealing with rapid assessment studies by a reduced group of analysts, in situations where it is urgent to support the conservation of a new relevant natural element.

To concretise and assess the representativeness concept (Brilha, 2016; Fassoulas et al., 2012; García-Cortés et al., 2019; Reynard et al., 2016), as the quality of a geological site to serve as a model to exemplify the geological features, events, and processes of a given domain, this paper follows the solid idea of Sharples (2002), who states that a geological feature is representative when it is well-developed. Having previously established defining units that ensure the morphological fit of the features to a model (the units U_1, U_2, and U_3 in this study), their final representativeness (the 'well development' said by Sharples) must be directly related to its physical magnitude, scale, or size (e.g., in the Canary Islands, the best example of a lava field is Timanfaya, the largest of all, and the best example of a dune field is Maspalomas, where the most developed dunes are).

Therefore, we have resorted directly to the use of a proxy of magnitude or size (in this case the surface area) to univocally and quantitatively estimate it. To concretise and asses the diversity concept, we accept that the number of distinct elements (richness) and their distributional balance or abundance equity (evenness) are the two basic parameters. This is stated from the ecology since the 1970 s (Magurran, 1988) and most recently from geodiversity studies (Benito-Calvo et al., 2009; Ferrer-Valero, 2018; Ferrer-Valero et al., 2019; Ferrer-Valero & Hernández-Calvento, 2020; Ibañez et al., 1995). Therefore, we used the Shannon-Weaver index (H′) as a classical measure of diversity to univocally and quantitatively estimate it.

5.2 | The advisability of conserving the Tajogaite volcano

The results obtained indicate that the Tajogaite Volcano has a high geoheritage value in the geological domain of the Canary Islands, which is one of the most prominent oceanic volcanic chain of the world. This high geoheritage value is supported, fundamentally, by its integrity and observability, in which the new volcanic formation occupies the highest position in the inventory (100th percentile) (Table 3). In addition, it has a high value for the representativeness indicator (85th percentile). Combining them, the new volcanic formation occupies the top positions in geoheritage evaluation among the similar volcanic complexes inventoried in the Canary Islands (Figures 7, 8a). Therefore, this study yields favourable results for the geoconservation and valorization of the new volcanic landscape of the Canary Islands (the Tajogaite Volcano), justifying the implementation of actions aimed at the conservation of this area.

The parameters of integrity and observability push the intrinsic value of the new volcanic formation to the top of the list due to the obvious fact of its recent formation and, therefore, its high level of natural preservation and low level of anthropogenic degradation. We must therefore affirm that there are similar geomorphological landscapes in the Canary Islands (Figure 4), but none of them have the levels of conservation and observability of the Tajogaite Volcano (Figures 5, 6), making it an outstanding geological element that must be conserved and promoted.

Furthermore, the Tajogaite Volcano has the greatest mismatch between intrinsic value and current environmental protection by legal figures (Figure 8b). Only the area of the main cone is included in the Cumbre Vieja Natural Park and the rest of the eruption has covered

FIGURE 9 Examples of non-conservationist human land uses on lava-deltas of the Canary Islands. (a) intensive open-air and greenhouse cultivation of bananas on lava delta of the El Remo (La Palma); (b) intense urban development on lava deltas in the north of Tenerife (Garachico); (c) mixture of urban and agricultural fabric in Punta del Hidalgo (Tenerife); (d) Small settlement in Jacomar (Fuerteventura), one of the most valuable lava deltas of the Canary Islands. [Colour figure can be viewed at wileyonlinelibrary.com]

