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UNEARTHING THE CHAÑARAL SHORELINE: HISTORICAL FOSSIL RECORDS AND THE VANISHING CONCHUELAS OF ATACAMA

Desenterrando la costa de Chañaral: Registros fósiles históricos y las conchuelas perdidas de Atacama

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Abstract. This study examines the shelly beds and fossiliferous marine outcrops historically documented along the coast of Chañaral, in the Atacama Region of Chile, by synthesizing nineteenth-century natural history records—including a review of taxonomic mollusk lists—with modern stratigraphic findings. By comparing the observations of naturalists such as Charles Darwin and Rudolf Amandus Philippi with data uncovered through recent paleontological monitoring of public works, the research traces the evolution of this coastal landscape. A central focus is the anthropogenic erasure of these geological features; once-prominent 'conchuela' (shell-limestone) deposits were likely exploited for their carbonate content to support local lime (cal) production. While local toponyms preserve the memory of this geological occurrence, high-energy natural events—including major tsunamis and recurrent flooding of the Río Salado—have effectively masked or buried the sites recorded by early explorers. Recent fieldwork conducted along the parallel northern axis of the Route 5 (Ruta 5) highway corridor rediscovered marine fossil beds, including cetaceans, preserved beneath alluvial sediments of the Río Salado. These findings validate historical accounts while demonstrating that archival natural history data are essential for identifying 'lost' paleontological localities and understanding the long-term impact of human activity on the geological record.

Keywords. Atacama coast, Quaternary uplift, Geo-historiography, Coquina.

Resumen. Este estudio examina los estratos de conchas (conchuela) y los afloramientos marinos fosilíferos documentados históricamente a lo largo de la costa de Chañaral, en la Región de Atacama, Chile, mediante la síntesis de registros de historia natural del siglo XIX —incluyendo una revisión de listas taxonómicas de moluscos— con hallazgos estratigráficos modernos. Comparar las observaciones de naturalistas como Charles Darwin y Rodulfo Amando Philippi con datos obtenidos a través del monitoreo paleontológico de obras públicas recientes permite rastrear la evolución de este paisaje costero. Un enfoque central es la desaparición antropogénica de estos rasgos geológicos; los depósitos de 'conchuela' (caliza de conchas), antes prominentes, probablemente habrían sido utilizados por su contenido de carbonato para sustentar la producción local de cal. Mientras que la toponimia local preserva la memoria de esta ocurrencia geológica, eventos naturales de alta energía —incluyendo grandes tsunamis e inundaciones recurrentes del Río Salado— han borrado, enmascarado o sepultado eficazmente los sitios registrados por los primeros exploradores. El trabajo de campo reciente en el acceso poniente de la Ruta 5 permitió redescubrir niveles de fósiles marinos, incluyendo cetáceos, preservados bajo sedimentos aluviales del Río Salado. Estos hallazgos validan los relatos históricos, demostrando que los datos de archivo de historia natural son esenciales para identificar localidades paleontológicas 'perdidas' y para comprender el impacto a largo plazo de la actividad humana en el registro geológico.

Palabras clave. Costa de Atacama, Alzamiento Cuaternario, Geo-historiografía, Coquina.

INTRODUCTION

The Atacama coastline of Chile has long been recognized as a premier site for observing the interplay between marine deposition and tectonic uplift. Central to this narrative is "conchuela" (Coquina): a local designation for calcareous rocks composed of densely packed marine shells, widespread in coastal bays from Tongoy (30° S) northward. It is distinct from the archaeological "conchales" (shell middens) found in *caletas* (coves) used by coastal prehispanic inhabitants (Jackson et al., 2004), while both may coexist in the same localities, *conchuela* is a natural bioclastic rock rather than an anthropogenic deposit. While these deposits were once prominent surface features noted by early explorers, their apparent disappearance from modern landscapes raises questions regarding geological preservation and historical resource exploitation. This paper seeks to bridge the gap between 19th-century field notes and modern excavations—specifically a 2024 discovery of fossilized whale remains, and some intact "shelly beds" found beneath alluvial deposits of the Río Salado. Located along Ruta 5 highway on the eastern outskirts of Chañaral, these sites sit 34 m above sea level and 3.5 km from the current coastline (Figure 1). By synthesizing historical records with these new findings, this research validates early natural history accounts and identifies a "lost" paleontological locality.

