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RESEARCH

Infralittoral benthic foraminifera from northern Chile

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Abstract
This communication analyzes the distribution of benthic foraminifera in the infralittoral zone of northern Chile located between 26° and 29°S at depths between 7 and 12 m. Twenty-six taxa have been identified, whose density is mainly conditioned by grain size and hydrodynamics of the environment. A comparison with other coastal sectors of the Pacific coast of South America allows us to identify the most representative species of this area from southern Chile to Colombia. The results obtained are very interesting for their possible application in the reconstruction of Holocene paleoenvironments in the Atacama Desert.

Keywords Benthic foraminifera · Environmental parameters · Infralittoral · Northern Chile · Applications

Resumen
Esta comunicación analiza la distribución de los foraminíferos bentónicos en la zona infralitoral del norte de Chile localizada entre 26º S y 29ºS a profundidades entre 7 y 12 m. Se ha identificado 26 taxones, con una densidad condicionada principalmente por el tamaño de grano y la hidrodinámica del medio. Una comparación con otros sectores costeros de América del Sur permite identificar las especies más representativas de este área desde el sur de Chile hasta Colombia. Los resultados obtenidos son muy interesantes por su aplicabilidad en la reconstrucción de paleoambientes holocenos en el desierto de Atacama.

Palabras clave Foraminíferos bentónicos · Parámetros ambientales · Infralitoral · Norte de Chile · Aplicaciones

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1 Introduction

In the last decades, numerous studies were focused on the analysis of recent benthic foraminifera for different purposes: (i) the distinction and interpretation of different sedimentary facies (González-Regalado et al., 2019); (ii) to document the response of living species to environmental stress (Alves et al., 2024); (iii) as proxies of the effects of climate change (Forderer et al., 2023); (iv) for reconstructing the paleoenvironmental evolution of coastal zones (Márquez & Ferrero, 2011); or (v) to detect tsunamigenic layers in Holocene sequences (Abad et al., 2022).

In coastal areas, grain size and organic matter are some of the most important determinants of foraminiferal distributions (Rostami et al., 2023). In addition, its study allows the detection of areas with strong anthropogenic contamination under ecological stress (Ganugapenta et al., 2025), the monitoring of coastal environments (Scott et al., 2007) and even contributes to the palaeoenvironmental reconstruction of biosphere reserves (González-Regalado et al., 2025). These examples state the importance and challenges of conducting these studies.

In Chile, most of the recent studies on benthic foraminifera have focused on the central and southern part of the country (e.g. Boltovskoy & Theyer, 1970; Hromic, 2009; Zapata et al., 1995, among others). The first studies on the benthic foraminifera of northern Chile were carried out by D'Orbigny (1839), followed later by other researchers (e.g. Cushman & Kellett, 1929; Páez et al., 2001). Overall, more than 500 species have been described (see a summary of the papers in Marchand et al., 2010), distributed biogeographically in the Peruvian-Chilean (3°S-42°S) and Magellanic (south of 42°S) provinces according to Zapata and Moyano (1997). On the other hand, Boltovskoy (1976) differentiated a Panamanian province that would coincide with the coast of Ecuador and Colombia. Nevertheless, the shallower areas of the Peruvian-Chilean province close to the Atacama region have been studied with respect to benthic foraminifera.

This brief communication studies the infralittoral benthic foraminifera of northern Chile located between 26° and 29°S. Its primary objectives are: 1) the taxonomic determination of the species present in the study area; 2) a comparison between their relative abundance and various environmental parameters, such as grain size or organic matter in the sediments; iii) a bibliographic review of the distribution of the main species on the Pacific coast of South America, in order to establish the most typical association of this area; and iv) a brief reflection on the possible applications of the results in the palaeoenvironmental reconstruction of Quaternary sequences of the adjacent coast.

