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Palaeobiodiversity and Palaeoecology of the Last Interglacial (MIS 5e) Marine Fauna and Flora from San Juanito (Punta del Hidalgo, Tenerife Island) in the Canary Islands

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Abstract

The Macaronesian archipelagos host exceptionally well-preserved coastal sedimentary deposits formed during the warmest period of the Last Interglacial episode, the Marine Isotope Substage 5e (MIS 5e). Numerous MIS 5e fossiliferous outcrops occur, scattered across several islands of the Canary Archipelago. Among these is San Juanito, a small outcrop located in the eastern sector of Punta del Hidalgo (northeast Tenerife Island), where MIS 5e sediments are distributed over an area of approximately 480 m^2. A multidisciplinary study was conducted, aiming to: (i) determine the age of the fossiliferous sediments; (ii) define the stratigraphic relationships between the sedimentary deposit and the underlying/overlying volcanic sequences; (iii) assess the taxonomic richness and the functional palaeobiodiversity of this palaeosite; and (iv) provide a comprehensive palaeoecological reconstruction of the MIS 5e environment. Based on two key ecostratigraphic indicator

species for the Canarian MIS 5e, the San Juanito sequence is here assigned to the Last Interglacial. Qualitative sampling yielded forty mollusc taxa, including three gastropods that represent new records—*Alvania johannae* Moolenbeek & Hoenselaar, 1998, *Krachia tiara* (Monterosato, 1874), and *Barleeia unifasciata* (Montagu, 1803)—bringing the current MIS 5e checklist for the Canary Islands to 202 gastropods and 80 bivalves. The highly cemented matrix of the San Juanito deposits prevented the collection of standardized 1 kg bulk sediment samples. Nevertheless, we strongly recommend adopting this quantitative approach in future studies of suitable MIS 5e outcrops across the archipelago. The faunal assemblage indicates that the San Juanito region was dominated by rocky shores during the MIS 5e, much like today. This paleoenvironmental reconstruction is based on the high frequency of species associated with hard substrates—including echinoids, vermetids, fissurellids, and patellids—and the overwhelming dominance (95%) of epifaunal gastropods.

Keywords: MIS 5e; Last Interglacial; faunal checklist; palaeoecological reconstruction; Canary Islands

1. Introduction

The warmest period of the Last Interglacial, corresponding to Marine Isotope Substage 5e (MIS 5e), represents one of the most relevant natural analogues for current global warming. Global thermal conditions during that interval were comparable to or slightly warmer than those foreseen in the future. Dated to approximately 129–116 ka [1–3], the MIS 5e interval is characterized by a eustatic sea-level highstand that has been globally estimated at +2 to +9 m relative to present mean sea level, with locally higher peaks depending on the model and proxy record considered [4].

In the northeastern Atlantic, and particularly within the Macaronesian geographic region, which encompasses five archipelagos (i.e., the Azores, Madeira, Selvagens, Canaries, and Cabo Verde), exceptionally well-preserved coastal sedimentary deposits formed during the MIS 5e. The interaction between tectonics, volcanism, coastal dynamics (erosion and sedimentation), and eustatic fluctuations [5] resulted in emergent marine sequences of high palaeoecological [6–11] and palaeobiogeographic significance [12–16]. This is especially true in the context of sea-level dynamics and associated climatic changes during the Quaternary.

Within the Canary Islands, Lanzarote and Fuerteventura host the most extensive MIS 5e coastal deposits, owing to their ancient geological age, relative tectonic stability during the late Pleistocene, and prevalence of coastal platforms suitable for marine sedimentation [17]. These deposits have long been recognized as raised beaches of the Upper Pleistocene or Last Interglacial, traditionally identified by the presence of the thermophilic gastropod *Thetystrombus latus* (Gmelin, 1791), previously referred to as *Strombus bubonius* or *S. latus* [18,19]. Meco & Petit-Maire [20] grouped these deposits under the term "Jandiense", defining a characteristic stratigraphy consisting of a basal level of strongly cemented, light-yellow calcarenites with scarce fauna, overlain by fossil-rich conglomerates. Their exposures may reach elevations of 5–6 m above present sea level (a.s.l.). U/Th dating carried out by Meco and colleagues on MIS 5e deposits from the Matas Blancas palaeosite (southeastern Fuerteventura) [8] suggested a single sea-level highstand during the Last Interglacial. In contrast, Zazo and colleagues proposed the occurrence of multiple sea-level and climatic oscillations during MIS 5e in Fuerteventura, Lanzarote, and Tenerife, based on U/Th ages and sedimentary facies analyses [21]. More recently, Martín-González and colleagues reviewed the coastal outcrops of Fuerteventura, significantly expanding the

number of exposures attributed to MIS 5e and documenting their fossil content in greater detail [22].

In contrast with Lanzarote and Fuerteventura, Tenerife—the oldest of the western Canary Islands, with an estimated age of approximately 12 Ma [23]—exhibits a comparatively limited marine fossil record [24]. This is likely due to the island's proximity to its volcanic constructional maximum during the Quaternary [25], which probably hindered the formation of stable sedimentary platforms. Studies on local Quaternary coastal deposits are scarce. Zeuner was the first to identify three marine erosion surfaces based on altimetric criteria [26], assigning them broadly to the Quaternary. Subsequent palaeontological analyses focused on selected deposits, notably Las Teresitas and Tachero [24,27,28]. More recently, other authors [29,30] provided detailed stratigraphic descriptions and chronological data for several of these coastal outcrops, and Johnson and colleagues [31] discussed the encrustations dominated by crustose coralline red algae on coastal boulders from the Last Interglacial epoch at Tachero.

Approximately half of the coastal deposits in Tenerife occur on the slopes of the Anaga Peninsula in the northeast and the remainder along the southwestern coast, enabling a comparison of their faunal composition. This spatial framework enables palaeoenvironmental reconstructions and interpretations of such deposits and the assessment of marine malacological palaeobiodiversity on opposite island flanks [32]. Additionally, these data facilitate biostratigraphic correlations with coeval deposits across other Macaronesian archipelagos. Two comprehensive field campaigns were designed to sample Last Interglacial deposits across the Canary Islands in October 2023 and September 2025. The San Juanito locality in Tenerife was explored by a joint multidisciplinary team with the specific aim to: (i) constrain the age of the fossiliferous strata; (ii) resolve the stratigraphic architecture between the sedimentary unit and the adjacent volcanic sequences; (iii) evaluate taxonomic richness and functional palaeobiodiversity; and (iv) reconstruct the local MIS 5e palaeoenvironment.

Geographical and Geological Setting

Tenerife is the largest island of the Canary Archipelago, located about 300 km off the northwest coast of Africa (Figure 1A). With an area of 2034 km^2, the island has a roughly triangular outline dominated by Mount Teide, which rises to 3715 m a.s.l. at its centre (Figure 1B). The relief is strongly asymmetric, characterized by steep coastal cliffs, large volcanic edifices, and a dense network of ravines radiating mainly from the central volcanic complex. Within this framework, the Anaga massif, located in the northeastern part of Tenerife, represents one of the oldest volcanic domains of the island (4.9–3.9 Ma [23]). It covers an area of approximately 140 km^2 and is characterized by a highly dissected relief, with sharp ridges and deep, narrow ravines radiating toward the coast. Elevations reach up to 1024 m a.s.l. at Cruz de Taborno, and the massif displays steep coastal cliffs and an irregular coastline shaped by long-term erosion and structural control [33].

The volcanic platform of Punta del Hidalgo (Figure 1C,D) and the cinder cone of Las Rosas were formed during a phase of Quaternary volcanic reactivation within the older volcanic Anaga massif. Detrital formations occur along hillsides and valley floors (talwegs), and most of the present-day shoreline is mainly composed of cliffs, pebble beaches and wave-cut platforms. The Punta del Hidalgo coastal platform was formed by lava flows emitted from the Las Rosas volcano, a small monogenetic Pleistocene edifice within the Anaga massif, whose lavas reached the shoreline and built a volcanic delta [34]. The area includes the San Juanito palaeosite, located near the hermitage of San Juanito, within the Punta del Hidalgo eastern coastal sector (Figure 1D).