The recent discovery of these buried shelly beds raises questions about the fate of the surface deposits described in historical accounts. While once apparently abundant, they are currently missing from urban areas like Chañaral, likely having been removed for lime production or other industrial purposes. Historically, *conchuela* beds

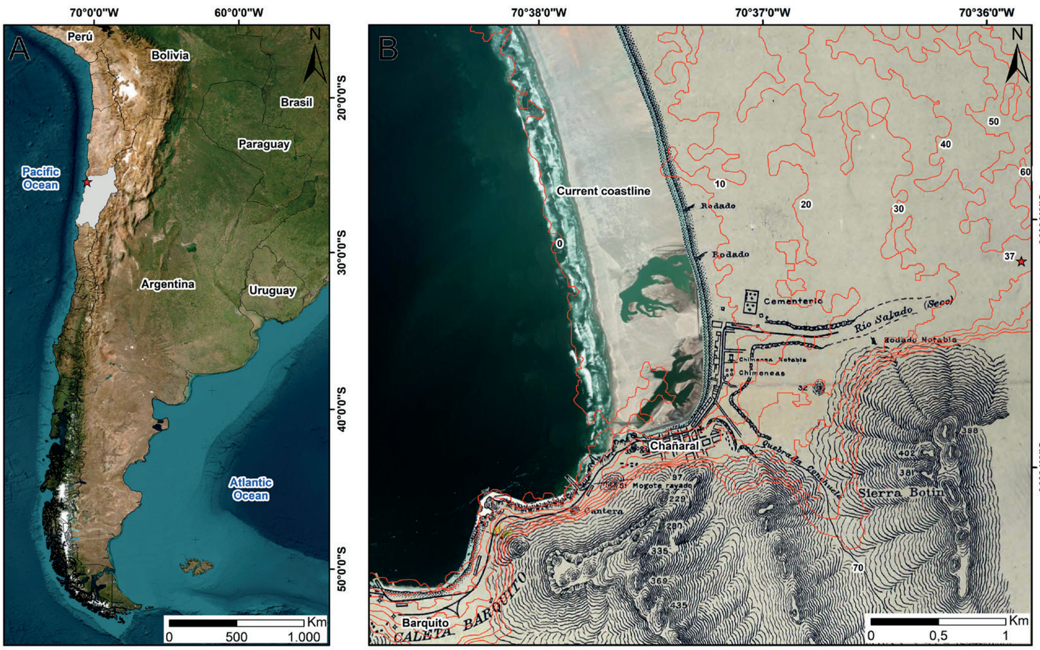

Figure 1 - Historical view of Chañaral de las Ánimas; the present-day coastline and its location in Chile and South America are shown. The star indicates marine sediments. Modified from Armada de Chile (1928) and Landsat.

were not merely geological curiosities but vital economic resources; high-purity shell limestone was systematically harvested and burned in local kilns to produce lime (*cal*) for construction and mining (Chirino-Gálvez and Vicencio-Campos, 2024; Nazer et al., 2016).

This raises a critical question about the fate of these vanishing outcrops and their paleofaunal content—a detail largely overlooked by historical accounts. While all fossils in Chile have been protected as national heritage under Law 17,288 since 1970, their dual classification as a carbonate source or ore under successive Mining Codes long obscured their protection, meaning no effective legal safeguards existed beforehand. In localities like Chañaral, the progressive demise of coastal *coquina* shell-beds stemmed directly from their intensive exploitation to manufacture quicklime (*cal*), a vital resource for both structural mortar and alkaline fluxing in the Atacama copper-smelting industry. For generations, this industrial consumption of biogenic fossils faced no regulatory friction; protection remained completely absent until the promulgation of the National Monuments Law in 1970. Even then, the law lacked operational teeth and remained largely ineffective until Supreme Decree (DS) 484/90 finally enabled rigorous administrative enforcement at the close of the twentieth century. Instead, nineteenth-century extraction operated entirely under the permissive framework of the Mining Code of 1875 (Larraín Zañartu, 1875). Article 3 of that code formally categorized these calcareous strata as "cales," explicitly listing them among the substances subject to private mineral exploitation. Even though contemporary scholars and legal theorists actively debated whether to separate organic paleofaunal remains from industrial mineral ores, the explicit inclusion of "and other fossil substances" (*y demás sustancias fósiles*) alongside materials like coal and limestone in the Civil Code taxonomy left these invaluable paleontological horizons legally exposed to unregulated industrial consumption (Donoso, 1873) —a legal reality that directly drove the widespread destruction of shellbeds around smelting towns across Northern Chile.

Consequently, identifying the original fossil assemblages in areas where the outcrops have been destroyed is a significant challenge. Historical extraction, combined with urban expansion, has largely removed the surface of *conchuela* layers described by Darwin and other voyagers in this area over a century ago. Nevertheless, this legacy survives in Chañaral's toponymy, where names like "Calle Conchuela" and an adjacent creek mark the former locations of these deposits.

