Geomorphologic Evidences of Great Flank Collapses in the Northwest of Gran Canaria (Canary Islands, Spain)

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Abstract

This work provides geological observations that support the existence of several large rock slides in the northwest sector of the Gran Canaria Island, which are now covered by recent lavas. Some erosional forms has been identified: a paleo-relief developed in Pliocene volcanic materials which could be related to a large rock slide, a number of streams with strong incision and sharp diversions which are related to the flanks of the fractured rock mass, a clear topographical unconformity between the oldest erosion surfaces, as well as a prior secondary scarp near de coastal border. Moreover, we have identified some aggradational morphologies: a debris avalanche deposit covering the offshore area of the island, several scoria cones which are developed following the main scarp of the rock slide and a field of volcanoes which covers the foot of the slide in the onshore part of the island. These observations confirm the existence of some large rock slides that affect successively the NW flank of Gran Canaria during the Miocene to Pliocene. These flank instabilities suggest a NE-SW extensional regime, which could be related to a NW-SE fault zone that divides the island into two sectors. This hypothesis is in agreement with the spreading process which has been proposed for other volcanic islands.

Keywords

Canary Islands • Flank collapse • Gran Canaria • Pliocene • Quaternary • Rock slide • Volcanic rock

Introduction

Gran Canaria is a circular volcanic island dating back more than 14.5 Ma, but eruptions have continued until very recent time. The geological evolution of the Gran Canaria comprises four main volcanic stages, alternating with periods of erosion (Balcells et al. 1992; Carracedo et al. 2002; Ancochea et al. 2004; Guillou et al. 2004; Pérez Torrado 2008; Schmincke and Sumita 2010). The first volcanic stage of the island was built during the Miocene (14.5–7.3 Ma) by a shield volcano of basic composition, which developed later a kilometric caldera collapse in the central part of the island. Two generations of superimposed stratovolcanoes were developed inside the caldera: Tejeda and Roque Nublo volcanoes. The Tejeda Volcano was related to the Miocene activity (Cycle I), but had a salic composition (rhyolitic to trachyphonolitic).

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The Roque Nublo Volcano was developed during the Pliocene (5.6–2.9 Ma) forming the basic to salic deposits of the Roque Nublo Cycle. The Plio-Quaternary activity of the last two stages is mainly related to fissure eruptions of basaltic composition (Post-Roque Nublo and Recent Cycles). This last activity developed a number of fields of cinder cones and their lavas, which have been related to a NW-SE rifting.

Several intensive erosive stages have been developed between the main volcanic cycles. The most significant flank collapses and large rock slides of Gran Canaria have been triggered in relation to these periods of erosion, in particular, at the final phases of the Miocene shield volcano (~ 9 Ma) and the end of Roque Nublo Cycle (3.5–2.9 Ma) (Funck and Schmincke 1998; Mehl and Schmincke 1999; Yepes et al. 2011). The oldest evidence of flank instability has been related to breccias levels which are found in discordant contact between the lavas of the Miocene shield volcano, located in the southwestern sector of the island (Schmincke 1993; Schmincke and Sumita 2010). Other evidence of this phenomenon would be the coastal morphology in arc extending between La Aldea and Agaete villages, in the western sector of the island (Coello and Coello 1999). This coast defines a deep coastal cliff that has some collapsed rock masses on his foot (Criado et al. 1998) and seems to involve the volcanic materials that define the western border of the Tejeda caldera (Yepes et al. 2011). Our research has been also motivated by the anomalous distribution of lithologies of the different volcanic cycles in the field, in particular the location of the deposits of the Roque Nublo Cycle in the southern and northern sectors of the island. These observations have been considered as evidence of two large flank collapses: one that took place in the Roque Nublo stratovolcano at the end of the Roque Nublo Cycle (García Cacho et al. 1994; Pérez Torrado et al. 1995), and another that would have occurred in the northeastern sector of the island (Hansen 2009). Finally, additional evidences of flank instabilities have been described in the offshore sector of the island. The anomalous topography found in this sector has been interpreted as submarine deposits of debris avalanches and debris flows, which can cover wide areas of the sea floor, related to large flank collapses (Funck and Schmincke 1998; Krastel et al. 2001; Acosta et al. 2003).

This paper provides geological and geomorphologic observations that support the existence of flank instabilities in the northwest sector of the Gran Canaria, in a circular sector of about 175 km^2, which could be defined between the Agaete, Arucas and Cruz de Tejeda villages (Fig. 1).