2 Study area

The study area encompasses the coastline of the Atacama region located between Chañaral de Aceituno (29°S) and Pan de Azúcar (26°S) (northern Chile) (Fig. 1a). This sector is located in the southern part of the Atacama Desert, characterized by a latitudinal climatic gradient from a BSk'(s) climate (cold semi-arid with dry summers) on the southern coast, to a BWk climate (cold desert) to the north (Sarricolea et al., 2017). Average annual rainfall does not exceed 10 mm in the northern limit of the study area (Navarro et al., 2021).

Low precipitation is controlled by the latitudinal location of the study area in front of the South Pacific anticyclone, a sub-tropical high-pressure belt generated by the global Hadley circulation (Reyers & Shao, 2019). The surface ocean circulation (Fig. 1b) shows the coastal flow from south to north as part of the Humboldt Current Surgence System (HCSS), considered one of the most productive systems on the planet (Montecino & Lange, 2009; Thiel et al., 2007). The productivity associated with the HCSS is mainly due to the coastal upwelling phenomena that accompany the current (Gosselin et al., 2013; Graco et al., 2007).

The northern Pacific coast of Chile has a semidiurnal and microtidal range. The average tidal range reaches 0.9 m and the significant wave height takes values between 1.79 and 2.04 m (Campos, 2016). The main and, at the same time, the most frequent source of storm surge comes from the southwest, with an average wave height approaching 3 m and maximums of 5 m (Campos, 2016). These values, compared to other Chilean coastal areas, are considerably smaller (Navarro et al., 2021).

3 Material and methods

Eight sampling stations have been selected in northern Chile (Fig. 1), distributed in the shallow subtidal zone of open coast and bays (Table 1: 7–12 m depth), for which the average slope between the sampling station and the coastline was calculated. Sampling was conducted in the summer of 2018 (January–February) and samples were collected in triplicate to avoid patchiness by professional divers under the MASEQATA project (FONDECYT-11180015) of the Chilean National Agency for Research and Development (ANID). All samples were taken in the first 10 cm of the surface. This boundary was chosen as several infaunal species of benthic foraminifera may be present at this depth (Fentimen et al., 2018; Goldstein et al., 1995).The samples were stored in aluminum boxes at 4 °C until arriving at the laboratory of the Universidad de Atacama.