MATERIALS AND METHODS

This study employs a historiographical approach to rediscover and analyze the "shelly beds" recorded along the Atacama coast. The primary methodology involves a critical review of 19th-century accounts, maps, and iconography, focusing on Charles Darwin's 1835 diaries and 1846 *Geological Observations*. These records were cross-referenced with the foundational surveys of Rodulfo Amando Philippi (1860), and other early explorers and surveyors to reconstruct historical observation sites on the coast of Atacama. To validate these archival findings, we integrated recent stratigraphic data and paleontological monitoring conducted since 2024 during the Río Salado riverbed public works project on Ruta 5 highway. Subsurface sampling and the documentation of a newly exposed vertebrate macro-fossil site were used to identify historical gaps in the region's official geological record.

RESULTS

Historical Background

A clear chronological sequence of observations emerges from a historiographical review of archival records and early geological maps. By synthesizing these accounts—beginning with Amédée-François Frézier in 1713 and continuing through the foundational works of Claudio Gay, Charles Darwin, Ignacio Domeyko, Rodulfo Amando Philippi, and Amado Pissis—this study reconstructs the historical record of the *conchuela* beds (Figure 2). These documents reveal a consistent pattern of surface outcrops that were once prominent features of the Atacama landscape, providing a vital baseline for modern geological comparisons.

One of the first reliable scientific and cartographic accounts of the Atacama coast was written by Frézier (1716). Since no coastal towns had been established at the time, he referred to the region as part of the "Coast of Copiapó," noting that the shore was "entirely covered in shells" (p. 141).

The Darwinian Baseline (1835)

The second most significant account stems from Charles Darwin's 1835 voyage aboard the *HMS Beagle*. While Captain FitzRoy's hydrographic team surveyed the coastline (Fitzroy, 1838; Medina, 1889), Darwin traveled overland from Valparaíso to Caldera, where he eventually rejoined the ship. During this expedition, Darwin visited coastal areas near Coquimbo, Caldera, and Chañaral de Aceituno, documenting elevated shell beds situated several meters above current sea level. Accompanied by his assistant, Symms Covington, he collected specimens that were later described by Sowerby (Darwin, 1846).

In his *Geological Observations on South America* (1846), Darwin argued that these beds provided empirical evidence for the gradual and episodic uplift of the South American continent. He documented the presence of *conchuela*—elevated calcareous rocks composed of modern marine shells—situated high above the current tidal reach. Darwin noted that these shells were often found in a state of partial decay, forming a "calcareous powder" in the arid climate. He also recorded the economic utility of these deposits, noting their use in lime production following a visit to the Hacienda of Quintero (Darwin, 1838). While Darwin's field notes focused on specific stops, he concluded that coastal uplift was a continental phenomenon. He remarked that elevated shell beds and marine terraces were consistent features across nearly 35 degrees of latitude, ranging from Chiloé (42° S) to

Figure 2 - Major voyagers and surveyors who described this coastal area of Atacama. From left to right: Frézier (**A**), Gay (**B**), Darwin (**C**), Philippi (**D**), and Pissis (**E**).

Paita, Peru (5° S). This observation was later compiled by Charles Lyell in his *Principles of Geology*, where he linked Darwin's findings to tectonic forces. Lyell supported this by citing the 1835 earthquake and Maria Graham's 1822 report, which described "several older elevated lines of beach... consisting of shingle mixed with shells" reaching fifty feet above the sea (Lyell, 1843, p. 436).

Other naturalists' records

French naturalist Claudio Gay collected fossil and recent invertebrates at Bahía Inglesa in 1841, which later enabled Hupé (1854) to describe two new fossil species. Ignacio Domeyko had been surveying the region since 1838 and, alongside Gay, was among the first to document the vast marine shell beds (coquinas) situated high above the current sea level. Domeyko (1875) famously described the landscape as "a nearly horizontal plain that rises by degrees or steps, and on its surface or immediately beneath it, slabs of shelly limestone rocks**.**" These early naturalists categorized these fossiliferous strata as Tertiary formations, distinguishing them by their "remains of fossil mollusks, similar to living ones, which undoubtedly belong to the transition of the Tertiary and Quaternary epochs" (as cited in Gotschlich, 1914).

In the summer of 1853–1854, the German naturalist Rudolph Philippi was commissioned by the Chilean government to explore the Atacama Desert. His primary coastal stopover in the region was Caldera, where he observed and meticulously documented the highly fossiliferous nature of the outcrops exposed along the coastal terraces and cliffs. Notably, not far from the shore, he located a ravine where he measured and drafted a stratigraphic section (Figure 3), commenting: "This same small ravine had in its upper part, at a distance of a league and a half from the sea, perpendicular walls about 12 feet high, which gave a very precise idea of the formation of these places. Immediately beneath the loose sand (**a**), which the winds bring from the beach, there is a thick layer, about four feet deep, of a conglomerate composed almost entirely of shells and shell fragments, which resists weathering better than the lower layers and is consequently prominent over them (see **b**). The shells all seem identical to those that the sea washes up on the beach. The following layer (**c**), one foot thick, contains many round pebbles ranging from the size of a walnut to that of an apple, which originate partly from granite, porphyry, and diorite. The bottom layer (**d**) is composed of a fine, brown sandy marl, containing about thirty thin layers—scarcely a line and a half thick—which are whitish and resist decomposition by air better than the marl itself; to my great admiration, I recognized that they were of very pure common salt. All these layers are horizontal."