The geomorphological observations are focused on the analysis of the drainage system, scarps, erosion surfaces, residual reliefs, cinder cones and offshore debris avalanche deposits. The geologic evidence is derived from the lithological relationships between the surface geology and 71 lithological columns that reach depths between 20 and 460 m (Fig. 4, Table 1). The surface data were derived from geological maps (Balcells et al. 1986; Barrera and Gómez 1986; Balcells and Barrera 1987a, b; Balcells et al. 1992), whereas the underground data were obtained from the wells and boreholes reported in Galindo et al. (2011). The descriptions of the lithological columns (Table 1) were obtained from the database of boreholes developed by the Geological Survey of Spain (Instituto Geológico y Minero de España, IGME) during different research projects.

Geomorphological Observations

The drainage system is centrifugal and it is modified by sharp river diversions with a NW-SE trend. These diversions seem to be related to the main NW-SE trend of the feeding dykes of the Post-Roque Nublo Cycle, conditioning the differential erosion of the substrate. These small anomalies in the drainage system would be a morphological expression of the NW-SE extension that would have undergone on Gran Canaria during the Post-Roque Nublo Cycle. The streams with the steepest slopes are located on the lateral edges of the study area (Agaete and Guía). At least one embedded stream that describes very sharp changes in its path can be recognized in both margins. The Berrazales (or Agaete) Ravine would be the most typical case in the western sector, and the San Andrés and Moya ravines in the eastern sector. These streams increase sharply their relative divergence close to the populations of Fontanales and Fagagesto, defining a wide circular sector of the island with a relief organization which is uncorrelated laterally with the geomorphology observed in the surrounding areas. These observations suggest that these streams with a variable path have been fitted in favour of very penetrative planes of weakness in the rock mass. These planes could be related to the lateral flanks of a large rock slide. This phenomenon is also observed at a small scale in the area between Agaete and Gáldar, coinciding with a morphostructural scarp (S_5). In addition, at the base of this scarp, a number of rock slide deposits have been recognized (Fig. 2).