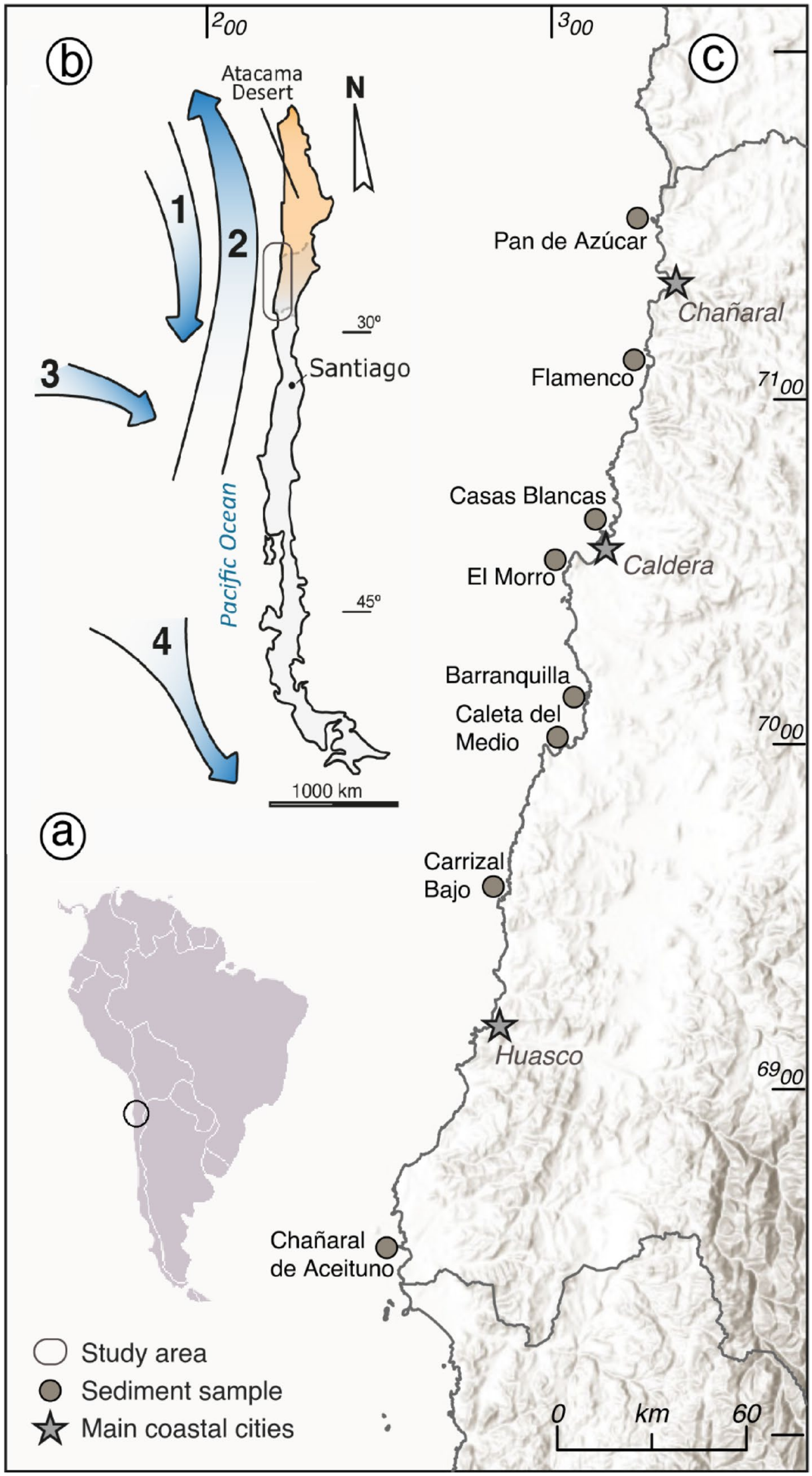

Fig. 1 **a** Map of South America with the location of the study area; **b** Ocean currents affecting the Chilean coasts: Warm countercurrent (1); Humboldt Current (2); Western Drift Current (3); Cape Horn Current (4); **c** Location of the studied area and sampling stations

Table 1 Coastal setting, grain size, organic matter and total benthic foraminiferal abundance of the samples. Percentages rounded to the first decimal number

Sample	Pan de Azúcar	Flamenco	Casas Blancas	El Morro	Barranquilla	Caleta del Medio	Carrizal Bajo	Chañaral del Aceituno
Group	1	2	2	1	1	1	1	1
Coast	Rocky cliff	Rocky coast with small beach	Center of a very narrow bay bounded by rocky headlands at 100 m	Center of a very narrow bay bounded by rocky headlands at 100 m	Very irregular rocky and cliffy coastline	Low cliffs and rocky coastline	Cliffy and rocky coastline, near the edge of a narrow bay	Low, irregular, rocky and cliffy coastline
Dinstance to the coast (m)	37	53	233	175	135	95	95	560
Depth (m)	10	7	9.3	9.5	9.9	11	12	11
Average slope (%)	27	13.2	4	5.4	7.3	11.6	12.6	2
Organic matter (%)	3.5	2.3	2.3	4.4	2.5	3.5	2.3	2.6
Gravel (%)	15.3	0.9	0	40.8	55.9	40.7	19.6	23.3
Very coarse sand (%)	41.9	0.5	0	26.9	22.6	43.9	21.3	39.9
Coarse sand (%)	38.7	2.7	0	16.1	6.8	13.4	27.5	21.1
Medium sand (%)	3.2	11.7	3.94	11.3	2.8	1.5	17.2	13.7
Fine sand (%)	0.4	64	82.7	4.2	0.8	0.5	9.3	1.6
Very fine sand (%)	0.4	19.8	11.8	0.7	0.1	0.1	4.9	0.3
Mud (%)	0.4	0.5	1.6	0	0.1	0	0.2	0.1
Species	Pan de Azúcar	Flamenco	Casas Blancas	El Morro	Barranquilla	Caleta del Medio	Carrizal Bajo	Chañaral del Aceituno
Ammonia beccarii	38.6	5.6	17.4	22	47.4		7	9.9
Anomalinoides incrassatus	8.2	22.5	13.8	8.5	5.8	18.9	24.2	8.1
Anomalinoides io	2.7		4.6	1			9.1	2.7
Anomalinoides praeacutus	3.5			4.8				1.3
Astacolus sp.	0.9							
Bolivina sp.	0.9			2				1.4
Buccella peruviana	19.3	29.6	14.5	13.2	23.2		7	12.7
Cibicides aknerianus	2.7	5.6	9.2	3.7	3.9	18.9	12.1	4.1
Cibicides moyanoi	2.7	11.3	27.9	22.8	11.6		6	5.4
Cibicidoides variabilis				1				3.9
Cibicidoides wuellerstorfi				1				
Discorbis vilardeboanus							3	1.3