urban and agricultural land. A territory as active as the Canary Islands should have some kind of legislative framework to safeguard a new volcanic element at least until the geoheritage values are established. It is therefore urgent to implement environmental protection measures to prevent the landscape degradation due to the introduction of new human non-conservationist land uses. The lava fields and especially the lava deltas have been the object of intense human occupation throughout history in the Canary Islands (Figure 9). In fact, very few lava deltas in the Canary Islands remain unaltered by human action. Particularly in Tenerife and La Palma, these lands have been intensively used for the development of urban fabrics (residential and tourist), transport infrastructures or agricultural uses. So much so that at present there are practically no free natural areas in the lava deltas that extend along the coasts. Therefore, the protection of this new volcanic feature means the preservation of an element of great volcanic and geomorphological interest that is difficult to observe in its entirety on the coasts of the Canary Islands. The almost unique possibilities of observing a volcanic landform of this type offer unquestionable opportunities for the development of ecotourism in the area (in this case geotourism). Given the evident need to make the most of the land on an island territories of the Canary Islands, with high anthropic pressure, with geotourism could offer a sustainable alternative for economic exploitation compatible with the conservation of the natural environment.

6 | CONCLUSIONS

The volcanic eruption that started on 19 September 2021 at La Palma (Canary Islands) gave rise to a spectacular volcanic formation composed of a main strombolian pyroclastic edifice, extensive lava fields along the central slope of the island and two lava deltas along the western coast. These types of monogenetic eruptions are relatively abundant in the Canary Islands and form a constituent part of the geological history of the archipelago, which is one of the most prominent oceanic volcanic chain of the world. The aim of this work has been to make an urgent estimate of the intrinsic geological value (in this case based in geomorphological type) of the new volcanic formation and to evaluate its inclusion as a geosite in the Spanish Inventory of Geosites (IELIG project, IGME-CSIC) as a preventive and initial conservation measure.

For this purpose, a systematic, classificatory-based inventory approach, designed ad hoc to assess the Tajogaite Volcano geoheritage value, has been adopted. On this, the re-conceptualization of valuable parameters and the adoption of numerical proxies based on measurable physical quantities have been practised. Once the three defining geomorphological units of the new volcanic landscape were established, similar volcanic formations existing in the geological domain of the Canary Islands were identified and mapped in order to estimate their intrinsic value comparatively. By means of GIS integration of digital orthophotos, high-resolution DEMs and 1:25,000 geological maps, a total of twenty-seven similar formations have been identified and mapped in the Canary Islands (highly concentrated on the islands of Tenerife and La Palma). This allowed us to estimate the assessment parameters indicated by the IELIG project: representativeness, rarity, diversity, integrity and observability. Representativeness has been assimilated to the magnitude of each formation, rarity to its scarcity in space, diversity to its internal richness and evenness, integrity to the degree of human alteration, and observability to its degree of vegetation cover.

The results indicate that the geomorphological value of the new Tajogaite Volcano is among the highest of the similar formations within the geological framework of the Canary Islands. Its geomorphological value is fundamentally based on its integrity and observability, and also, albeit secondarily, on its representativeness. This means that the main value of the new Tajogaite Volcano is its current state of conservation with respect to natural processes and human action, when compared with similar volcanic formations in the Canary Islands. In addition, the low level of environmental protection of the area where the new volcanic formation has developed determines a maximum current mismatch between the estimated value and its level of environmental protection.

This provides a direct opportunity for the conservation of the new volcanic formation to turn the Tajogaite Volcano into a strong geotourism attraction on La Palma. In this sense, its cataloging as a national geosite in the IELIG project becomes a key step in the adoption of a conservationist management of this new space. In addition, it will be necessary to identify the most significant volcanic elements of this eruption in order to legally protect them by a category of Protected Natural Area under Canarian regional legislation.

ACKNOWLEDGMENTS

This work has been developed within the IVRIPARC 2779/2021 project funded by the OAPN “Impacts, vulnerability and resilience of geodiversity and geological heritage facing the global change in the Canary Islands National Parks” (IGME, CSIC) and funded by the Spanish Ministry of Science and Innovation to the IGME-CSIC, RD 1078/2021. Nicolás Ferrer Valero is a beneficiary of the ‘Catalina Ruiz’ research staff training programme of the Regional Ministry of Economy, Knowledge and Employment of the Canary Islands Government, as well as of the European Social Fund (APCR2021010018/6431001 - CATALINA RUIZ 2021 SI-1776). We are grateful for the work of the two reviewers who improved the original manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Nicolás Ferrer https://orcid.org/0000-0002-3402-6183
Juana Vegas https://orcid.org/0000-0001-9137-0020