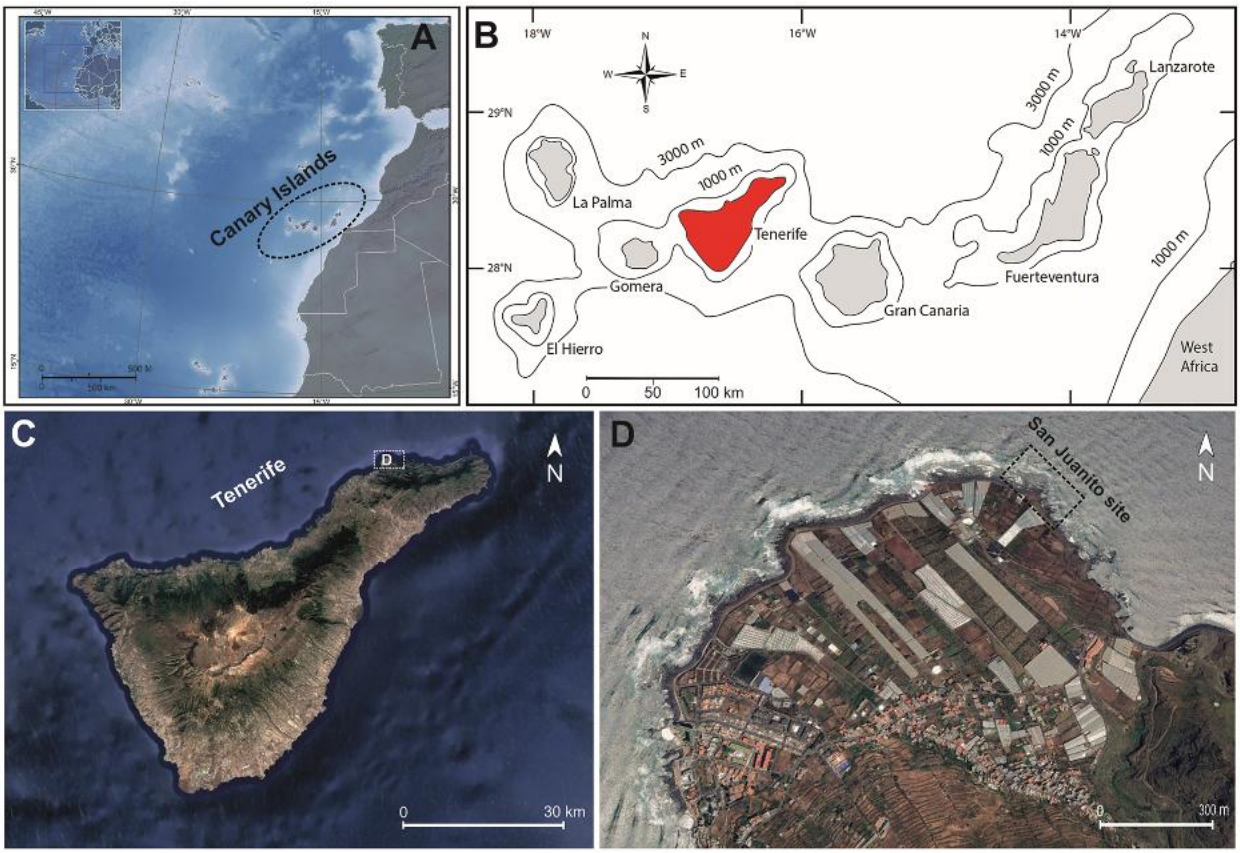

Figure 1. Location maps of the Canary Islands in the Atlantic. (**A**): The Canary Islands, in the East Atlantic. (**B**): The Canary Archipelago showing the location of Tenerife Island (highlighted in red). (**C**): Detailed map of Tenerife showing topography and indicating the location of the study site at San Juanito, Punta del Hidalgo. (**D**): Close-up view of the study locality at San Juanito, on the north coast of Tenerife.

2. Materials and Methods

The San Juanito outcrop (Figure 2A,B) was studied during the "PaleoMACA" 2023 workshop held in Tenerife (22–25 October 2023), and subsequently, during the 2nd and the 3rd International Workshops "Palaeontology in Canary Islands", in October 2023 and September 2025. Research focused on reconstructing the overall structure, geometry, and field relationships between the sedimentary deposit and the underlying volcanic sequences. Attention was paid to documenting observed sedimentary structures, the lateral and vertical continuity of facies, and the stratigraphic position and taphonomic features of the fossil assemblages. Rock slabs were collected from the different sedimentary facies for thin-section analysis, and representative sedimentary structures were documented through field photography.

The uppermost elevation of the MIS 5e fossiliferous deposits was measured with GNSS (Global Navigation Satellite System), using a Topcon HIPER_SR receiver mounted on a 1.8 m fixed-height survey pole stabilized by a tripod. The raw data were processed using the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) online service, provided by Natural Resources Canada (NRCan). Data were reduced in static mode using IGS final orbit and clock products, with coordinates referenced to the ITRF2020 (IGS20) frame. Ellipsoidal heights (PPP GNSS solutions) were referred to present-day sea-level heights (orthometric heights) using a global satellite geoid model (EIGEN-6C3stat model).

Figure 2. Features of the exposures at San Juanito. (**A**): General view of the MIS 5e outcrop, with the Roque Dos Hermanos hill (344 m) in Punta del Frontón visible in the foreground, and the Picacho Magín hill (253 m) in the background. (**B**): Detail of the best exposed MIS 5e sector at San Juanito. (**C**,**D**): Photographs illustrating the high degree of cementation of this Last Interglacial deposit. In (**C**), a bivalve shell bioeroded with clionaid sponge boring *Entobia* isp. (see red arrows). In (**D**), a concave-up patellid gastropod shell (red arrow) suggesting settling through the water column.

Macrofossils were photographed in situ, prior to extraction, during qualitative sampling across the outcrop. Due to the high degree of cementation of fossil-bearing deposits (Figure 2C,D), standardized 1 kg bulk samples could not be obtained for quantitative analysis. Instead, qualitative samples were examined for fossils in the laboratory, with all collected mollusc specimens identified to the lowest possible taxonomic level. These data were compiled into a checklist and supplemented with records from the literature, from the Macaronesian Palaeobiodiversity Database (MPDb, https://macpaleo.uac.pt/) and a survey of the fossil collection at the Museo de Ciencias Naturales de Tenerife (MCNT). The best-preserved specimens were photographed, including the new MIS 5e records from Tenerife.

Functional traits of molluscs were compiled from two master databases curated by the first author. Currently, these datasets comprise information on 1943 recent shallow-water gastropods spanning depths of 0–50 m [16] and 1829 recent shallow-water bivalves from depths of 0–100 m [35]. For gastropods, traits included larval development mode (planktotrophic vs. non-planktotrophic), shell composition (aragonite vs. low-Mg calcite), locomotion (actively mobile, slow-moving, facultatively mobile, or stationary), life habit (epifaunal vs. semi-infaunal), diet (carnivore, herbivore/grazer, or suspension feeder), and substrate preference (hardground (including rocks, shells, corals, gorgonians, coralline algae, rhodoliths, etc.), gravel/pebbles, coarse sand, fine sand, sandy-mud to muddy-sand, algae, and macrophyte meadows). For bivalves, traits included shell composition (aragonite vs. low-Mg calcite), locomotion (facultatively mobile or stationary), life habit (epifaunal, boring, or infaunal), diet (suspension feeder or omnivore), and substrate (hardground, gravel/pebbles, coarse sand, fine sand, sandy-mud to muddy-sand, and macrophyte meadows).

Mollusc nomenclature follows MolluscaBase (https://www.molluscabase.org/), and the World Register of Marine Species (WoRMS) database (http://www.marinespecies.org/) was used for the remaining invertebrate species. Algal nomenclature follows AlgaeBase [36]. All material is deposited in the fossil collections of the Department of Biology, University of the Azores (Ponta Delgada, São Miguel Island), under reference number DBUA-F 1709.

3. Results

3.1. Field Observations, Lithology, Microfacies and Stratigraphy

The San Juanito site is located on the north coast of Tenerife (28.577487° N, 16.318705° W). The MIS 5e deposits are exposed at a maximum elevation of 2.55 ± 0.12 m above present mean sea level, have a lateral extension of about 70 m, and extend approximately 20 m seaward of the San Juanito hermitage (Figures 2B and 3A). The sedimentary succession is discontinuously exposed over an area of approximately 480 m^2. The MIS 5e deposits rest on an uneven basaltic substrate associated with the Las Rosas volcano lava delta, generally inclined toward the sea (Figure 3A–C), and are partially covered by unconsolidated sandy–pebbly recent sediments. In the lower part of the succession, the deposits consist of brownish calcarenites with dispersed reddish scoria (Figure 4A), boulders (Figure 4B), and smaller basalt clasts, as well as bioclasts (Figure 4C–E). Locally, coarse volcanic material is more abundant and forms a conglomerate supported by a calcarenitic matrix. These deposits attain a maximum thickness of about 1 m and are here referred to as the pre-MIS 5e deposits.