Table 1 (continued)

Species	Pan de Azúcar	Flamenco	Casas Blancas	El Morro	Barranquilla	Caleta del Medio	Carrizal Bajo	Chañaral del Aceituno
Hanzawaia boueana	3.6							
Heterolepa ornata							3	
Lepidodeuterammina ochracea				0.6	1.9			13.6
Lobatula lobatula	3.6	5.6	2.3	0.6	1.9			3.3
Melonis affinis	0.9	5.6					12.1	2.7
Planulina ariminensis	5.5	5.6	4.8	5.4	2.3			10.1
Planulina wheeleri				1				
Quinqueloculina seminulum	2.7	2.9	0.5		1.9	18.9	3	2.7
Quinqueloculina sp.			2.7	7.6		38	1.4	10.1
Rosalina sp.	0.9							
Rosalina globularis		5.6	2.5	4.1			6	6.8
Triloculina planciana							3	
Triloculina trigonula	3.5					4.9		
Valvulineria inflata				0.6			3	
Individuals/gram	22	176	351	59	105	36	115	43

An aliquot of 50 g (bulk dry sediment) were separated for granulometric analysis. The particle size distribution of the sediments was obtained using a column of sieves (mesh sizes: 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0,063 mm). In addition, other 50 g of bulk dry sediment were separated for organic matter content estimation. The percentage of organic matter (% MO) was determined by weight loss after ignition (LOI) at 500°C in a muffle for 4 h in the Metallurgy laboratories of the Universidad de Atacama (Chile).

For microfaunistic analysis, 100 g of sediment were dry sieved through a 125 mm sieve and the total foraminiferal populations were studied. This fraction is frequently used in studies on benthic foraminifera (Milker & Schmiedl, 2012; Schonfeld et al. 2012; Puerres et al., 2022) and is mostly sufficient for determining the ecological quality status of samples (Klootwijk & Alve, 2022). After counting and classifying 300 specimens per sample, the percentages of the species and the number of individuals per gram of each sample were calculated. The most significant taxa were extracted into cells and all of them were photographed with a camera attached to a Flexacam C3 Leica loupe. Their taxonomic classification has been based on Ingle et al. (1980), Zapata et al. (1995), Paéz et al. (2001), Figueroa et al. (2005), Finger et al. (2013), Erdem and Schönfeld (2017), Tavera et al. (2022) and the World Register of Marine Species.

4 Results

4.1 Sediment

Six of the eight samples (Group 1) present considerable percentages of gravels (Table 1: 15.32%-55.87%), very coarse sands (21.32%-43.87%) and coarse sands (6.75%-38.71%), mostly made up of turritellid gastropods, with smaller fragments of bryozoans, red algae and other mollusks. The two remaining samples (Table 1; Group 2: Casas Blancas and Flamenco) showed a clearly lower grain size, with leptokurtic curves clearly dominated by fine sands (63.96%-82.68%)