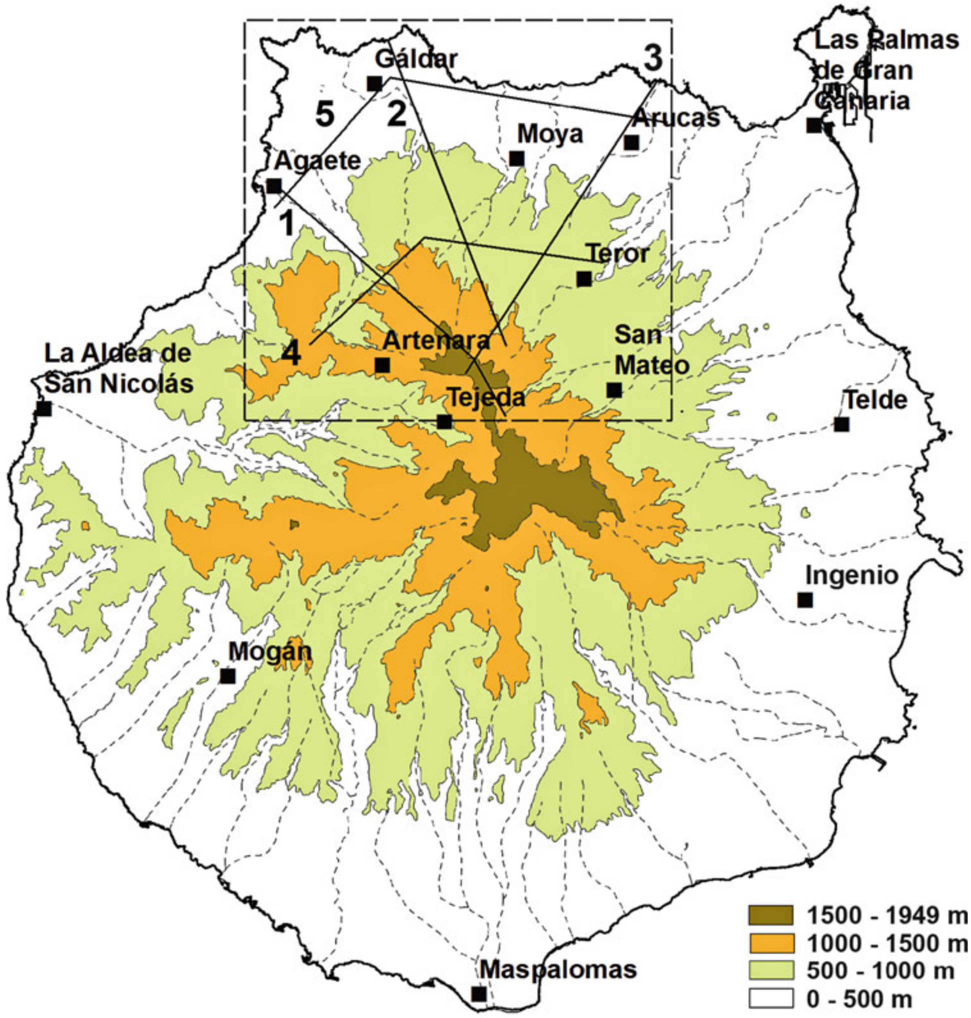

Fig. 1 Topographic map showing the location of the northwest sector of the Gran Canaria (Canary Islands, Spain). The *dashed black square* shows the area of Fig. 3.

In the coastal zone, most of the ravines are interrupted or deviated by a wide flat-bottomed valley with a NW-SE trend and a few isolated cinder cones (Gáldar, Gallinero and Montaña Clavijo) of the Recent Cycle (Fig. 3). The peripheral location of this small volcanic field could be in agreement with lithostatic unloading related to the foot area of a slipped mass. These observations suggest that the occurrence of the flank instabilities in Gran Canaria could be extended during the Post-Roque Nublo Cycle. In addition, the head area is disconnected from the summit of the island by a number of cinder cones of the Recent Cycle (e.g. Pinos de Gáldar, Juncalillo and Montañón Negro). This observation suggests the existence of a lateral spreading due to the intrusion of dykes during the Post-Nublo Roque and Recent cycles, a process that has already been described in other volcanic islands (McGuire et al. 1990; Elsworth and Voight 1995; Voight and Elsworth 1997; Day et al. 1999; Galindo 2005; Cecchi et al. 2005; Del Potro and Hürlimann 2007). The process of intrusion of dykes took place until the end of the Cycle I, a period in which the orientation of the stress field related to volcanism changed: from a radial pattern change to a NW-SE fissural regime (Yepes et al. 2011). In addition, the lateral spreading would be amplified by the age of the island, as it would provide a longer period to increase the weight of the volcano and, subsequently, to produce an unstable condition as other authors has been proposed in similar volcanic areas (Lo Giudice and Rasa 1992; Clague and Denlinger 1994; Van Wyk de Vries and Francis 1997; Borgia et al. 2000; Reid et al. 2001).

The relief inflections allow distinguishing remnants of four different erosional surfaces (S_0, S_2, S_4 and S_6) (Figs. 2 and 3). The older structural surface (S_0), defined by the lava flows of the Phonolitic Formation (Cycle I), can be related to a surface of summits where the lava flows of the subsequent volcanic

Table 1 Wells and boreholes data of the NW sector of Gran Canaria Canaria (cf. Galindo et al. 2011)