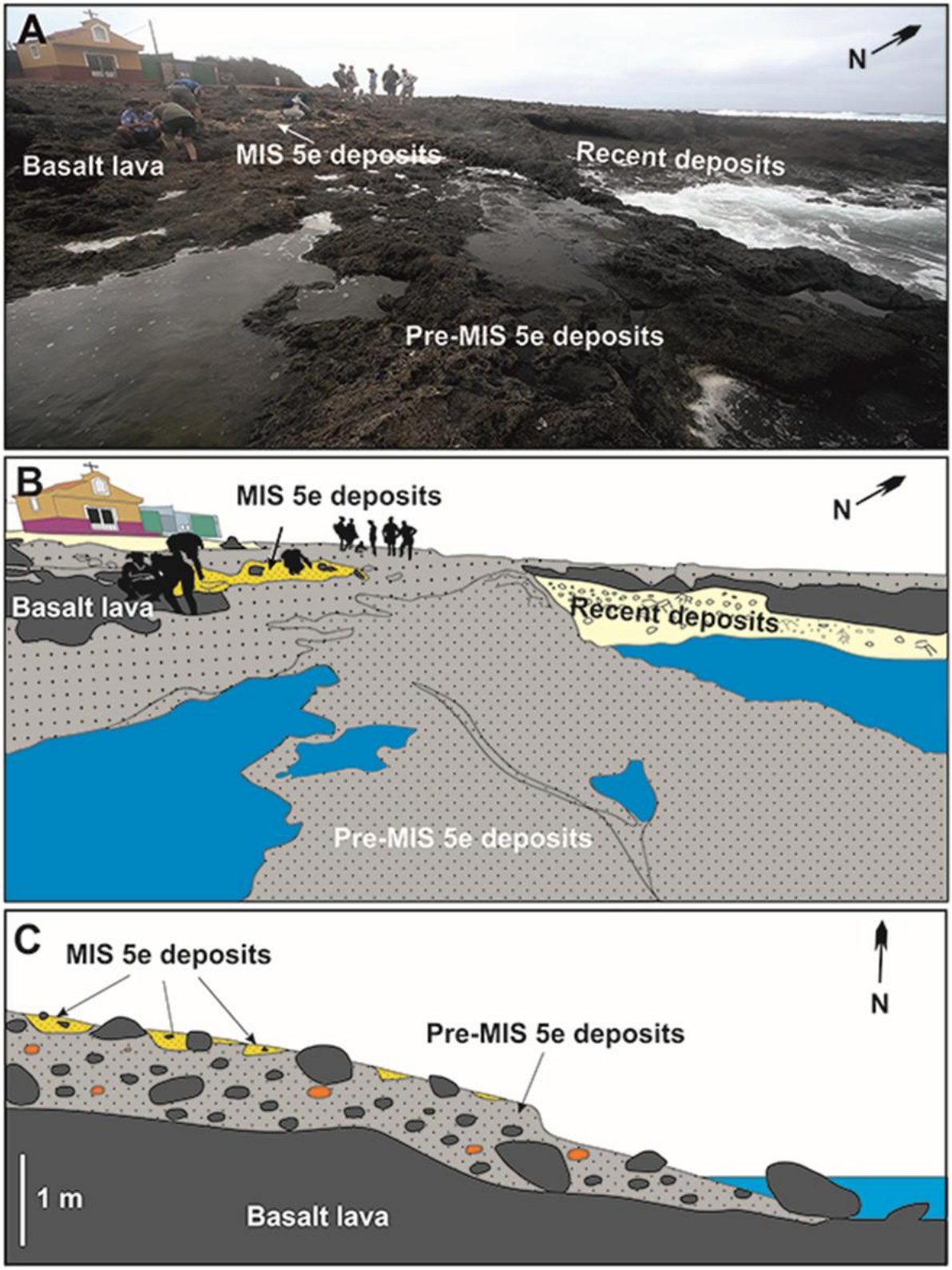

Figure 3. Spatial relationships between the pre-MIS 5e and the MIS 5e deposits. (**A**): The MIS 5e deposits at San Juanito rest on an irregular basaltic substrate that generally slopes seaward. Much of this basal substrate is overlain by coarse volcanic material, forming a conglomerate supported by a calcarenitic matrix (pre-MIS 5e deposits). (**B**,**C**): Idealized sections showing the spatial distribution of the basaltic platform, the pre-MIS 5e conglomerate, and the subsequent MIS 5e and recent successions.

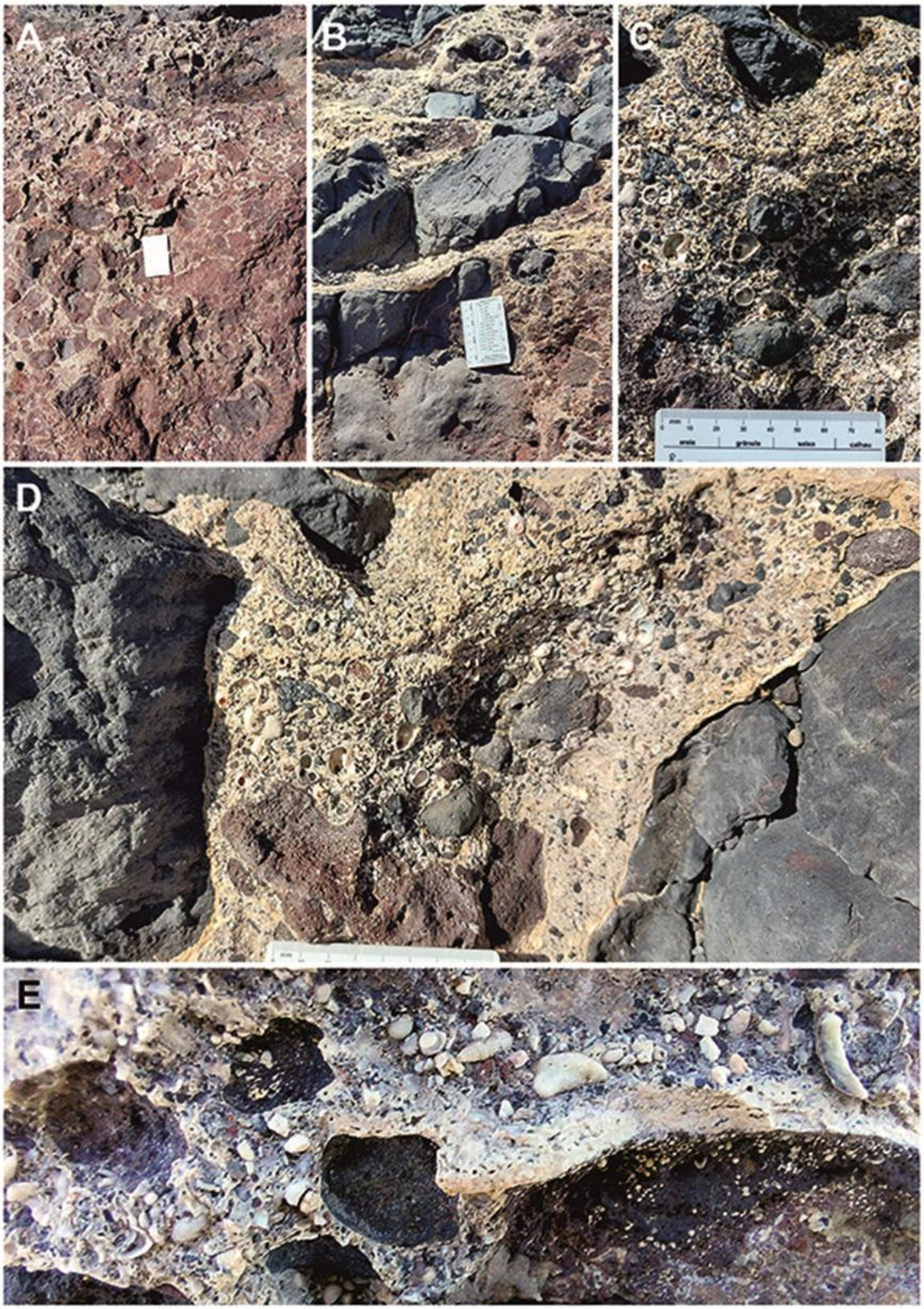

Figure 4. Pre-MIS 5e (**A**,**B**) and MIS 5e sediments (**C**–**E**) at San Juanito. (**A**): Brownish calcarenites with dispersed reddish scoria. (**B**): Basaltic boulders and smaller clasts. (**C**–**E**): Abundant, highly cemented calcarenite, containing abundant mollusc gastropods and fewer disarticulated bivalve valves. Note the presence of the supralittoral gastropod *Tectarius triatus* (Te) and the bivalve *Cardita calyculata* (Ca). (**A**–**D**) White scale card: 80 mm.