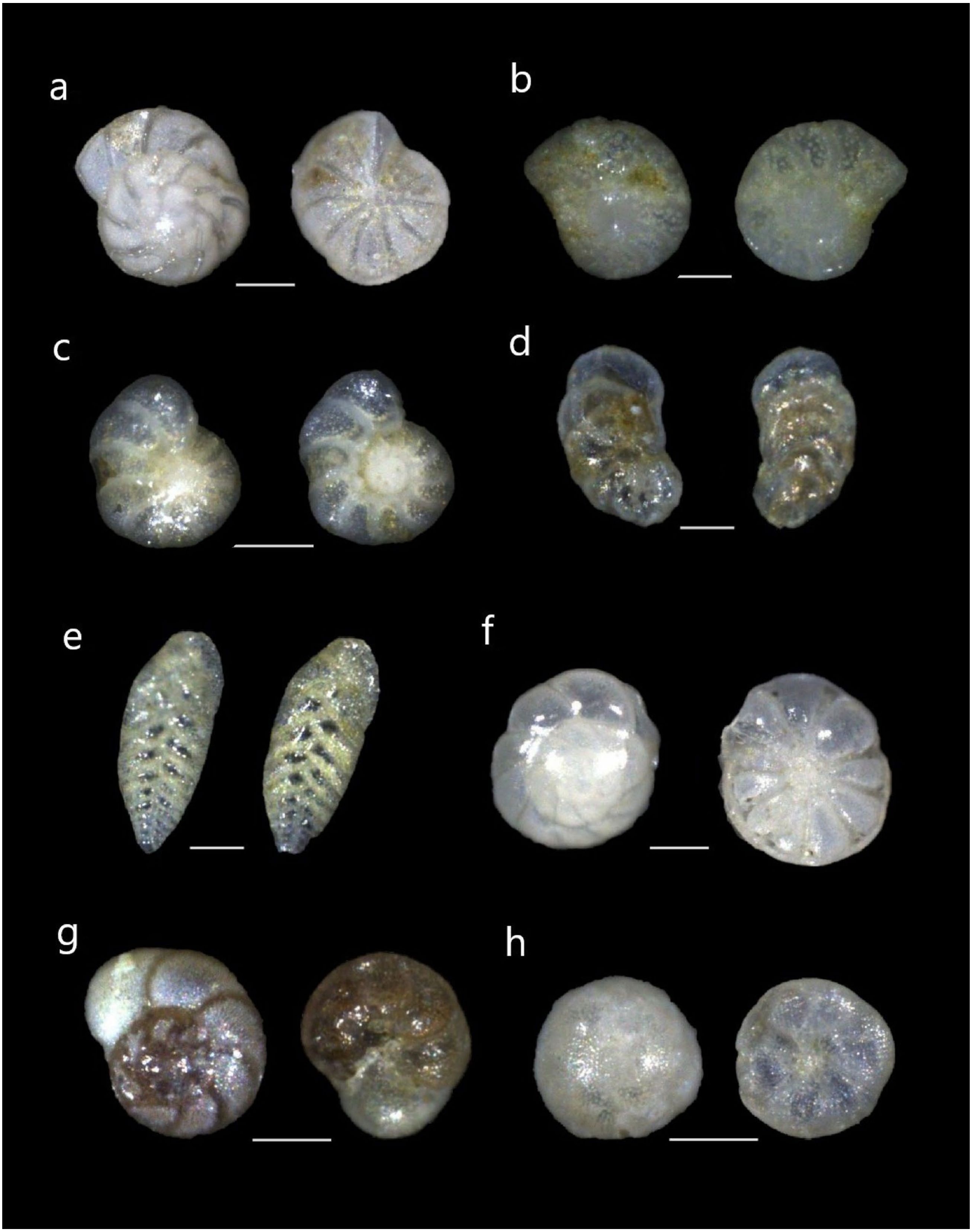

Fig. 2 Main taxa of benthic foraminifera. **a** *Ammonia beccarii*. **b** *Anomalinoides incrassatus*. **c** *Anomalinoides io*. **d** *Astacolus* sp. **e** *Bolivina* sp. **f** *Buccella peruviana*. **g** *Cibicides aknerianus*. **h** *Cibicides moyanoi*. Scale: 100 µm