							Thickness of main lithologies (m)							
Cross section	Reference number	IGME Borehole	X (UTM)	Y (UTM)	Z (m)	P (m)	SH	CR	CPRN	FDLP	CRN	C1-FF	C1-FRT	C1-FB
1	1	0639 TP	432368	3107372	113	105	–	–	–	–	–	–	–	105
	2	0640 TP	433290	3106562	177	72	–	–	–	–	–	–	–	72
	3	1625 TP	434575	3105432	261	120	–	116	–	–	–	–	–	4
	4	3425 TP	436979	3103318	1,021	300	–	–	220	–	80	–	–	–
	5	2411 TP	437112	3103202	1,076	464	–	–	304	–	160	–	–	–
	6	1487 TP	437247	3103082	1,068	251	–	–	236	–	–	–	–	–
	7	1492 BTP	437504	3102856	1,090	236	–	–	236	–	–	–	–	–
	8	1430 TP	438147	3102291	1,246	336	–	–	111	–	225	–	–	–
	9	3394 TP	438560	3101928	1,271	210	–	–	75	–	135	–	–	–
	10	5363 BTP	441123	3099265	1,596	237	–	–	7	–	230	–	–	–
2	11	0143 CP	437414	3113381	123	107	10	0	90	–	–	7	–	–
	12	0410 TP	437674	3112703	151	126	14	0	112	–	–	–	–	–
	13	0103 TP	437883	3112156	313	81	–	–	0	–	–	73	–	8
	14	4769 TP	438609	3110256	447	298	–	–	200	–	–	98	–	0
	15	2077 TP	438669	3110099	497	320	–	–	70	–	–	80	–	170
	16	0675 TP	438953	3109356	539	369	–	–	40	–	–	150	–	179
	17	2558 TP	439746	3107280	766	452	–	–	212	–	–	240	–	–
	18	2224 TP	439768	3107224	816	401	–	–	401	–	–	–	–	–
	19	3179 TP	440270	3105910	811	314	–	–	314	–	–	–	–	–
	20	3536 TP	440429	3105493	865	250	–	–	235	–	15	–	–	–
	21	5503 TP	440554	3105166	856	250	–	–	80	–	170	–	–	–
	22	3228 TP	440605	3105033	858	302	–	–	69	–	233	–	–	–
	23	0739 TP	440893	3104280	904	331	–	79	252	–	–	–	–	–
	24	3032 TP	441496	3102702	894	155	–	–	–	–	155	–	–	–
	25	1449 TP	441684	3102211	1,032	140	–	–	–	–	140	–	–	–
	26	3078 TP	441712	3102138	893	91	–	–	–	–	91	–	–	–
	27	3177 TP	441891	3101669	980	157	–	–	–	–	157	–	–	–
	28	3098 TP	441998	3101388	1,039	138	–	–	–	–	138	–	–	–
	29	3033 BTP	442064	3101217	1,107	146	–	–	–	–	146	–	–	–
3	30	3033 TP	441409	3100964	1,164	118	–	–	–	–	118	–	–	–
	31	3033BTP	441526	3101143	1,107	146	–	–	–	–	146	–	–	–
	32	3098 TP	441733	3101459	1,039	138	–	–	–	–	138	–	–	–
	33	3177 TP	442027	3101908	980	157	–	–	–	–	157	–	–	–
	34	1449 TP	442033	3101917	1,032	140	–	–	–	–	140	–	–	–
	35	3078 TP	442227	3102214	893	91	–	–	–	–	91	–	–	–
	36	1450 TP	442436	3102534	868	100	–	18	–	–	82	–	–	–
	37	3391 TP	442982	3103369	938	198	–	–	–	–	198	–	–	–
	38	3573 TP	443437	3104063	869	149	–	–	–	–	149	–	–	–
	39	3287 TP	443445	3104076	836	263	–	–	–	–	263	–	–	–
	40	1340 TP	443735	3104518	755	207	–	–	43	–	164	–	–	–
	41	1277 TP	443778	3104585	782	180	–	–	180	–	–	–	–	–
	42	0269 CP	444038	3104982	612	50	–	50	–	–	–	–	–	–
	43	1918 TP	444300	3105382	752	203	–	–	–	–	203	–	–	–
	44	1733 TP	444466	3105635	804	105	–	–	40	–		65	–	–
	45	0755 TP	445256	3106843	633	172	–	–	110	26	20	–	–	16
	46	1485 TP	445496	3107209	587	156	–	–	89	–	67	–	–	–
	47	1993 TP	446018	3108007	461	219	–	–	35	–	74	111	–	–

(*continued*)

Table 1 (continued)