REFERENCES

Acosta, J., Uchupi, E., Smith, D., Muñoz, A., Herranz, P., Palomo, C., & ZEE Working Group. (2003). Comparison of volcanic rifts on La Palma and

El Hierro, Canary Islands and the Island of Hawaii. *Marine Geophysical Research*, *24*, 59–90. https://doiorg.bibproxy.ulpgc.es/10.1007/s11001-004-1162-6

Anguita, F., & Hernán, F. (2000). The Canary Islands origin: A unifying model. *Journal of Volcanology and Geothermal Research*, *103*(1–4), 1–26. https://doi.org/10.1016/S0377-0273(00)00195-5

Becerra-Ramírez, R., Gosálvez, R. U., Escobar, E., González, E., Serrano-Patón, M., & Guevara, D. (2020). Characterization and Geotourist resources of the campo de Calatrava volcanic region (Ciudad Real, Castilla-La Mancha, Spain) to develop a UNESCO global Geopark project. *Geosciences*, *10*(11), 441. https://doi.org/10.3390/geosciences10110441

Benito-Calvo, A., Pérez-González, A., Magri, O., & Meza, P. (2009). Assessing regional geodiversity: The Iberian Peninsula. *Earth Surface Processes and Landforms*, *34*(10), 1433–1445. https://doi.org/10.1002/esp.1840

Blanco-Montenegro, I., Montesinos, F. G., & Arnoso, J. (2018). Aeromagnetic anomalies reveal the link between magmatism and tectonics during the early formation of the Canary Islands. *Scientific Reports*, *8*, 42. https://doi.org/10.1038/s41598-017-18813-w

Bostick, V. B., Niles, W. E., McCLellan, W. A., Oakes, E. H., & Wilbanks, J. R. (1975). *Inventory of natural landmarks of the Great Basin. Complied for the Natural Park service, United States Department of the Interior. 686 p and appendix*. The University of Nevada. Las Vegas.

Brilha, J. (2016). Inventory and quantitative assessment of geosites and geodiversity sites: A review. *Geoheritage*, *8*(2), 119–134. https://doi.org/10.1038/s41598-017-18813-w

Brilha, J. (2018). Geoheritage: Inventories and evaluation. In E. Reynard & J. Brilha (Eds.), *Geoheritage* (pp. 69–85). Elsevier.

Bruschi, V. M., & Cendrero, A. (2005). Geosite evaluation; can we measure intangible values? *Alpine and Mediterranean Quaternary*, *18*(1), 293–306.

Carcavilla, L., López-Martínez, J., & Durán, J. J. (2007). Patrimonio geológico y geodiversidad: investigación, conservación, gestión y relación con los espacios naturales protegidos. Instituto Geológico y Minero de España Ed, Madrid.

Carracedo, J. C. (1999). Growth, structure, instability and collapse of Canarian volcanoes and comparisons with Hawaiian volcanoes. *Journal of Volcanology and Geothermal Research*, *94*(1), 1–19. https://doi.org/10.1016/S0377-0273(99)00095-5

Carracedo, J. C., Day, S., Guillou, H., Rodríguez Badiola, E., Canas, J. A., & Pérez Torrado, F. J. (1998). Hotspot volcanism close to a passive continental margin: The Canary Islands. *Geological Magazine*, *135*(5), 591–604. https://doi.org/10.1017/S0016756898001447

Carracedo, J. C., Day, S. J., Guillou, H., & Pérez-Torrado, F. J. P. (1999). Giant quaternary landslides in the evolution of La Palma and El Hierro, Canary Islands. *Journal of Volcanology and Geothermal Research*, *94*(1), 169–190. https://doi.org/10.1016/S0377-0273(99)00102-X

Carracedo, J. C., Rodríguez Badiola, E., Guillou, H., Nuez Pestana, J. D. L., & Pérez-Torrado, F. J. (2001). Geology and volcanology of La Palma and El Hierro, Western Canaries.