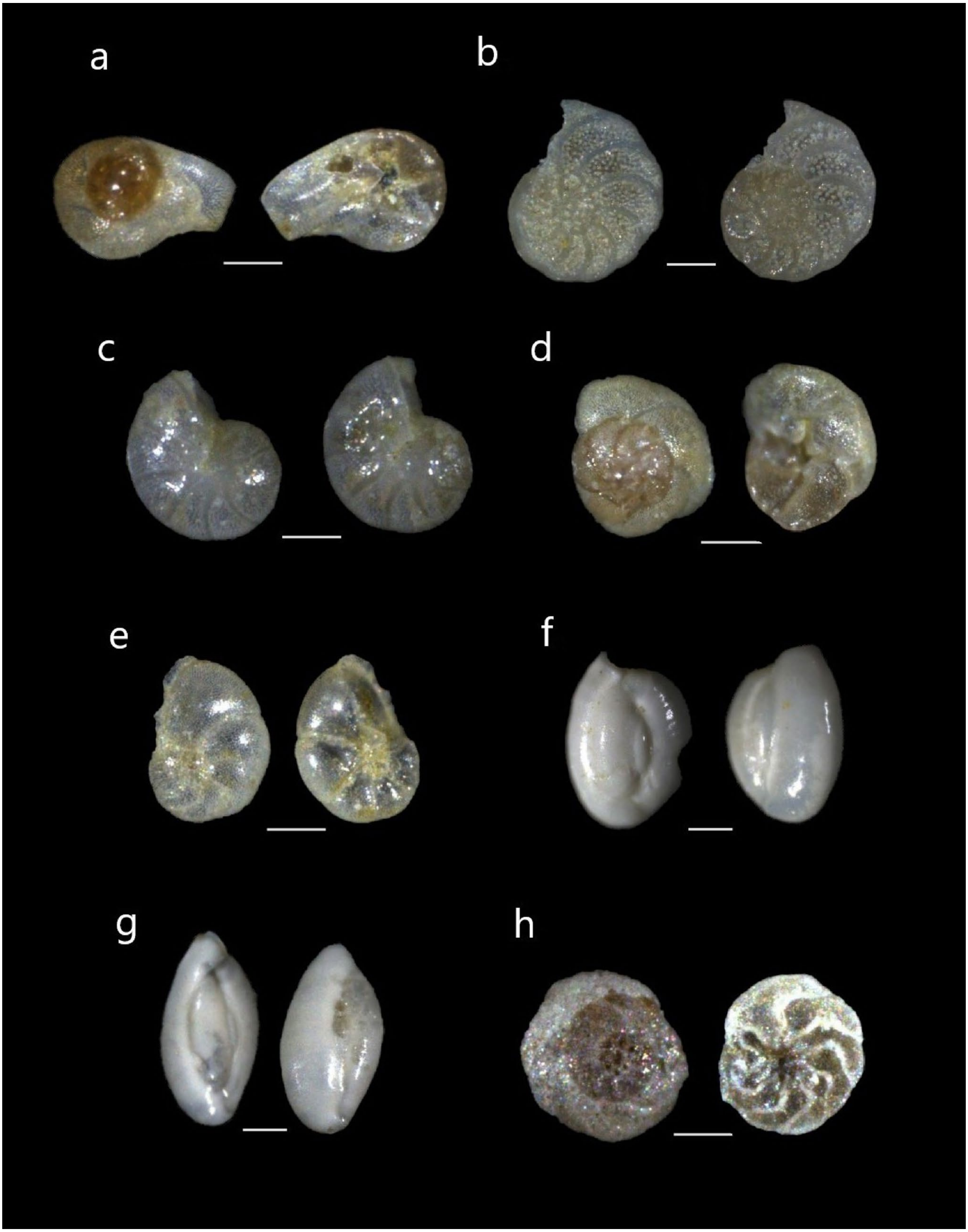

Fig. 3 Main taxa of benthic foraminifera. **a***Discorbis vilardeboanus*. **b***Planulina ariminensis*. **c***Melonis affinis*. **d***Rosalina globularis*. **e***Valvulineria inflata*. **f***Triloculina trigonula*. **g***Quinqueloculina seminulum*. **h***Lepidodeuterammina ochracea*. Scale: 100 µm