In thin section (Figure 5), the pre-MIS 5e calcarenites are bioclastic–peloidal packstones according to the classification by [37], containing a minor admixture (up to a few percent) of millimetre- to submillimetre-sized rounded to subrounded basalt, brownish scoria clasts, and other volcanoclastic (tuffitic) grains (Figure 5A–E). The bioclast assemblage is dominated by coralline algae and bivalve shell debris. Less common components include echinoid spines (*Arbacia* sp.), echinoderm plates, small gastropod shells (Figure 5B), serpulid polychaete tubes, bryozoans, and tests of benthic calcareous foraminifers. Bioclasts are typically fragmented and abraded, and commonly show recrystallization, micritization envelopes (Figure 5E), and occasional microborings (Figure 5B). The matrix is composed mostly of micritic, irregular peloids, which are up to a few tens of microns in size (Figure 5C,D). Among the coralline algae, *Sporolithon* sp. (Figure 5D), *Amphiroa* sp. (locally overgrown by *Lithoporella* sp.; Figure 5C), and *Lithophyllum* sp. [probably *Lithophyllum prototypum* (Foslie) Foslie, 1905; cf. Figure 5E] have been identified. At the outcrop scale, some gastropod shells display clionaid sponge borings (*Entobia* isp.). Rarely, some boulders exhibit patches of coralline algal crusts.

The whitish MIS 5e calcarenites occur on top of the pre-MIS 5e deposits. They form pockets in the underlying pre-MIS 5e deposits containing dispersed basaltic pebbles and boulders. The pockets fill shallow depressions and do not exceed 30 cm in thickness. The vertical range of MIS 5e pockets is approximately 110 cm (Figure 3C). Basal parts of the pockets tend to show coralline algal encrustations.

In thin section (Figure 6), the MIS 5e calcarenites are bioclastic packstones, locally bindstones, and contain a small proportion of volcanic and volcanoclastic grains of variable size (Figure 6A–E). The bioclasts are dominated by fragmented coralline algae and gastropod shells, with bivalves being less abundant and hardly cemented to the substrate (Figure 4C–E). Coralline algae are generally poorly preserved but include possible *Mesophyllum* sp. (Figure 6E) and representatives of the subfamily Mastophoroideae. Echinoid spines represented by the shallow-water species *Paracentrotus lividus* (Lamarck, 1816) and *Arbacia lixula* (Linnaeus, 1758) are common, whereas benthic calcareous foraminifers and serpulid polychaete tubes (Figure 6C) are rare. Most bioclasts are abraded, with micritized envelopes, and some have microborings (Figure 6C). Most mollusc shells are recrystallized. Some mollusc shells and echinoid spines are sufficiently well preserved to allow identification. Several volcanic pebbles and bioclasts are partially to fully encrusted by coralline algae (Figure 6C,D). In places, algal crusts coat adjacent bioclasts, forming bindstones sensu [38]. The matrix consists of micrite and, in places, micritic peloids. Several gastropod and bivalve shells observed in the exposure contain *Entobia* isp. produced by clionaid sponges (Figure 2C).

3.2. Palaeobiodiversity of the MIS 5e Marine Molluscs

In total, 40 taxa of molluscs are reported, comprising 38 species of gastropods and two bivalve species (Figures 7 and 8). The two bivalve species, *Cardita calyculata* (Linnaeus, 1758) (Figure 7X,Y) and *Ctena decussata* (O.G. Costa, 1829) (Figure 7S,T), have extensive chronostratigraphic ranges, spanning from the Miocene to Recent times. Among the gastropods, only one species (2.6%)—*Diodora graeca* (Linnaeus, 1758)—exhibits a broader range, extending from the Eocene to the Recent [16]. In contrast, four gastropods (10.6%) display ranges comparable to those of the bivalves (Miocene to the Recent), while the majority (33 species; 86.8%) are recorded from the Pleistocene to present times.

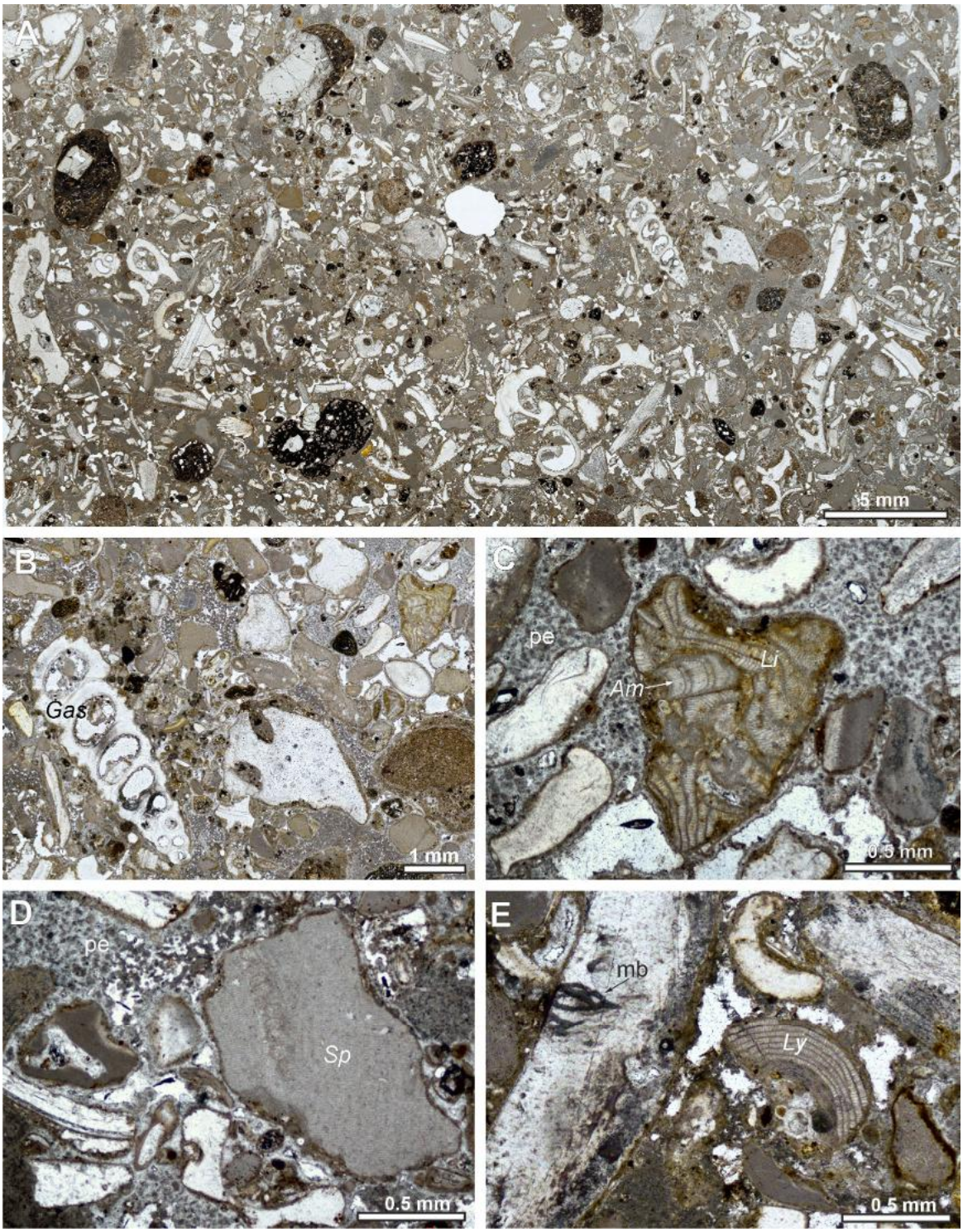

Figure 5. Microfacies of the pre-MIS 5e calcarenites. (**A**): The bioclastic–peloidal packstone with dispersed volcanic and volcanoclastic grains. (**B**): Gastropod (Gas) shell and abraded bioclasts. Echinoid plate in the middle with borings. Most bioclasts belong to coralline algae. (**C**): The coralline algae *Amphiroa* sp. (Am) overgrown by *Lithoporella* (Li) and peloids (pe) in the matrix. Note the regularly alternating tiers of long cells and short cells characteristic of the genus *Amphiroa*, and the large and vertically elongated cells, resembling a palisade fence, which are diagnostic for *Lithoporella*. (**D**): The coralline alga *Sporolithon* sp. (Sp) and peloids (pe) in the matrix. Note the characteristic line of large stalk cells. (**E**): Bioclasts of diverse origin with distinct micritization envelopes. The coralline alga, possibly *Lythophyllum prototypum* (Ly), and microborings (mb) in recrystallized mollusc shell.