This historic layout constitutes the earliest traceable graphical representation of the Quaternary marine sequences in coastal Atacama. To provide a modern lithological calibration, Philippi's original 1860 field illustration (right) is contrasted directly with a newly constructed parallel log (left) that standardizes his original stratigraphical measurements and layer descriptions using modern symbology (Figure 3).

There, Rudolph Amandus Philippi also observed that near the coast (up to 5 km inland), the surface was often covered with "countless marine shells", saying that these were typically Quaternary mollusk fragments similar to those found on modern beaches, reflecting high-energy coastal deposition. The following coastal stopover further north was Chañaral de las Ánimas, a recently settled little coastal hamlet used as the port for the Animas and Salado mines located inland close by (Figure 4).

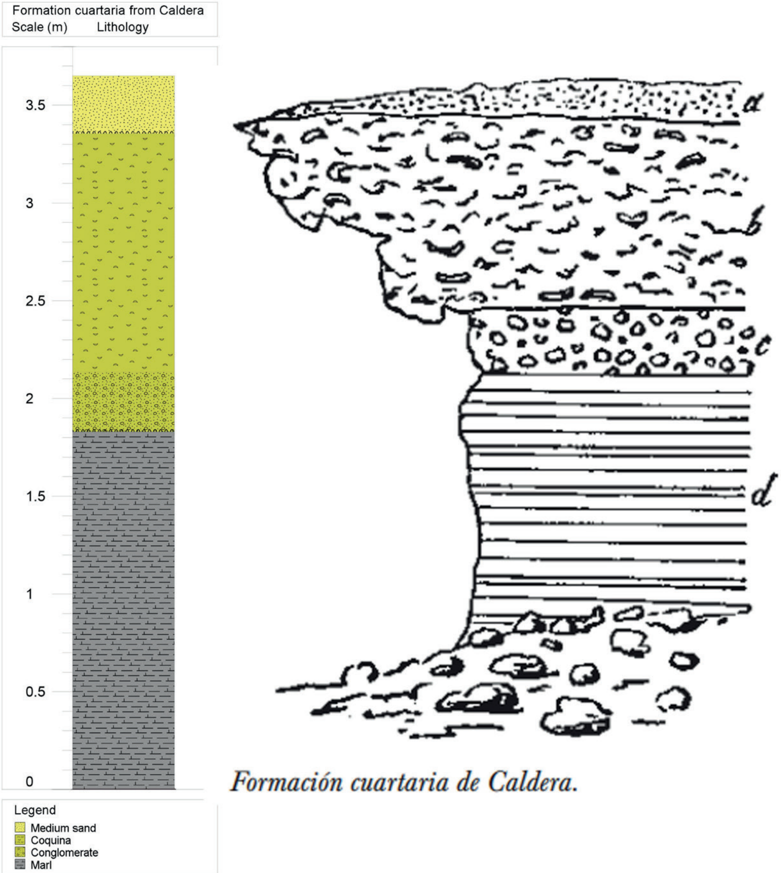

Figure 3 - Quaternary marine bed section (Philippi, 1860).

Figure 4 - View of Chañaral de las Ánimas hamlet in 1853 (Philippi, 1860).

Philippi travelled through the dry valley of the Río Salado trail, and commented that only twice in a century—and aided by strong rainfalls—did the water rearch the sea, as was verified in 1848 (Philippi, 1860). His description stated that "The valley runs from East to West and is almost straight; it is half a league wide and is composed entirely of sand and gravel, the product of the decomposition of the nearby hills. From all the ravines, enormous masses of gravel emerge, rising to a great height on the slopes of the hills—a common phenomenon at this latitude, yet difficult to explain, which did not escape Darwin's notice, who was greatly amazed to see this gravel reach a height of 2,000 feet (see his *Journ. of researches, etc.*, 2nd ed., p. 318)" coinciding with what Darwin had observed in the Copiapó valley further south.

While Philippi explored the Atacama Desert, the geographer Amadée Pissis was surveying the region to produce its first geographical and mineralogical maps. Pissis (1875) identified what he described as the youngest "sands with shelly beds," noting that "this formation is found once again near Huasco, in Chañaral, in Coquimbo, and in Tongoy" (p. 268).