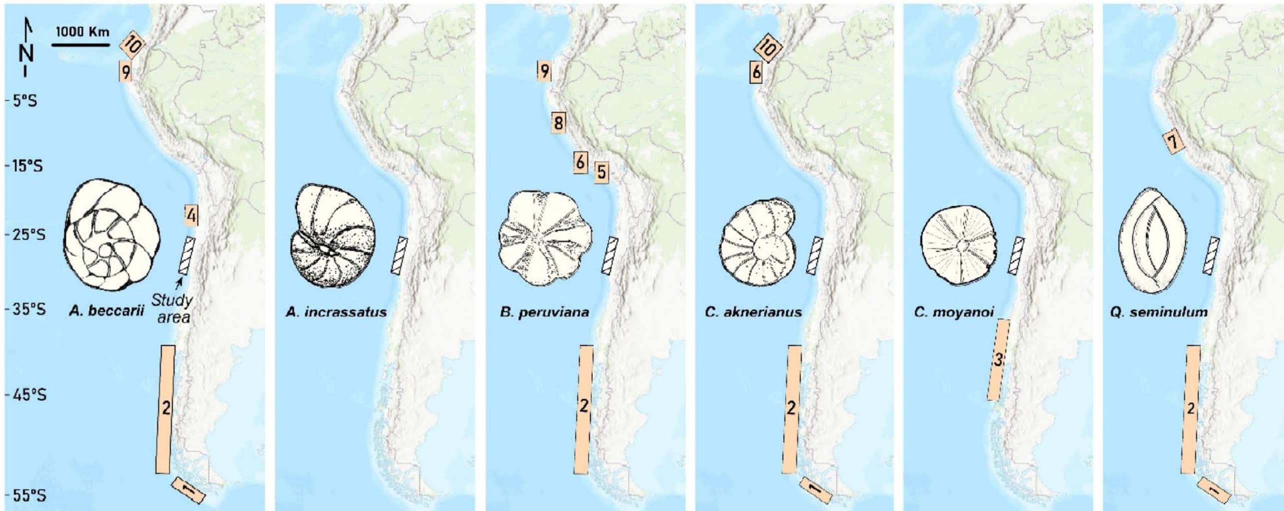

Fig. 4 Biogeographic range of the most abundant species on the Pacific coasts of South America. References: 1. Hromic (2009); 2. Zapata and Moyano (1997); 3. Figueroa et al. (2005); 4. Páez et al. (2001); 5. Romero (2021); 6. Merma (2020); 7. Verano (1974); 8. Romero et al. (2023); 9. Gualancañay (1986); 10. Gualancañay (2013)

and minor percentages of very fine sands (11.81%-19.82%). Group 2 samples were taken at a slightly shallower depth (7–9.3 m) than the previous six samples (9.5–12 m).

These two groups of samples are also differentiated by their organic matter content. In general, coarser sediments of group 1 have higher percentages of organic matter (2.32%-4.41%; mean: 3.14%) than the two finer samples of group 2 (2.25%-2.34%; mean: 2.29%).

4.2 Benthic foraminifera

Twenty-six taxa have been identified, twenty-two of them at the specific level. The species richness per sample varies from 5 (Caleta del Medio) to 17 (El Morro and Chañaral del Aceituno). The most abundant species are *Ammonia beccarii* (Linnaeus, 1758) (Fig. 2a; 0–47.48%; mean: 21.14%), *Anomalinoides incrassatus* (Fichtel & Moll, 1798) (Fig. 2b; 5.8%-24.17%; mean: 13.74%), *Buccella peruviana* s.l. (d'Orbigny, 1839) (Fig. 2f; 0–29.58%; mean: 17.07%), *Cibicides aknerianus* (d'Orbigny, 1846) (Fig. 2g; 0–18.92%; mean: 7.53%), *Cibicides moyanoi* Figueroa et al., 2005 (Fig. 2h; 0–27.88%; mean: 12.54%) and *Quinqueloculina seminulum* (Linnaeus, 1758) (Fig. 3g; 0–18.92%; mean: 4.67%).