Cross section	Reference number	IGME Borehole	X (UTM)	Y (UTM)	Z (m)	P (m)	Thickness of main lithologies (m)							
							SH	CR	CPRN	FDLP	CRN	C1-FF	C1-FRT	C1-FB
4	48	5247 TP	437124	3104867	974	280	–	–	280	–	–	–	–	–
	49	3515 TP	437399	3105124	1,052	382	–	–	80	–	302	–	–	–
	50	3397 TP	437595	3105308	970	300	–	–	300	–	–	–	–	–
	51	3346 TP	438743	3105925	948	343	–	–	343	–	–	–	–	–
	52	3310 TP	438895	3105904	921	330	–	–	126	–	204	–	–	–
	53	3179 TP	440042	3105746	811	314	–	–	314	–	–	–	–	–
	54	3536 TP	440158	3105730	865	250	–	–	235	–	15	–	–	–
	55	4392 TP	441128	3105595	779	282	–	–	90	–	192	–	–	–
	56	0586 TP	443613	3105252	597	83	–	–	29	–	54	–	–	–
	57	0269 CP	443637	3105248	612	50	–	50	–	–	–	–	–	–
	58	2178 TP	443687	3105241	605	113	–	–	6	39	67	–	–	–
	59	1918 TP	444216	3105168	752	203	–	–	–	–	203	–	–	–
	60	1733 TP	444798	3105088	804	105	–	–	40	–	–	65	–	–
5	61	2196 TP	434952	3111928	111	80	10	–	70	–	–	–	–	–
	62	0833 TP	436025	3113125	87	62	29	–	23	–	11	–	–	–
	63	2037 TP	436283	3113414	101	84	7	–	77	–	–	–	–	–
	64	0830 TP	436333	3113469	110	75	–	–	75	–	–	–	–	–
	65	0213 TP	441649	3113031	17	19	–	–	–	–	–	19	–	–
	66	0395 TP	441978	3112977	10	187	–	–	–	–	–	5	–	182
	67	0044 SI	443811	3112677	48	42	–	–	33	–	9	–	–	–
	68	0913 TP	444346	3112589	99	65	–	–	65	–	–	–	–	–
	69	0021 TP	444748	3112523	36	27	–	–	–	–	27	–	–	–
	70	0010 TP	446388	3112255	112	111	–	–	–	–	78	33	–	–
	71	5899 TP	448486	3111911	143	137	–	97	30	–	10	–	–	–

C1-FB Cycle I. Basaltic Formation, *C1-FF* Cycle I. Phonolitic Formation, *C1-FRT* Cycle I. Rhyolitic-Trachytic Formation, *CPRN* Post-Roque Nublo Cycle, *CR* Recent Cycle, *CRN* Roque Nublo Cycle, *FDLP* Las Palmas Detritic Formation, *SH* Holocene sediments, *P* depth of borehole, *Z* height of the top of the borehole above sea level

Fig. 2 Panoramic view of the NW sector of Gran Canaria between Gáldar and Agaete villages, showing the erosional surfaces (S_0, S_2, S_4 and S_6) and the location of the rock slides deposits. The photo has been taken from Montaña Almagro

stages (Roque Nublo, Post-Roque Nublo and Recent cycles) have been gradually embedded. Hence, the most recent surface (S_6) defines the most embedded reliefs in the NW sector of the island. We have noticed a temporal alternation between these erosion surfaces and the stratigraphic unconformities (S_1, S_3 and S_5), which are recognized later with lithological cross sections and interpreted as the sliding surfaces. This alternation of forms and processes support the hypothesis of large island flank instability along several volcanic cycles. This idea would be compatible with the existence of one or more translational rock slides with a very slow rate of movement. Triggering factors for this type of instability would be very old, reducing their energy. This fact suggests three remarks: (a) the recent processes of erosion could be able to generate new morphologies but not to remove the inherited forms, (b) the lava flows of the most recent cycles