A more detailed account comparing Tertiary and Quaternary fossiliferous outcrops on the coast of Coquimbo and Atacama was written by A. Rémond (1867). The specimens he collected were identified by Philippi; Rémond, like others before him, recognized Quaternary Sea beaches up to 150 m.a.s.l and compiled a list of 19 mollusk species already recorded in published reports. Among these, he noted *Pecten purpuratus* as one of the few fossils in the lower division found in a perfect state of preservation, unlike many other fragmented remains.

Industrial Erasure and the "Cal" (Lime) Legacy

The rapid "disappearance" of these surface features around urban areas throughout the late 19th and early 20th centuries was primarily driven by industrial extraction rather than natural geomorphological processes. High-purity *conchuela* (coquina) was systematically harvested by local settlers and mining operations for a dual purpose: either calcined into quicklime (cal) for structural mortars or, as documented by Nazer et al. (2016), fed directly into reverberatory furnaces as a raw alkaline fluxing agent. This massive chemical addition was essential for lowering the melting point of silica-rich copper ores, leaving a distinct signature of 8% to 26% calcium oxide (CaO) trapped by weight within the historical slags of the large corporate smelting companies in Chañaral and Caldera.

Consequently, the contemporary toponymy of Chañaral—most notably Calle Conchuela and its adjacent creek (*Quebrada Conchuela*)—functions as a linguistic fossil. These names mark the geographical locations where prominent paleontological and geological outcrops were historically quarried into oblivion (Figure 5). Monroy (2000) notes that this specific toponymy originally reflected the dense abundance of pristine marine shell assemblages exposed along the northern boundaries of the town during its early 19th-century settlement. Over time, these residual geological features were doubly obscured: first by intensive industrial harvesting for the lime kilns, and subsequently by thick, successive sequences of historical alluvial deposits carrying mining tailings from the recurrent flood pulses of the Río Salado basin (Monroy, 2000).

The geological nature of these deposits is further confirmed by Rudolph Philippi (1860), who, during his 1854 crossing of the Río Salado, documented the presence

Figure 5 - Crossing between the main street (Merino Jarpa) and the former Conchuela creek.

of shell-bearing sands in the same coastal strata later described by Pissis (1875). This reinforces the argument that the toponymy 'Conchuela' stems from a widely recognized bioclastic formation rather than the archaeological *conchales* mistakenly suggested by later historians, like Monroy (2000).

The former shelly bed recorded by the local toponymy is currently covered by a street running along the old Conchuela creek that was occupied by the earlier Chañaral´s urban growth along the flats of the main street (Merino Jarpa) of this mining port, and finally, it was washed away, together with the surrounding buildings, by the major tsunami that occurred in 1922 (Cereceda et al., 2011).

Furthermore, any shell deposits along the inland shore north of Chañaral Bay would have been obliterated by floods and anthropogenic sedimentation associated with mining tailings. Between 1926 and 1974—particularly from 1938 onwards (Olave, 2025)—more than 150 million tonnes of tailings from the Potrerillos copper mine were discharged into Chañaral de las Ánimas Bay, covering an area of approximately 4.5 km² (Neary and García-Cevesich, 2008). Tailings discharge continued until 1975, directly affecting more than 20 km of coastline (Paskoff & Petiot, 1990) and extending the shoreline seaward by over 1 kilometer. At the mouth of the Río Salado, these accumulated mining tailings formed a 10- to 15-meter-thick progradational layer directly on top of the original beach sediments as documented by Wisskirchen and Dold (2006). Over time, this artificial deposit has served as a continuous source for aeolian sands; driven by prevailing winds, these fine sediments have blanketed the coastal zone of Chañaral Bay, migrating inland to encroach progressively upon the townsite and local infrastructure.

The 1922 Event: Earthquake, Tsunami, and Alluvial Aftermath

The geological record of Chañaral would have been further obscured by a series of catastrophic events in the 20th century (Figure 6). The Great Atacama Earthquake and Tsunami of November 10, 1922, delivered a 9-meter surge that scoured the coastal shelf, physically removing surface deposits (Cereceda et al., 2011). Simultaneously, the erratic hydrology of the Río Salado has triggered multiple "aluviones" (mudflows), most notably in 1929, 1972 and 2015, and those in May of 1848, in 1859 and 1877 in the XIX century (Vidal Gormaz, 1881). The average width of the bed through the XIX century was stated to be 2.5 km wide and it is recorded that already was covered with sand and gravel (ripio). These events have worked as a "geological reset," burying the 19th-century landscape under meters of sediment and mud. This burial protected the deeper, intact shell beds from further industrial extraction, effectively sealing them away from scientific view for over a century.

Since its establishment as a port hamlet in 1833, Chañaral has maintained a record of significant historical events, including tsunamis and recurrent flooding within a 2.5 km wide Río Salado riverbed (Vidal Gormaz, 1881). Accounts detailing the evolution of this mining port frequently cite major inundations from the Río Salado, alongside the devastating impact of the 1922 tsunami. Based on these historical accounts and cartographic data, a new graphic compilation is presented here, illustrating the landscape's evolution of the area (Figure 7).