Carracedo, J. C., & Troll, V. R. (2016). *The geology of the Canary*. Elsevier.

Civico, R., Ricci, T., & Scarlato, P. (2022). High-resolution digital surface model of the 2021 eruption deposit of cumbre Vieja volcano, La Palma, Spain. *Scientific Data*, *9*, 435. https://doi.org/10.1038/s41597-022-01551-8

De Lima, F. F., Brilha, J. B., & Salamuni, E. (2010). Inventorying geological heritage in large territories: A methodological proposal applied to Brazil. *Geoheritage*, *2*(3), 91–99. https://doi.org/10.1007/s12371-010-0014-9

Del Arco, M. J., Wildpret, W., Pérez, P. L., Rodríguez, O., Acebes, J. R., García, A., Martín, V. E., Reyes, J. A., Salas, M., Díaz, M. A., Bermejo, J. A., González, R., Cabrera, M. V., & García, S. (2006). *Mapa de vegetación de Canarias*. Santa Cruz de Tenerife. GRAFCAN Ediciones.

Dingwall, P. R., Weighell, T., & Badman, T. (2005). Geological world heritage: A global framework: A contribution to the global theme study of world heritage natural sites.

Dóniz-Páez, J., Becerra-Ramírez, R., González-Cárdenas, E., Guillén-Martín, C., & Escobar-Lahoz, E. (2011). Geomorphosites and geotourism in volcanic landscape: The example of La Corona del Lajial cinder cone (El Hierro, Canary Islands, Spain). *Geo Journal of Tourism and Geosites*, *2*(8), 185–197. https://doi.org/10.3390/geosciences10110441

Dóniz-Páez, J., Beltrán-Yanes, E., Becerra-Ramírez, R., Pérez, N. M., Hernández, P. A., & Hernández, W. (2020). Diversity of volcanic geoheritage in the Canary Islands, Spain. *Geosciences*, *10*(10), 390. https://doi.org/10.3390/geosciences10100390

Duque, L. C., Abril, J., García Salinas, F., & Elízaga, E. (1979). *Desarrollo de la metodología del inventario de puntos de interés geológico en el Sector Oriental de la Cordillera Cantábrica* (p. 107). Centro de Documentación IGME.

Elizaga, E., Abril, J., Duque, L. C., García Salinas, F., & Murcia, V. (1980). Los puntos geológico-mineros de interés singular como patrimonio natural. Su inventario y metodología de estudio. I Reunión Nacional de Geología Ambiental y Ordenación del Territorio. Volumen de Comunicaciones, 21. Santander.

Ellis, N. V., Bowen, D. Q., Campbell, S., Knill, J. L., AP, M. K., Prosser, C. D., Vincent, M. A., & RCL, W. (1996). *An introduction to the geological conservation review. GCR series 1* (p. 131). Joint Nature Conservation Committee.

Fassoulas, C., Mouriki, D., Dimitriou-Nikolakis, P., & Iliopoulos, G. (2012). Quantitative assessment of geotopes as an effective tool for geoheritage management. *Geoheritage*, *4*(3), 177–193. https://doi.org/10.1007/s12371-011-0046-9

Ferrer-Valero, N. (2018). Measuring geomorphological diversity on coastal environments: A new approach to geodiversity. *Geomorphology*, *318*, 217–229. https://doi.org/10.1016/j.geomorph.2018.06.013

Ferrer-Valero, N., & Hernández-Calvento, L. (2020). Coastal geomorphic chronosequences across broad spatiotemporal scales. Metrical observations from the Cape Verde hotspot. *Earth Surface Processes and Landforms*, *45*(3), 511–525. https://doi.org/10.1002/esp.4738

Ferrer-Valero, N., Hernández-Calvento, L., & Hernández-Cordero, A. I. (2019). Insights of long-term geomorphological evolution of coastal landscapes in hot-spot oceanic islands. *Earth Surface Processes and Landforms*, *44*(2), 565–580. https://doi.org/10.1002/esp.4518

Galindo, I., Martín-González, E., Sánchez, N., Vegas, J., Romero, C., Lozano, G., Márquez, A., Coello, J. J., Casillas, R., Martín-Luis, C., Léon, R., Vázquez, J.-T., Yepes, J., & Mangas, J. (2022). Inventory of geological sites of interest in the Canary Islands. *Geo-Temas*, *19*, 28–31.