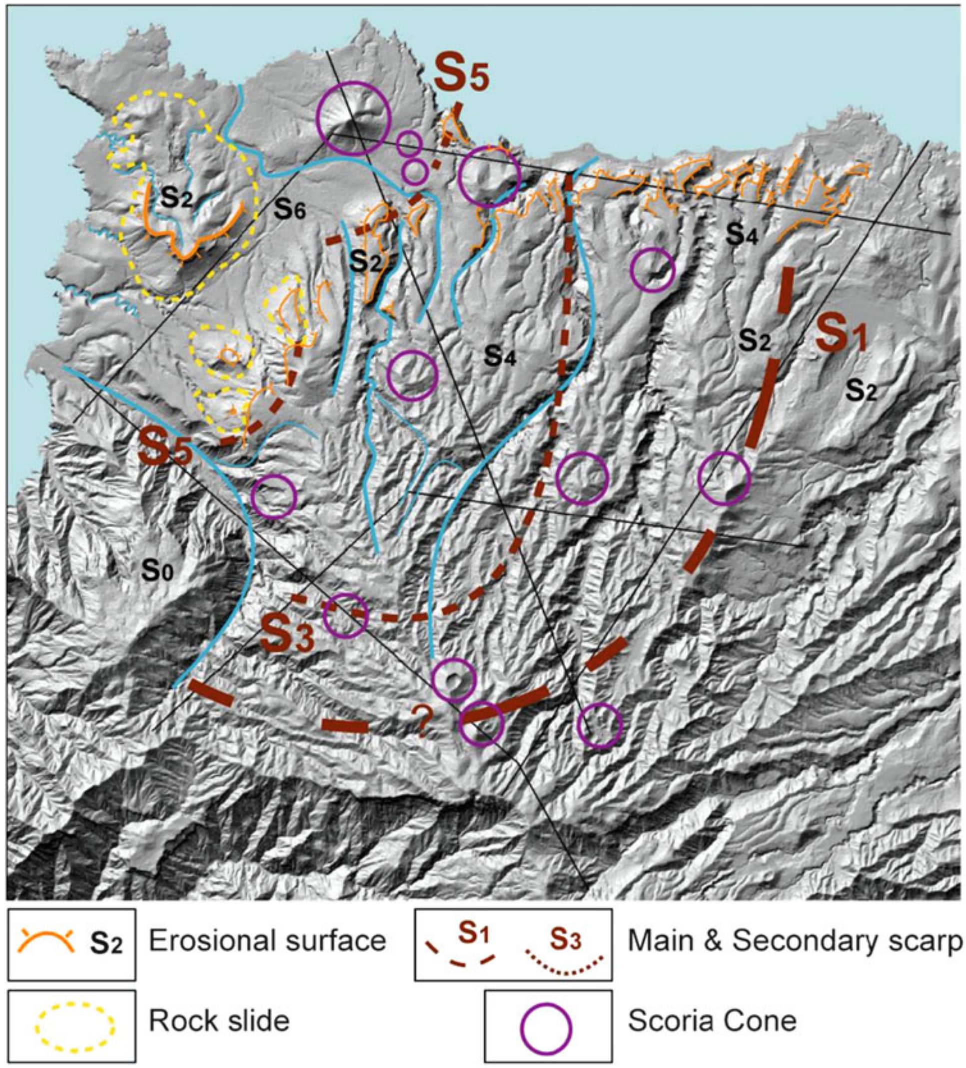

Fig. 3 Shaded relief image showing the main geomorphological features observed at the NW sector of the Gran Canaria (see text for more details)

are embedded in the preexisting reliefs, and (c) the old sliding surfaces cover a greater extent than modern sliding surfaces.

The wide NE-SW valley is flanked by steep scarps, where old materials of the Cycle I outcrop (Figs. 3 and 4). These materials are difficult to correlate topographically with the surface of summits described above (S_0) and, in addition, the southern scarp is covered by recent rock slides. These observations suggest that this valley could be the geomorphologic evidence of a secondary scarp (S_5) that could be developed at the foot of a prior sliding mass (S_3), resulting in a large rocky block (Montaña Almagro) disconnected of the main trend of the topography (Figs. 2 and 3). This hypothesis would be in agreement with the debris-avalanche deposits identified by other authors at the foot of the island shelf, between Agaete and Gáldar (Acosta et al. 2003).

Along the northern coast, there is a very steep escarpment with a height of several hundred meters. This relief has been interpreted as a result of a general tilt of the island to the south (Menéndez et al. 2008). However, the offshore investigations of the island shelf show the existence of several debris avalanche deposits close to Galdar (Acosta et al. 2003). Therefore, the complexity of the vertical movements experienced by the volcanic terrains indicates a polygenic character to the morphogenesis of the relief. The height of these coastal cliffs is compatible with the occurrence of an old flank slide and a later differential rising of a coastal block of the island.