As observed, the coastline has consistently prograded westward over time. Furthermore, the 1922 tsunami inundation penetrated significantly inland, causing extensive erosion along the Río Salado and the former Conchuela Creek. Concurrently, particularly from 1928 onward, frequent flooding of the Río Salado—as-

Figure 6 - Chañaral view after Tsunami of 1922 (**A-C**) and the Chañaral view after 1972 Flood. Source: Museo Regional de Atacama.

Figure 7 - Landscape evolution of Chañaral: 1898 (**A**); 1922 (**B**); 2013 (**C**); 2025 (**D**). Own elaboration based on San Roman (1898), Marina de Chile (1928), SHOA (2001), and Google Earth.

sociated with mine tailing sedimentation and pollution—has progressively infilled the bay.

The earlier fossil record

While early accounts frequently mention these widespread shell beds—particularly in the Caldera area—where urban and industrial expansion has since obliterated many of these deposits near modern cities. As previously suggested, these beds were historically exploited as a primary source of carbonate for lime production in cities such as La Serena, Coquimbo, and Tongoy (Chirino-Gálvez and Vicencio-Campos, 2024). The earliest descriptions, dating back to Juan and Ulloa in 1744, identified several species within the *conchuela*, including 'choros' (Mytilidae), 'pies de burro' (*Concholepas concholepas*), and 'bulgados' (various gastropods and clams).

During his 1835 travels, Darwin detailed the stratigraphy and fossil content of these beds further south, specifically around Coquimbo and somewhat at Chañaral de Aceituno. Upon visiting the coast of Copiapó, he noted the same shell beds composed of *coquina*, where he identified a giant oyster species. An early account listing several of these species was later provided by Sowerby (in Darwin, 1846**)**. Years later, Philippi (1860**)** visited the coastal area around Caldera, and observed that the shells scattered across the coastal terraces appeared identical to species living on the modern shore. He identified these specimens as *Donacilla chilensis*, *Solen dombeyi*, *Venus rufa*, *Concholepas* sp., *Oliva* sp., and *Turritella angulata*. Subsequently, Philippi compiled the first paleontological monograph describing Cenozoic Chilean fossils, offering an extensive review of regional fossil marine invertebrates that explicitly included several Atacama localities (Philippi, 1887). Since the original historical taxonomic names used in the nineteenth century and established by d'Orbigny (1842), Hupé (1854), Philippi (1887), and Möricke (1896) have been extensively revised (e.g. Guzman et al., 2000; Griffin and Nielsen, 2008; Santelli and del Rio, 2019), an updated species inventory is provided in Table 1.

Table 1. Comparative register of historical 19th-century designations and current valid taxonomic nomenclature for fossil marine invertebrates from the Atacama coastal region.

Historical 19th-Century Designation	Modern Scientific Name	Group
Donacilla chilensis	*Mesodesma donacium* (Lamarck, 1818)	Bivalve (Macha)
Pectunculus aff. intermedius	*Glycymeris (Glycymeris) ovata (*Broderip, 1832)	Bivalve (Clam)
Solen dombeyi	*Tagelus dombeii* (Lamarck, 1818)	Bivalve (Navajuela)
Venus rufa	*Eurhomalea rufa* (Lamarck, 1818)	Bivalve (Almeja/Taca)
Venus domeykoana	*Amiantis domeykoana* (Philippi, 1887)	Bivalve (Clam)
Venus fuenzalidai	*Eurhomalea fuenzalidai* (Philippi, 1887)	Bivalve (Clam)
Pecten vidali	*Dietotenhosen hupeanus* (Philippi, 1887)	Pectinidae (Scallop)
Pecten purpuratus	*Argopecten purpuratus* (Lamarck, 1819)	Pectinidae (Scallop)
Concholepas sp.	*Concholepas concholepas* (Bruguière, 1789)	Gastropod (Loco)
Concholepas nodosa	*Concholepas nodosa* Möricke, 1896	Gastropod (Loco)
Monoceros blainvillei	*Chorus blainvillei* (d'Orbigny, 1842)	Gastropod (Snail)
Monoceros crassilabrum	*Acanthina monodon* (Pallas, 1774)	Gastropod (Snail)
Monoceros doliaris	*Chorus doliaris* (Philippi,1887)	Gastropod (Snail)
Monoceros giganteus	*Chorus giganteus* (Lesson, 1831)	Gastropod (Snail)
Turritella cingulata	*Incatella cingulata* (Sowerby, 1825)	Gastropod (Snail)
Turritella cingulatiformis	*Incatella cingulatiformis* (Möricke, 1896)	Gastropod (Snail)
Fusinus steinmanni	*Austrofusus steinmanni* (Möricke, 1896).	Gastropod (Snail)
Oliva sp. / *O. buchanani*	*Oliva peruviana* Lamarck, 1811	Gastropod (Snail)