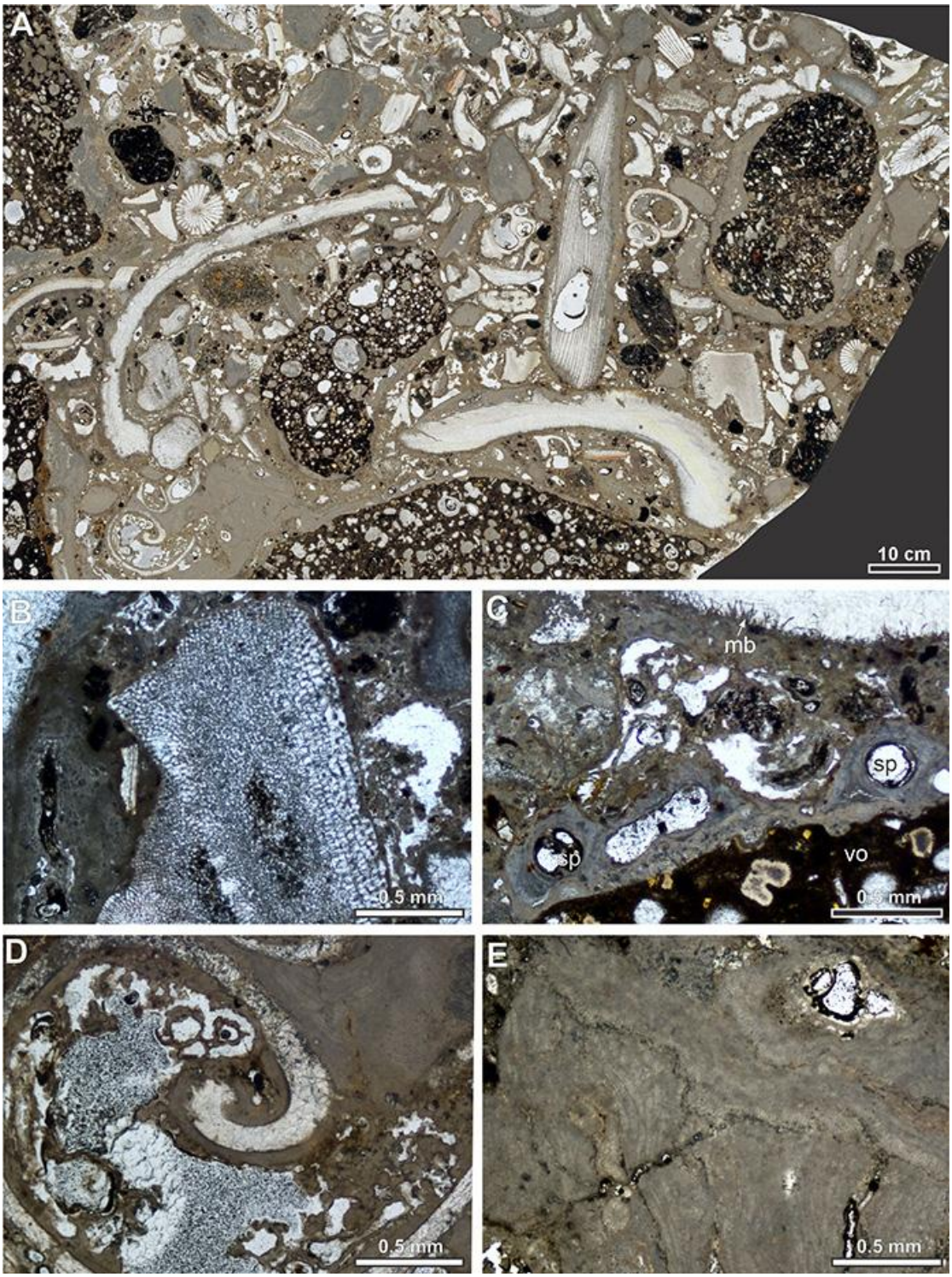

Figure 6. (**A**): Microfacies of the MIS 5e calcarenites. (**B**): An echinoid coronal plate in a micritic matrix. (**C**): Algal–micritic matrix between a volcanic grain (vo) and recrystallized mollusc shell with microborings (mb). Cross-sections of two serpulid tubes (sp) coated by algal encrustations embedded in an algal crust of the volcanic grain. (**D**): Algal encrustation of a recrystallized gastropod shell with microborings. Peloids filling part of the shell interior. (**E**): The coralline alga, possibly *Mesophyllum* sp.

Figure 7. Last Interglacial marine molluscs from San Juanito. (**A**): *Tectarius striatus* (12.5 mm), TFMCFO-2261. (**B**): *Diodora gibberula* (16.9 mm), TFMCFO-1361. (**C**): *Phorcus sauciatus* (16.8 mm), TFMCFO-2114. (**D**): *Gibbula candei* (13.3 mm), TFMCFO-2262. (**E**): *Stramonita haemastoma* (25.0 mm), TFMCFO-2117. (**F**,**G**): *Hinia lineata* (7.0 mm), TFMCFO-2266. (**H**): *Phorcus atratus* (9.0 mm in diameter), TFMCFO-2265. (**I**): *Trimusculus mammillaris* (9.7 mm), TFMCFO-2262a. (**J**): *Jujubinus gravinae* (6.2 mm), TFMCFO-2416. (**K**,**L**): *Bittium incile* (7.2 mm), TFMCFO-2418. (**M**,**N**): *Naria spurca* (20.5 mm), TFMCFO-2419. (**O**,**P**): *Clanculus berthelotii* (8.3 mm), TFMCFO-2421. (**Q**,**R**): *Tritia pfeifferi* (11.2 mm), TFMCFO-2422. (**S**,**T**): *Ctena decussata* (21.4 mm), TFMCFO-2120. (**U**,**V**): *Claremontiella nodulosa* (16.9 mm), DBUA-F 1709. (**W**): *Patella piperata* (42.9 mm), TFMCFO-1723. (**X**,**Y**): *Cardita calyculata* (17.3 mm), TFMCFO-2260. (**Z**): *Mitrella broderipii* (7.0 mm), DBUA-F 1709. (**A1**): *Ebenomitra ebenus* (7.9 mm), DBUA-F1709. (**A2**): *Thericium lividulum* (16.8 mm), DBUA-F 1709.