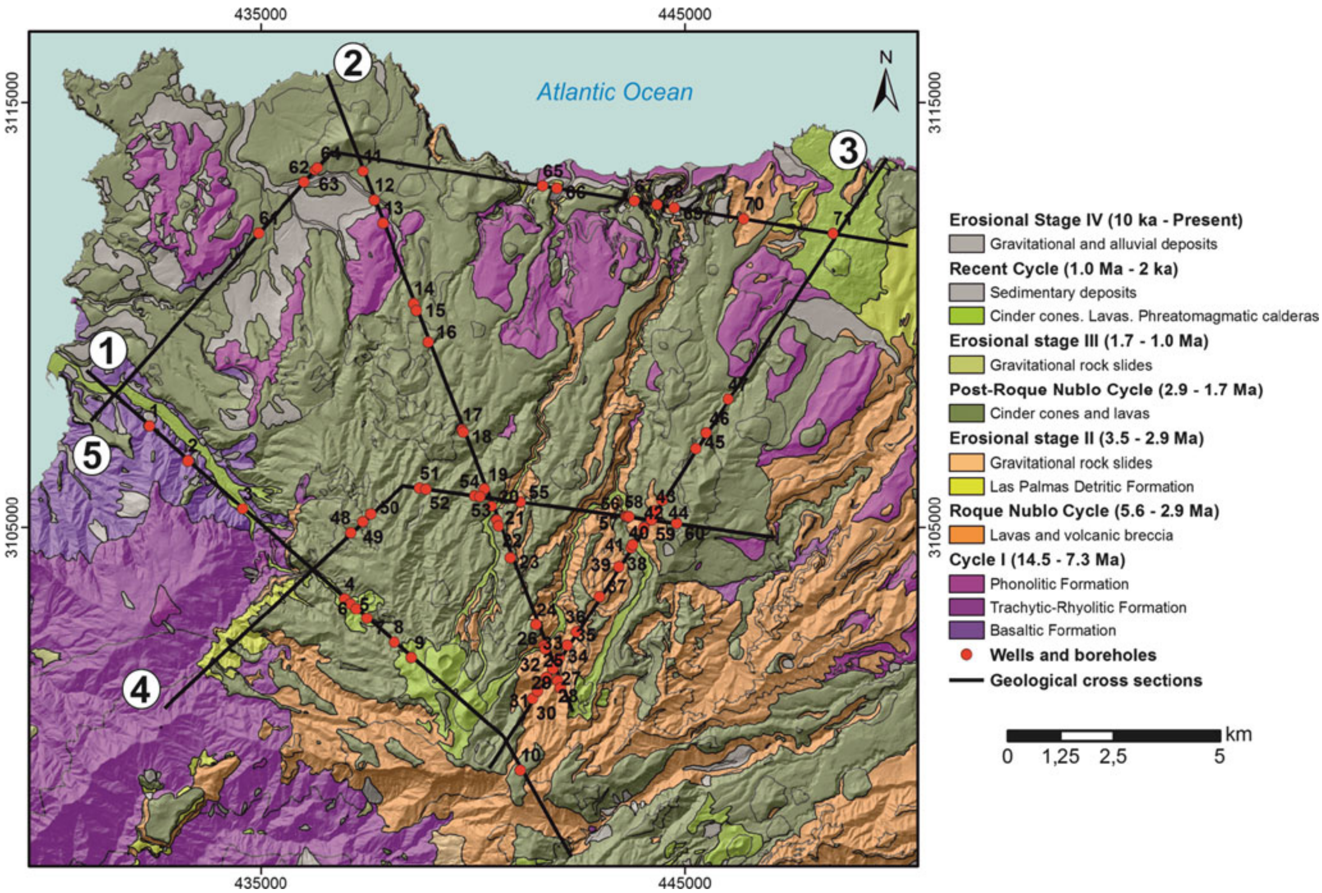

Fig. 4 Map of the superficial geology of the NW sector of Gran Canaria showing the main volcanic and erosional stages. The location of the five lithological cross-sections (*black lines*) and the 71 wells and boreholes (*red dots*) are also depicted

Geological Investigations

Lithological cross-sections (Fig. 5) show sharp changes in the thickness of the formations of the Roque Nublo and Post-Roque Nublo cycles. The contact between the two formations suggests the existence of a paleo-relief compartmentalised in wide flat-bottomed valleys, separated by residual reliefs. This paleo-relief defines an erosion surface (S_3) embedded between the remains of two previous structural surfaces: the top of the Roque Nublo Cycle (S_2) and the surface of summits (S_0).

The age of the paleorelief is implied by a recent structural surface (S_4) which is defined by the lava flows of the Post-Roque Nublo Cycle of Pleistocene age. A thinning of the prior substratum, defined by the most recent materials of the Cycle I (Trachytic-Rhyolitic and Phonolitic formations), has been found below the paleo-relief described above (S_3). This discontinuity (S_1) confirms the occurrence of previous translational rock slides of Miocene to Pliocene age.

Discussion and Conclusions

The large flank instability found in the northwest sector of the Gran Canaria Island would be related to the intrusion of dykes during the end of the Cycle I and suggests a NE-SW extensional regime, which could be related to a central NW-SE fault zone that divides the island in two sectors: northeast and southwest. This stress regime seems to be established for an extended period of time, suggesting the coexistence of other triggering factors such as the lateral spreading of the volcanic edifice due to the combined effect of the weight of the volcano and the time. Moreover, the existences of two different lahar deposits (Las Palmas Detritic Formation) in the stratigraphic sequence of the island (Balcells et al. 1992) suggest the occurrence of highly explosive eruptions. The earthquakes related to these explosive periods could also be considered as a triggering factor of the large flank instabilities in Gran Canaria Island.