In his 1969 monograph, Dietrich Herm analyzed the Pliocene and Pleistocene marine formations in northern and central Chile, focusing on mollusk fauna development. Within the Caldera basin, he originally assigned a Plio-Pleistocene age to the Bahía Inglesa Formation, utilizing malacological assemblages to infer local paleoenvironments and paleoclimatic shifts—specifically noting a distinctive regional cooling trend. Furthermore, Herm correlated marine terraces spanning nearly ten degrees of latitude, from Mejillones (23° S) in the north to Cachagua (32°35′ S) in the south, using the intermediate Caldera sequences (27°04′ S) as a central reference. By identifying uniformity in the malacological assemblages overlying the older crystalline basement rocks, he successfully established the macro-regional continuity of these Pliocene and Pleistocene marine localities (Herm, 1969). A comparison of Herm's historical datasets with recent findings along the Río Salado in Chañaral reveals that the dominance of species such as *Argopecten purpuratus* aligns with the middle Pleistocene terraces situated between 30 and 40 m a.s.l.

Figure 8 - Historical Quaternary localities with marine terraces in Northern Chile.

Consequently, a compilation of the northern Chilean localities historically recorded with comparable 'shelly beds' and marine terraces includes, from north to south: Mejillones, Pan de Azúcar, Caldera, Bahía Inglesa, Chañaral de Aceituno, Caleta Hornos, Coquimbo, and Located between Pan de Azúcar and Caldera, this new record from Chañaral extends the known distribution, and validates a historical fossil locality previously uknown to recent researchers (Figure 8).

Modern Paleontological Monitoring tracing the past

The "missing" geological heritage of Darwin's era has been re-exposed through modern infrastructure development. During two years of monitoring public works in the Río Salado bed bordering Ruta 5 (the Pan-American Highway) on the eastern outskirts of the town, the authors observed a previously unrecorded fossil bed (Figure 9). The subsurface stratigraphy and fossil remains were remarkably consistent with those currently defined as the Estratos de Caldera. Researching these findings revealed that these 'shelly beds' had been cited in 19th-century accounts. Beneath layers of 20th-century alluvial