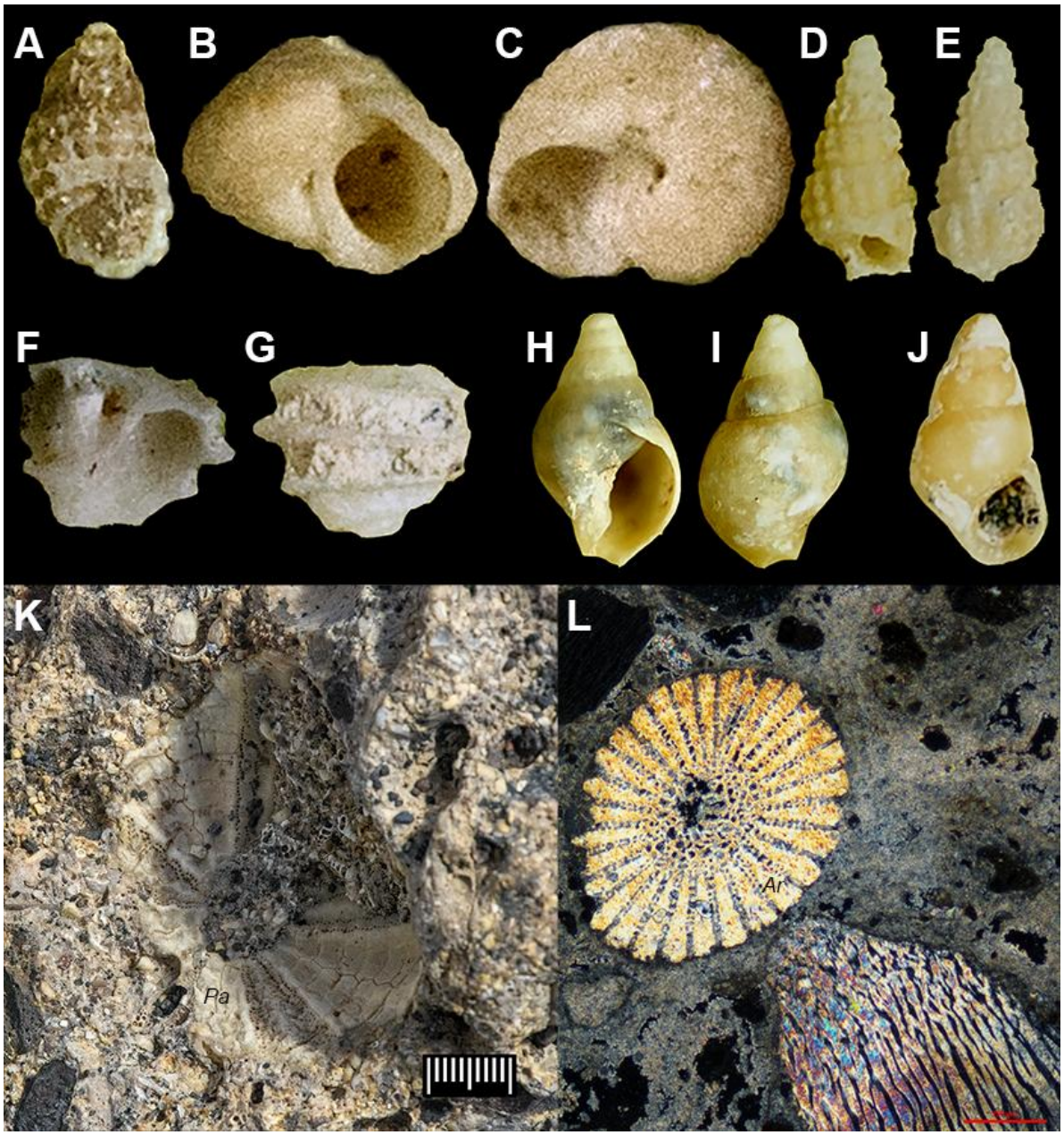

Figure 8. Last Interglacial marine molluscs and echinoderms from San Juanito. (**A**): *Alvania johannae* (2.5 mm), DBUA-F 1709. (**B**,**C**): *Gibbula aurantia* (3.0 mm), DBUA-F 1709. (**D**,**E**): *Krachia tiara* (2.5 mm), DBUA-F 1709. (**F**,**G**): *Fossarus ambiguus* (2.0 mm), DBUA-F 1709. (**H**,**I**): *Tritia conspersa* (5.0 mm), DBUA-F 1709. (**J**): *Barleeia unifasciata* (Montagu, 1803) (3.5 mm), DBUA-F 1709. (**K**): Inner side of the test of the echinoid *Paracentrotus lividus* (Lamarck, 1816) (Pa) (scale = 1 cm). (**L**): Spine of the echinoid *Arbacia lixula* (Linnaeus, 1758) (Ar) (scale = 250 μm), in cross-section.

In the most recent account of MIS 5e shallow-water marine molluscs from the Canary Islands, Ref. [39] reported 194 gastropods and 80 bivalve species. Importantly, the present study adds three new records to the MIS 5e gastropod checklist for the archipelago: *Alvania johannae* Moolenbeek & Hoenselaar, 1998 (Figure 8A), *Krachia tiara* (Monterosato, 1874) (Figure 8D,E), and *Barleeia unifasciata* (Montagu, 1803) (Figure 8J). When combined with data from the literature, this brings the total number to 202 gastropod species and 80 bivalve species currently reported from the MIS 5e of the Canary Islands (Table 1) [40]. Furthermore, the present study contributes six additional gastropod records to the checklist for the San Juanito outcrop, all previously reported from the Canary Islands: *Claremontiella nodulosa* (C. B. Adams, 1845) (Figure 7U,V), *Columbella adansoni* Menke, 1853, *Fossarus ambiguus* (Linnaeus, 1758) (Figure 8F,G), *Mitrella broderipii* (G. B. Sowerby I, 1844) (Figure 7Z), *Thetystrombus latus* (Figure 5B), and *Trimusculus mammillaris* (Linnaeus, 1758) (Figure 7I).

Table 1. Palaeobiodiversity of the MIS 5e malacofauna in the Macaronesian archipelagos. Data retrieved from Ávila database [40] on the Last Interglacial (MIS 5e) Atlantic and Mediterranean Molluscs.

Archipelago	Gastropod Species	Bivalve Species	Total
Azores	125	28	153
Madeira	54	29	83
Canaries	202	80	282
Cabo Verde	53	30	83

3.3. Functional Traits

Functional trait analysis indicates that the MIS 5e gastropod assemblage from the San Juanito outcrop is evenly divided in terms of larval development: 19 taxa exhibit planktotrophic development, and 19 are non-planktotrophic. Furthermore, all 40 mollusc species possess shells entirely composed of aragonite. Regarding locomotion, most gastropod species are actively mobile (73.7%), followed by facultatively mobile (18.4%). Slow-moving (5.3%) and stationary gastropod species (2.6%) represent a smaller proportion of the MIS 5e assemblage. In terms of life habit, most gastropods are epifaunal (94.7%), with only two species (5.3%) classified as semi-infaunal; in contrast, the two bivalve species at San Juanito are infaunal. Regarding their diet, twenty out of the thirty-eight gastropod species are herbivores/grazers, whereas twelve species are carnivores, followed by five omnivores (i.e., species that can act as carnivores and as herbivores/grazers), with suspension feeders represented by a single species (*Vermetus* sp.). Of the two bivalve species reported, one is a suspension feeder, whereas the other is chemosymbiotic (Table 2).

Table 2. Checklist and functional trait information of fossil molluscs reported from the Pleistocene (MIS 5e) deposit at San Juanito on Tenerife Island (Canary Archipelago). GAS: Gastropoda; BIV: Bivalvia; n.a.: Not applicable. The number "1" denotes the presence of a character state. Trait data retrieved from [35] for bivalves and [16] for gastropods.

				Larval Development		Shell Composition		Locomotion			Life Habit				Diet			
Class	**Species**	**Family**	**Genus**	**Planktotrophic**	**Non-Planktotrophic (Lecithotrophic + Direct Development)**	**Aragonite**	**Low-Mg Calcite**	**Actively Mobile**	**Slow-Moving**	**Facultatively Mobile**	**Stationary**	**Epifaunal**	**Semi-Infaunal**	**Infaunal**	**Carnivore**	**Herbivore/Grazer**	**Suspension Feeder**	**Chemosymbiotic**	**Omnivore**
GAS	*Acanthina dontelei* García-Talavera & Sánchez-Pinto, 2002	Muricidae	*Acanthina*		1	1		1				1				1			
GAS	*Alvania johannae* Moolenbeek & Hoenselaar, 1998	Rissoidae	*Alvania*		1	1		1				1				1			
GAS	*Barleeia unifasciata* (Montagu, 1803)	Anabathridae	*Pisinna*		1	1		1				1				1			
GAS	*Bittium incile* R.B. Watson, 1897	Cerithiidae	*Bittium*		1	1		1				1				1			
GAS	*Clanculus berthelotii* (A. d'Orbigny, 1840)	Trochidae	*Clanculus*		1	1		1				1				1			
GAS	*Claremontiella nodulosa* (C. B. Adams, 1845)	Muricidae	*Claremontiella*	1		1		1				1			1				
GAS	*Columbella adansoni* Menke, 1853	Columbellidae	*Columbella*	1		1		1				1							1

Table 2. *Cont.*

Class	Species	Family	Genus	Larval Development		Shell Composition		Locomotion			Life Habit				Diet			
				Planktotrophic	Non-Planktotrophic (Lecithotrophic + Direct Development)	Aragonite	Low-Mg Calcite	Actively Mobile	Slow-Moving	Facultatively Mobile	Stationary	Epifaunal	Semi-Infaunal	Infaunal	Carnivore	Herbivore/Grazer	Suspension Feeder	Chemosymbiotic	Omnivore
GAS	*Conus* sp.	Conidae	*Conus*		1	1		1				1			1				
GAS	*Diodora gibberula* (Lamarck, 1822)	Fissurellidae	*Diodora*		1	1				1		1							1
GAS	*Diodora graeca* (Linnaeus, 1758)	Fissurellidae	*Diodora*		1	1				1		1							1
GAS	*Fossarus ambiguus* (Linnaeus, 1758)	Planaxidae	*Fossarus*	1		1				1		1				1			
GAS	*Gemophos viverratus* (Kiener, 1834)	Pisaniidae	*Gemophos*	1		1		1				1			1				
GAS	Gibbula candei (A. d'Orbigny, 1840)	Trochidae	*Gibbula*		1	1		1				1				1			
GAS	*Haliotis tuberculata* Linnaeus, 1758	Haliotidae	*Haliotis*		1	1	1	1				1				1			
GAS	*Hinea lineata* (da Costa, 1778) = *Angiola lineata* (da Costa, 1778)	Planaxidae	*Hinea*	1		1		1				1				1			
GAS	*Isara cornea* (Lamarck, 1811) = *Mitra cornea* Lamarck, 1811	Mitridae	*Isara*	1		1		1				1			1				