Galindo, I., Vegas, J., Romero, C., Llorente, M., Martín-González, E., Rubio, J. C., Díaz, G. A., Mangas, J., Mateo, E., & Sánchez, N. (2019). Geoheritage inventory of the Lanzarote and Chinijo Islands UNESCO global Geopark. In E. Mateo, J. Vegas, & J. Martínez-Frías (Eds.), *Lanzarote and Chinijo Islands Geopark: From Earth to space* (pp. 31–45). Springer.

García-Cortés, A. (Ed.). (2008). *Spanish geological frameworks. An approach to Spanish geological heritage of internacional relevance* (p. 235). Instituto Geológico y Minero de España.

García-Cortés, A., Rábano, I., Locutura, J., Bellido, F., Fernández-Gianotti, J., Martín-Serrano, A., Quesada, C., Barnolas, A., & Durán, J. J. (2001). First Spanish contribution to the Geosites project: List of the geological frameworks established by consensus. *Episodes*, *24–2*, 79–92. https://doi.org/10.18814/epiiugs/2001/v24i2/002

García-Cortés, Á., Vegas, J., Carcavilla, L., & Díaz-Martínez, E. (2019). *Bases conceptuales y metodología del Inventario Español de Lugares de Interés Geológico (IELIG)/ conceptual base and methodology of the Spanish inventory of sites of geological interest (IELIG)* (p. 109). Instituto Geológico y Minero de España.

Guilbaud, M. N., Ortega-Larrocea, M. D. P., Cram, S., & van Wyk de Vries, B. (2021). Xitle volcano Geoheritage, Mexico City: Raising awareness of natural hazards and environmental sustainability in active volcanic areas. *Geoheritage*, *13*(1), 1–27. https://doi.org/10.1007/s12371-020-00525-9

Hausen, H. (1969). Some contributions to the geology of La Palma (Canary Islands). *Societas Scientiarum Fennica Communications in Mathematical Physics*, *35*, 1–140.

Hernandez-Pacheco, A., & Valls, M. C. (1982). The historic eruptions of La Palma Island (Canaries). Arquipélago. *Série Ciências da Natureza*, *3*, 83–94.

Hoernle, K., & Carracedo, J. C. (2009). *Canary Islands geology*. University of California Press.

Hoernle, K., Tilton, G., & Schmincke, H. U. (1991). SrNdPb isotopic evolution of gran Canaria: Evidence for shallow enriched mantle beneath the Canary Islands. *Earth and Planetary Science Letters*, *106*(1–4), 44–63. https://doi.org/10.1016/0012-821X(91)90062-M

Hoernle, K. A. J., & Schmincke, H. U. (1993). The role of partial melting in the 15-ma geochemical evolution of gran Canaria: A blob model for the canary hotspot. *Journal of Petrology*, *34*(3), 599–626. https://doi.org/10.1093/petrology/34.3.599

Hoernle, K. A. J., Zhang, Y. S., & Graham, D. (1995). Seismic and geochemical evidence for large-scale mantle upwelling beneath the eastern Atlantic and western and Central Europe. *Nature*, *374*(6517), 34–39.

Ibañez, J. J., De-Albs, S., Bermúdez, F. F., & García-Álvarez, A. (1995). Pedodiversity: Concepts and measures. *Catena*, *24*(3), 215–232. https://doi.org/10.1016/0341-8162(95)00028-Q

Instituto Canario de Estadística (ISTAC). (2021). http://www.gobiernodecanarias.org/istac/estadisticas/demografia/

JNCC Joint Nature Conservation Committee. (1977). Guidelines for selection of Earth Science SSSIs. JNCC.