These small protists are more abundant (Table 1: 176–351 individuals/gram) in group 2 with smaller grain sizes, coinciding with very high percentages of fine sands and low organic matter contents (2.25–2.34%). On the contrary, they are scarce (22–43 individuals/gram) in the samples with percentages higher than 39% of very coarse sands.

5 Discussion

5.1 Benthic foraminifera and environmental parameters

Grain size is one of the most limiting parameters for benthic foraminifera. Several studies have shown that the density of these microorganisms decreases in coarse sediments (Murray, 2006; Armynot de Chatelet et al. 2009; Aiello et al., 2021), which could explain the low densities observed in the study area in sediments dominated by coarse sands to gravels. On the other hand, the highest densities were found in very protected bays with low average slope, a more favorable scenario for the development of these microorganisms than high-energy environments (Wilson et al., 2008).

These highest densities of benthic foraminifera are concentrated in sediments with very low percentages of organic matter, although a significant negative correlation between these two variables cannot be established. The effect of organic matter on foraminifera has been largely has been widely debated, with some studies showing that an increase in this parameter correlates positively with an increase in the density and diversity of these microorganisms (e.g. Cearreta, 1988; Debenay et al., 2001; Martins et al., 2015), while other studies show the opposite (review in Armynot du Chatelet 2009).

5.2 Biogeography of the main species on the Pacific coast of South America

A review of several papers focused on the distribution of benthic foraminifera along the Pacific coasts of South

America shows the importance of the study area as a link between the faunas located as far north as Panama and the Strait of Magellan to the south. According to this literature (see Fig. 4 caption), *Ammonia beccarii*, *Buccella peruviana*, *Cibicides aknerianus* and, to a lesser extent, *Quinqueloculina seminulum* can be considered as the most representative species of this coast, independently of the zoogeographic provinces delimited above. In addition, this paper extends the northern range of *Cibicides moyanoi* (see Figueroa et al., 2005) and is the first record of *Anomalinoides incrassatus* in this area.

Ammonia beccarii is a cosmopolitan epipelic-endopelic species (Debenay et al., 1998). It is very common in coastal environments of South America, where it usually coexists with *Quinqueloculina seminulum* and *Buccella peruviana* (Cusminsky et al., 2006; Laprida et al., 2011). *Quinqueloculina seminulum* is frequent in infralittoral areas, although it has been found on the continental slope (Figueroa et al., 2006; Zapata, 1999). On the other hand, *Buccella peruviana* is indicative of the cold-fresh Subantarctic Shelf Water (Eichler et al., 2016) and is usually abundant in upwelling zones (Gomes et al., 2020), such as the study area, although it has a wide distribution in coastal areas in South America (e.g. Bernasconi et al., 2022; Hromic, 2011).

6 Conclusions

The current work supposes a first appraisal of the benthic foraminifera assessment in the infralittoral from northern Chile, with important findings in the presence, distribution and abundance (even first records of species) in relation to sediment characterization:

1. The distribution of these microorganisms is primarily conditioned by the grain size and the hydrodynamic gradient.
2. A comparison with other Pacific coastal areas of South America reveals that *Ammonia beccarii*, *Buccella peruviana* s.l., *Cibicides aknerianus* and *Quinqueloculina seminulum* can be considered as the most representative species of this coastline.
3. The results may be applicable to the paleoenvironmental reconstruction of sediment cores and Pleistocene marine terrace deposits from coastal South America.

This study highlights the knowledge gap and the necessity of further benthic research and sedimentological studies to draw up the past, present and future status of the Pacific coast.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interests The authors declare no competing interests.

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