Table 2. *Cont.*

Class	Species	Family	Genus	Larval Development		Shell Composition		Locomotion			Life Habit				Diet			
				Planktotrophic	Non-Planktotrophic (Lecithotrophic + Direct Development)	Aragonite	Low-Mg Calcite	Actively Mobile	Slow-Moving	Facultatively Mobile	Stationary	Epifaunal	Semi-Infaunal	Infaunal	Carnivore	Herbivore/Grazer	Suspension Feeder	Chemosymbiotic	Omnivore
GAS	*Jujubinus gravinae* (Dautzenberg, 1881)	Trochidae	*Jujubinus*		1	1		1				1				1			
GAS	*Krachia tiara* (Monterosato, 1874)	Cerithiopsidae	*Krachia*	1		1		1				1			1				
GAS	*Manzonia* sp.	Rissoidae	*Manzonia*		1	1		1				1				1			
GAS	*Mitrella broderipii* (G. B. Sowerby I, 1844)	Columbellidae	*Mitrella*		1	1		1				1			1				
GAS	*Naria spurca* (Linnaeus, 1758) = *Erosaria spurca* (Linnaeus, 1758)	Cypraeidae	*Naria*	1		1		1				1							1
GAS	*Patella aspera* Röding, 1798	Patellidae	*Patella*	1		1	1			1		1				1			
GAS	*Patella ordinaria* Mabille, 1888 = *Patella crenata* Gmelin, 1791 sensu d'Orbigny, 1840	Patellidae	*Patella*	1		1	1			1		1				1			
GAS	*Patella piperata* Gould, 1846	Patellidae	*Patella*	1		1	1			1		1				1			
GAS	*Phorcus atratus* (Wood, 1828)	Trochidae	*Phorcus*		1	1		1				1				1			

Table 2. *Cont.*

Class	Species	Family	Genus	Larval Development		Shell Composition		Locomotion			Life Habit				Diet			
				Planktotrophic	Non-Planktotrophic (Lecithotrophic + Direct Development)	Aragonite	Low-Mg Calcite	Actively Mobile	Slow-Moving	Facultatively Mobile	Stationary	Epifaunal	Semi-Infaunal	Infaunal	Carnivore	Herbivore/Grazer	Suspension Feeder	Chemosymbiotic	Omnivore
GAS	*Phorcus sauciatus* (L. Koch, 1845)	Trochidae	*Phorcus*		1	1		1				1				1			
GAS	*Ebenomitra ebenus* (Lamarck, 1811)	Costellariidae	*Ebenomitra*		1	1		1				1			1				
GAS	*Pusia zebrina* (A. d'Orbigny, 1840) = *Vexillum zebrinum* (A. d'Orbigny, 1840)	Costellariidae	*Pusia*		1	1		1				1			1				
GAS	*Stramonita haemastoma* (Linnaeus, 1767)	Muricidae	*Stramonita*	1		1		1				1			1				
GAS	*Talisman scrobilator* (Linnaeus, 1758)	Bursidae	*Talisman*	1		1		1				1			1				
GAS	*Tectarius striatus* (P. P. King, 1832)	Littorinidae	*Tectarius*	1		1		1				1				1			
GAS	*Thericium lividulum* (Risso, 1826) = *Cerithium lividulum* Risso, 1826	Cerithiidae	*Cerithium*		1	1		1				1				1			

Table 2. *Cont.*

Class	Species	Family	Genus	Larval Development		Shell Composition		Locomotion			Life Habit				Diet			
				Planktotrophic	Non-Planktotrophic (Lecithotrophic + Direct Development)	Aragonite	Low-Mg Calcite	Actively Mobile	Slow-Moving	Facultatively Mobile	Stationary	Epifaunal	Semi-Infaunal	Infaunal	Carnivore	Herbivore/Grazer	Suspension Feeder	Chemosymbiotic	Omnivore
GAS	*Thericium vulgatum* (Bruguière, 1792) = *CerIthium vulgatum* Bruguière, 1792	Cerithiidae	*Cerithium*	1		1		1				1				1			
GAS	*Thetystrombus latus* (Gmelin, 1791)	Strombidae	*Thetystrombus*	1		1		1				1							1
GAS	*Trimusculus mammillaris* (Linnaeus, 1758)	Trimusculidae	*Trimusculus*	1		1				1		1				1			
GAS	*Tritia conspersa* (Philippi, 1849)	Nassariidae	*Tritia*	1		1			1				1		1				
GAS	*Tritia pfeifferi* (R. A. Philippi, 1844)	Nassariidae	*Tritia*		1	1			1				1		1				
GAS	*Vermetus* sp.	Vermetidae	*Vermetus*		1	1					1	1					1		
BIV	*Cardita calyculata* (Linnaeus, 1758)	Carditidae	*Cardita*	n.a.	n.a.	1				1				1			1		
BIV	*Ctena decussata* (O.G. Costa, 1829)	Lucinidae	*Ctena*	n.a.	n.a.	1				1				1				1	

4. Discussion

4.1. Depositional Environment

The location and facies characteristics of the sedimentary rocks indicate shallow, open-marine conditions, likely above or near the fair-weather wave base. The dominance of crushed and abraded bioclastic components in the pre-MIS 5e calcarenites suggests persistent wave action (Figure 5). However, the common occurrence of micritization points to a moderate- to low-energy photic zone, warm waters, relatively low sedimentation rates, and supersaturation with calcium carbonate [41,42]. This interpretation is further supported by the presence of peloids, which may originate from micritization or abrasion of small carbonate mud aggregates [43]. It is therefore likely that abraded bioclasts were produced in higher-energy settings and subsequently transported and deposited in slightly deeper, calmer waters, where they underwent microboring and micritization.

The overlying MIS 5e calcarenites were deposited on an eroded and already cemented pre-MIS 5e substrate. This is evidenced by their occurrence in pockets, some of which display algal crusts at their base. This indicates that erosion preceded deposition, and no lithoclasts of pre-MIS 5e calcarenites were observed within the MIS 5e deposits. Fragmentation, abrasion, and micritization (Figure 6), similar to those observed in the underlying deposits, suggest that bioclasts originated in zones affected by persistent wave action and were subsequently redeposited in a calmer, moderate- to low-energy environment. The more pronounced development of algal encrustations, locally binding the sediment, as well as the presence of better-preserved mollusc shells—some encrusted by coralline algae—supports this interpretation. In addition, the presence of a concave-up patellid shell (Figure 2D) suggests settling of the transported shell through the water column with rapid burial that prevented subsequent reorientation.

The duration and nature of the hiatus between the pre-MIS 5e and MIS 5e deposits remain unclear. The presence of reddish scoria in the former suggests derivation from a different volcanic source than that of the MIS 5e deposits. It is also possible that the brownish colour of the pre-MIS 5e deposits reflects subaerial weathering following a phase of emersion. Overall, the apparent decrease in depositional energy from the pre-MIS 5e to MIS 5e environments may be related to transgression during the Last Interglacial associated with rising sea level.

4.2. Age Assignment of the San Juanito Outcrop

The application of archipelago-specific ecobiostratigraphic indicator species within Macaronesia is a well-established, accurate, and cost-effective method to constrain the age of the studied palaeosites [14–16,39]. The presence of the warm-water gastropods *Thetystrombus latus* and *Claremontiella nodulosa*, both species widely regarded as ecostratigraphic indicator species for MIS 5e deposits in the Canary Islands (sensu [39]), supports previous assignments of a Last Interglacial age for this deposit [24,44]. *Acanthina dontelei* García-Talavera & Sánchez-Pinto, 2002 is an extinct gastropod species reported from the MIS 5e sedimentary deposits of the Selvagens and the Canary archipelagos [39,45]. San Juanito also hosts other thermophilic species commonly associated elsewhere with Macaronesian MIS 5e deposits, despite their lack of formal MIS 5e ecostratigraphic indicator status for the Canaries, including *Gemophos viverratus* (Kiener, 1834) and *Hinea lineata* (da Costa, 1778).

4.3. Palaeobiodiversity of the MIS 5e Marine Fauna and Flora

Research on Last Interglacial faunas has a long-standing tradition in the Mediterranean (see [46] for a recent review) and along the West African Atlantic coast [47]. More recently, scientific interest has expanded toward the North Atlantic [48] and the Macaronesian archipelagos (especially the Azores and Canary archipelagos). While reviews in these

regions have primarily focused on marine molluscs, they also encompass a wide range of other taxa, including vertebrates (e.g., whales [49], fishes [50], birds [51–55]), and invertebrates (e.g., echinoderms [56,57], crustaceans [58], brachiopods [6]), as well as algae [59,60]. Furthermore, recent studies have emerged regarding MIS 5e deposits from the Western Atlantic, spanning French Guiana [61] to South America, including Uruguay [62] and Argentina [63,64].