Joyce, E. B. (2010). Australia's geoheritage: History of study, a new inventory of geosites and applications to geotourism and geoparks. *Geoheritage*, *2*(1), 39–56. https://doi.org/10.1007/s12371-010-0011-z

Langenheim, V. A., & Clague, D. A. (1987). The Hawaiian-Emperor volcanic chain. Part 2 (pp. 55–84). Hawaiian Volcano Observatory.

Lyell, E. (1865). *Elements of geology* (6th ed.). John Murray.

Magurran, A. E. (1988). *Ecological diversity and its measurement*. Princeton University Press.

Megerle, H. E. (2020). Geoheritage and geotourism in regions with extinct volcanism in Germany; case study Southwest Germany with UNESCO global Geopark Swabian Alb. *Geosciences*, *10*(11), 445. https://doi.org/10.3390/geosciences10110445

Németh, K., Casadevall, T., Moufti, M. R., & Marti, J. (2017). Volcanic geoheritage. *Geoheritage*, *9*(3), 251–254. https://doi.org/10.1007/s12371-017-0257-9

Reynard, E., Perret, A., Bussard, J., Grangier, L., & Martin, S. (2016). Integrated approach for the inventory and management of geomorphological heritage at the regional scale. *Geoheritage*, *8*(1), 43–60. https://doi.org/10.1007/s12371-015-0153-0

Reynolds, J. (2001). Notes to accompany RIGS recording, assessment and designation and notification sheets. In Notes on the UKRIGS Conference. Penirth.

Różycka, M., & Migoń, P. (2018). Customer-oriented evaluation of geoheritage—On the example of volcanic geosites in the west Sudetes, SW Poland. *Geoheritage*, *10*(1), 23–37. https://doi.org/10.1007/s12371-017-0217-4

Schmincke, H. U., & Sumita, M. (1998). Volcanic evolution of gran Canaria reconstructed from apron sediments: Synthesis of vicap project drilling. In proceedings of the ocean drilling program. In P. P. E. Weaver, H. U. Schmincke, J. V. Firth, & W. Duffield (Eds.), *Scientific Results* (Vol. 157). Ocean Drilling Program.

Shannon, C., & Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois Press.

Sharples, C. (2002). *Concepts and principles of geoconservation*. Tasmanian Parks & Wildlife Service website.

Silverman, B. W. (1986). *Density estimation for statistics and data analysis*. Chapman and Hall.

Szepesi, J., Harangi, S., Ésik, Z., Novák, T. J., Lukács, R., & Soós, I. (2017). Volcanic geoheritage and geotourism perspectives in Hungary: A case of an UNESCO world heritage site, Tokaj wine region historic cultural landscape, Hungary. *Geoheritage*, *9*(3), 329–349. https://doi.org/10.1007/s12371-016-0205-0

Vegas, J., Sánchez, N., Romero, C., & Galindo, I. (2019). *Manual for the elaboration of the Inventory of Sites of Geological Interest in the Canary Islands*. NIPO 697-19-003-2 (p. 52). Instituto Geologico y Minero de España.

Von Buch, L. (1825). *Physikalische Beschreibung der Kanarischen Inseln* (Vol. 2, p. XIV + 388 + 381). Hofdruckerei von Königlichen Akademie.

Wilson, J. T. (1963). A possible origin of the Hawaiian islands. *Canadian Journal of Physics*, *41*(6), 863–870. https://doi.org/10.1139/p63-094

How to cite this article: Ferrer, N., Vegas, J., Galindo, I., & Lozano, G. (2023). A geoheritage valuation to prevent environmental degradation of a new volcanic landscape in the Canary Islands. *Land Degradation & Development*, *34*(9), 2494–2507. https://doi.org/10.1002/ldr.4623