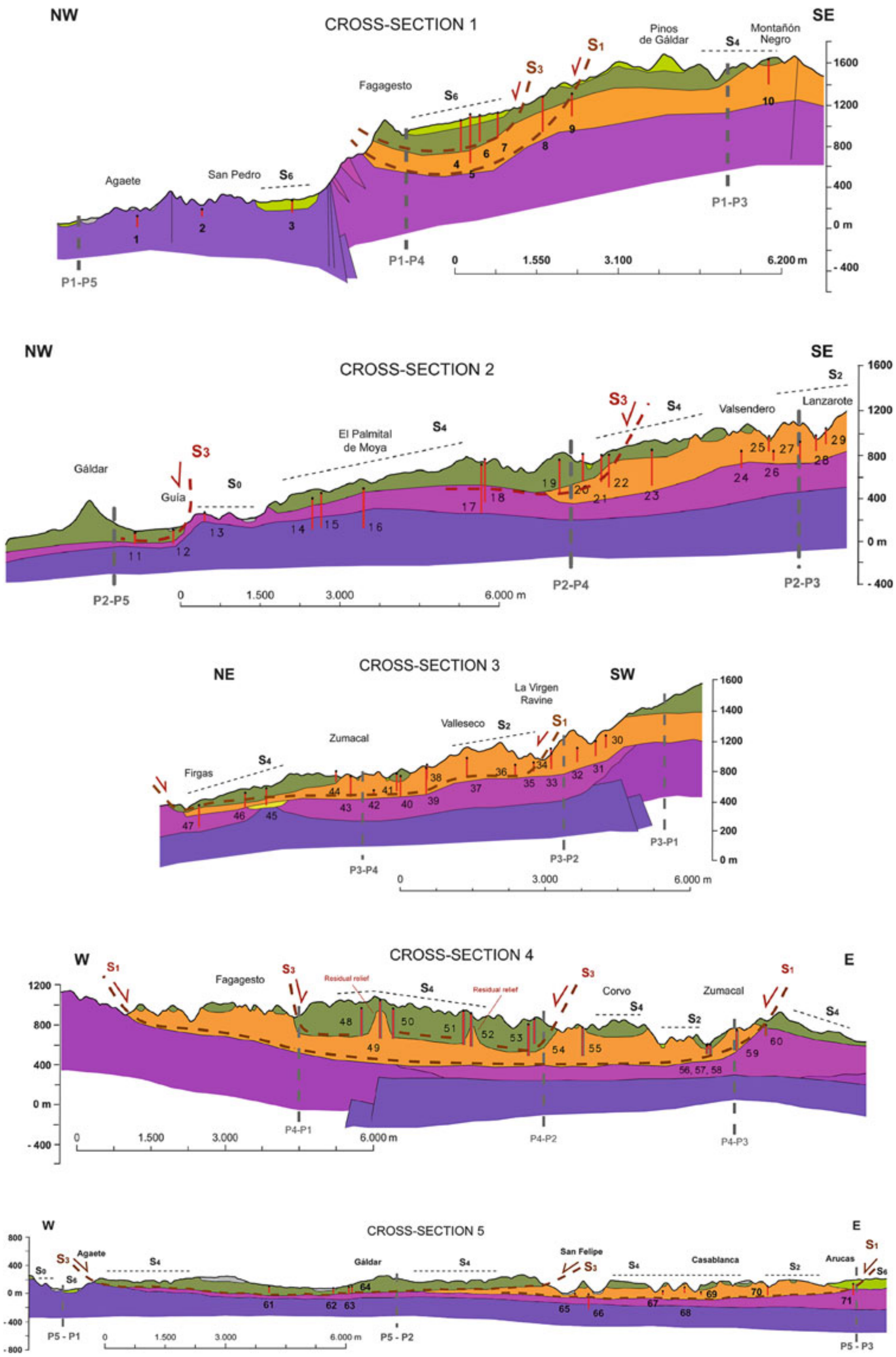

Fig. 5 Longitudinal (1–3) and transversal (4–5) cross-sections derived from the wells and boreholes data (*red lines*). See Fig. 4 for localization

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