MIS 5e mollusc diversity is considerably higher in the Canaries (282 taxa) and the Azores (153) than in Madeira or Cabo Verde (83 each; Table 1). The Azorean data are particularly remarkable given that Santa Maria is the only island in the archipelago that has a marine fossil record, while the Canaries benefit from numerous Last Interglacial fossiliferous deposits across several islands, including La Gomera, Fuerteventura, Lanzarote, Gran Canaria, and Tenerife [22,24,65,66]. In contrast, when analysing MIS 5e palaeobiodiversity by outcrop rather than by archipelago (Table 3), the Azores host the two most diverse sites: Prainha, with 120 reported species, and Ponta do Cedro, with 91. These are followed by Penedo in Porto Santo Island (Madeira Archipelago, 84 taxa) [67] and Tachero in Tenerife Island (Canary Archipelago, 78 taxa).

Table 3. Comparison of the palaeobiodiversity across the most representative MIS 5e outcrops in the Macaronesian archipelagos. # GAS: Number of gastropod species; # BIV: Number of bivalve species.

Archipelago	Island	Palaeosite	# GAS	# BIV	Total	References
Azores	Santa Maria	Ponta do Cedro	76	15	91	[11]
Azores	Santa Maria	Pedra-que-pica	47	6	53	[68]
Azores	Santa Maria	Prainha	100	20	120	[69–71]
Azores	Santa Maria	Lagoinhas	48	3	51	[70,72,73]
Azores	Santa Maria	Vinha Velha	62	8	70	[9]
Madeira	Porto Santo	Penedo (nearby the marina)	61	23	84	[67]
Madeira	Porto Santo	Porto dos Frades	4	7	11	[74]
Canaries	Gran Canaria	Las Palmas	16	4	20	[8]
Canaries	Tenerife	El Médano	23	4	27	[66]
Canaries	Tenerife	Las Teresitas	6	2	8	[24,66]
Canaries	Tenerife	Punta Negra	38	18	56	[24,66]
Canaries	Tenerife	San Juanito (Punta del Hidalgo)	38	2	40	This work
Canaries	Tenerife	Tachero	59	19	78	[24,31]
Canaries	Fuerteventura	Barranco de Río Cabras (Aeroporto)	35	7	42	[22,65]
Canaries	Fuerteventura	Matas Blancas	17	5	22	[22]
Canaries	Fuerteventura	Punta del Tigre	22	3	25	[22]
Canaries	Fuerteventura	Punta la Hondura-La Guirra	41	8	49	[22]
Canaries	Fuerteventura	Saladar de Morro Jable	28	7	35	[22,65]

The San Juanito locality is a small, restricted MIS 5e exposure. This site has been surveyed multiple times by the local TFMC team, as well as during two dedicated MIS 5e expeditions to the Canary Islands conducted by the joint TFMC and MPB teams, involving more than 10 experienced researchers. In our experience, palaeosites characterized by cemented substrates typically yield lower palaeobiodiversity compared to those with friable sediments, which permit standardized 1 kg bulk sampling. Therefore, the lower

species richness recorded at San Juanito is a true ecological or taphonomical characteristic of the site, rather than a methodological artifact. Among the 18 Macaronesian MIS 5e palaeosites studied, San Juanito ranks 11th, with only 40 recorded mollusc species. Despite this relatively low diversity, we classify it as a site of moderate palaeobiodiversity. It is remarkable that 7.5% of the reported taxa represent new additions to the MIS 5e fossil record of the Canary Islands. This highlights that the MIS 5e record of the Canary Islands is far from exhaustive and suggests that a detailed analysis of the micro-molluscan fraction will probably produce novelties for regional biodiversity inventories.

Antoine and colleagues [61] recently described a hyperdiverse MIS 5e assemblage from Kourou on the continental shores of French Guiana, comprising 181 species. This total includes twelve foraminiferans, two cnidarians, nineteen bryozoans, eighty-seven molluscs (two scaphopods, thirty-five bivalves, and fifty gastropods), eleven arthropods, four echinoderms, and a significant vertebrate component of eleven elasmobranchs and thirty-five actinopterygians. In Macaronesia, the only comparable palaeosite is Prainha, on Santa Maria Island (Azores). Although less diverse, with 135 reported MIS 5e species, Prainha shows a similar taxonomic breadth, including four algae, one whale, two bony fishes, four arthropods, four echinoderms, and one hundred and twenty molluscs (twenty bivalves and one hundred gastropods). Thus, even though Prainha has a smaller vertebrate record, its malacological diversity is even higher than that of the French Guiana site, with 120 mollusc species compared to the 87 found in the continental assemblage. Furthermore, it is worth noting the disparity in sampling effort: While the Prainha dataset comes from 8 kg of processed sediment [9], the Kourou study analysed more than 775 kg [61].

Regarding coralline algae, four taxa were identified in pre-MIS 5e sediments (Figure 5), whereas only one (*Mesophyllum* sp., Figure 6E) was found in the MIS 5e deposits. Currently, three species of this genus are present in the Canary Islands: *Mesophyllum ectocarpon* (Foslie) W.H.Adey, 1970; *M. erubescens* (Foslie) Me.Lemoine, 1928; and *M. lichenoides* (J.Ellis) Me.Lemoine, 1928. These species also occur today in the Cabo Verde Archipelago. Unfortunately, the scarcity of the coralline fossil record at San Juanito precludes a more detailed analysis.

4.4. Palaeoecological Reconstruction and Functional Traits

As is the case today, rocky shores were prevalent in the San Juanito region during the Last Interglacial. This interpretation is supported by the high proportion of species associated with hard substrates, gravel, or pebble bottoms, accounting for all of the echinoderms, twenty-two of the thirty-eight gastropods and one of the two bivalves recorded. Moreover, the dominance of epifaunal gastropods (95%), the occurrence of vermetids, and the presence of two Fissurellidae and three Patellidae species further reinforce this interpretation. The latter are specialized grazers that forage on sponges [75] and rocky-shore algal carpets, respectively [76]. In certain areas, algae-covered rocky substrates supported various omnivorous gastropods (e.g., *Columbella adansoni*) alongside herbivore/grazer gastropods such as *Barleea unifasciata*, *Alvania johannae*, and *Manzonia* sp. Additionally, pockets of sand accumulated in natural depressions across the predominantly rocky seafloor provided habitats for species associated with mobile sediments, including the gastropods *Hinea lineata*, *Naria spurca* (Linnaeus, 1758), *Thericium lividulum* (Risso, 1826), *Thericium vulgatum* (Bruguière, 1792), and *Thetystrombus latus*, as well as the infaunal chemosymbiotic bivalve *Ctena decussata*. Finally, we suggest that macrophyte meadows were possibly present at San Juanito during the Last Interglacial. This is evidenced by the occurrence of the gastropod *Mitrella broderipii*, a species frequently associated with these ecologically relevant environments.

5. Conclusions

The Canary Islands boast over 300 inventoried sites of geological interest, many of which preserve significant fossil remains and ichnological records (trace fossils). This palaeontological wealth constitutes an essential archive for understanding island palaeoclimatology and palaeobiogeography. As Martín-González and colleagues highlight [77,78], such palaeosites offer a detailed record of past biological colorizations, providing a window into how species evolve and go extinct/extirpated in response to shifting climates. These records further provide a baseline for understanding how human intervention has reshaped island biodiversity over time. Consequently, a detailed grasp of the geological, taphonomical, and biological processes contributing to the formation of Last Interglacial fossiliferous deposits in the Canary Islands is essential. Such knowledge serves as a critical tool for evaluating the preservation status of these sites and ensuring their long-term, sustainable management [44,79].

Tenerife hosts 47 sites of geological interest [80]. Eleven are classified as palaeosites, seven of which represent the Last Interglacial period [32]. This study offers the first comprehensive description of the MIS 5e deposits at San Juanito, in Punta del Hidalgo, providing new insights into the palaeoecological conditions and depositional processes of these fossiliferous sediments. The uppermost elevation of this palaeosite reaches 2.55 ± 0.12 m a.s.l., and, despite a relatively low palaeobiodiversity—with only 40 mollusc taxa identified—meticulous sorting of qualitative samples yielded three new records for the MIS 5e Canary Islands checklist. Consequently, the total MIS 5e palaeobiodiversity for the archipelago now stands at 202 gastropods and 80 bivalves.

Palaeontological research in the Canary Islands has yet to adopt standardized 1 kg sampling protocols, a gap that currently limits the implementation of in-depth palaeoecological studies and prevents the application of functional diversity-based approaches (see [11] for a review) and the use of more robust statistical analyses. Future work in the archipelago will prioritize the application of these methods in outcrops with unconsolidated sediments, overcoming the sampling challenges posed by highly cemented deposits like those at San Juanito.

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Abbreviations

The following abbreviations are used in this manuscript:

DBUA-F	Mollusc fossil collection of the Department of Biology, University of the Azores, São Miguel Island, Azores, Portugal.
TFMCFO	Fossil collection of the Museo de Ciencias Naturales de Tenerife, Canary Islands, Spain.

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