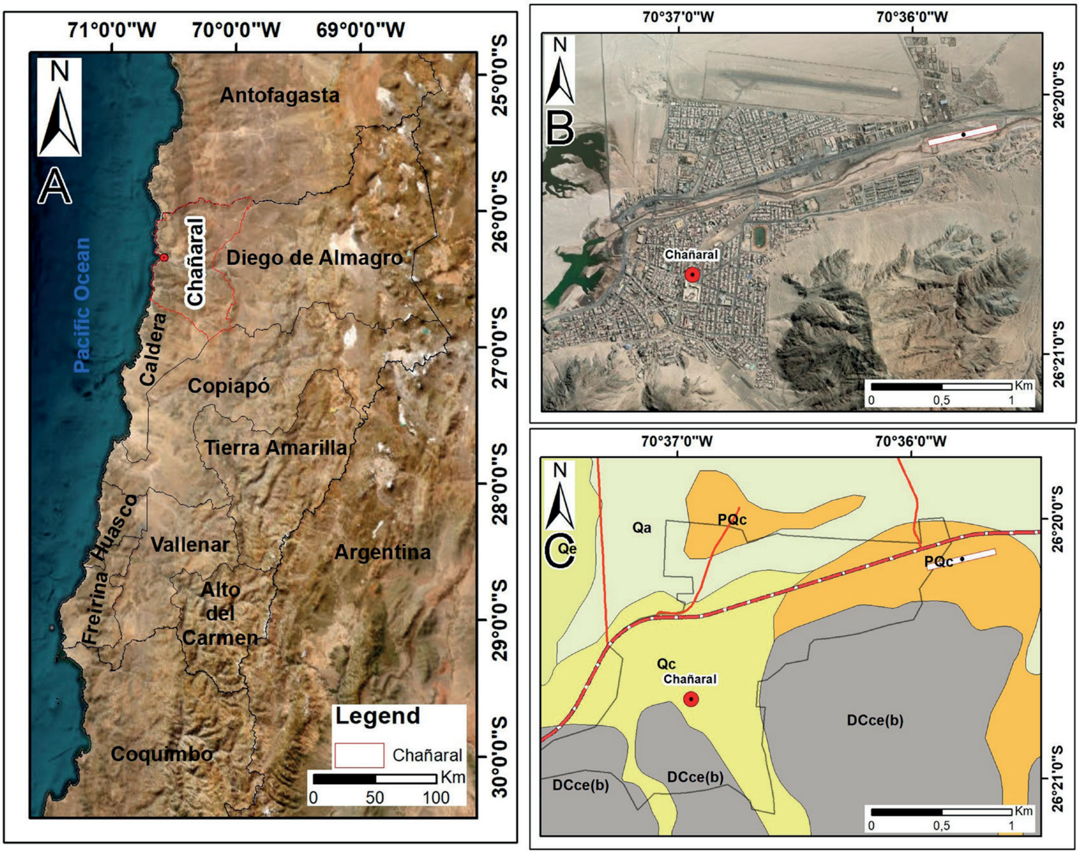

Figure 9 - Chañaral localities and local geology. **A**, Geographical location; **B**, Recent excavation area in white; **C**, Geological map framework (modified from Godoy and Lara, 2005).

mud and associated with older colluvial deposits (PQc), calcareous shell beds and some fossilized whale remains were identified.

This find confirms that the *conchuela* beds were not merely shallow surface accumulations but are part of a significant marine sequence better known further south. While the surface rocks observed by Darwin and other naturalists were likely consumed by lime kilns when they were not thick enough to persist, or were buried or eroded by floods and tsunamis, the deeper record—including large marine vertebrates—would have remained intact. These deposits have awaited the episodic, massive excavations of the 21st century—like those documented further south at Cerro Ballena near Caldera—to bring this evidence back to light (Pyenson et al., 2014).

Subsurface preservation is not exceptional. Excavations 3 to 4 km from the current shoreline along Ruta 5 highway revealed that while surface layers were depleted, some calcareous shell beds—often cemented with sandstone—persist at depth. These layers contain high concentrations of molluscan fossils, including *Argopecten purpuratus* and mytilids like *Choromytilus giganteus*, consistent with Darwin's original descriptions. A significant highlight of this inquiry is the discovery of cetacean remains embedded within the lower, shell-rich levels. This find provides a higher-resolution paleobiological marker than previously recorded surface fragments, suggesting a catastrophic or high-energy depositional event in a near-shore environment.

Stratigraphy and History

Since Darwin's first observations in 1835, early voyagers recognized these *conchuela* pavements associated with a series of marine terraces along the Atacama coast. These features were studied early on further north in Mejillones and further south in Caldera and Coquimbo. However, the definition of the stratigraphic setting remained unclear until the turn of the century (Godoy and Lara, 1998). At that time, the area adjacent to the fossil locality was described through several informal sedimentary units, including alluvial (Qa), colluvial (Qc), aeolian (Qe), and inactive colluvial (PQc) deposits, according to the Chañaral and Diego de Almagro Sheet (Godoy and Lara, 1998) and the Western El Salvador Sheet, Atacama Region (Godoy and Lara, 2005). Local sedimentary deposits in the dry bed of the Río Salado are characterized by the transport of consolidated fluvial material through layers of fine alluvial deposits. Beneath these layers lies a calcareous substrate rich in silicon, calcium, iron, and aluminum. This base is primarily composed of a densified sand matrix containing shells and petrified mollusks that would relate to Estratos de Caldera.

Modern technical descriptions provided by standard geological maps (Godoy and Lara, 1998, 2005) remarkably validate Philippi's 1860 intuition. Specifically, the weather-resistant fossiliferous 'layer b' described by Philippi in the cliffs near Caldera corresponds to the Estratos de Caldera (Marquardt, 1999). This unit, equivalent to the Pan de Azúcar Littoral Deposits (Qlp), consists of up to two meters of sand, silt, and coquinas.

Recent field observations by the authors along the Río Salado riverbed (Figure 10A) confirm that these partially cemented, fossil-rich levels—containing taxa such as *Concholepas concholepas*, *Argopecten purpuratus*, and various clams and mytilids—remain hidden from view (Figure 10B-C). They are covered by alluvial and aeolian sediments and lie directly above the Inactive Colluvium (PQc). While the PQc represents a Late Miocene to Pliocene timeframe (6.3 to 2.9 Ma), the Qlp unit identified during the monitoring process confirms a Quaternary age (Herm, 1969).

The sequence is capped by anthropogenic sediments, identified in modern texts as 'sediments of anthropic origin' integrated within the fine-to-medium-grained active dune sands (Qe). This modern layer represents a historical change Philippi could not have witnessed: the 20th-century environmental impact of mining in Chañaral. Between 1938 and 1990, 330 millions of tons of untreated tailings from Salvador-Potrerillos were dumped into the Río Salado (Neary and García-Cevesich, 2008), where recurrent catastrophic floods subsequently carried these tailings in the riverbed and along the coast. This process has fundamentally altered the coastal sedimentation and geomorphology he originally described, creating a distinct 'anthropic' stratigraphic layer that marks the region's recent industrial history.

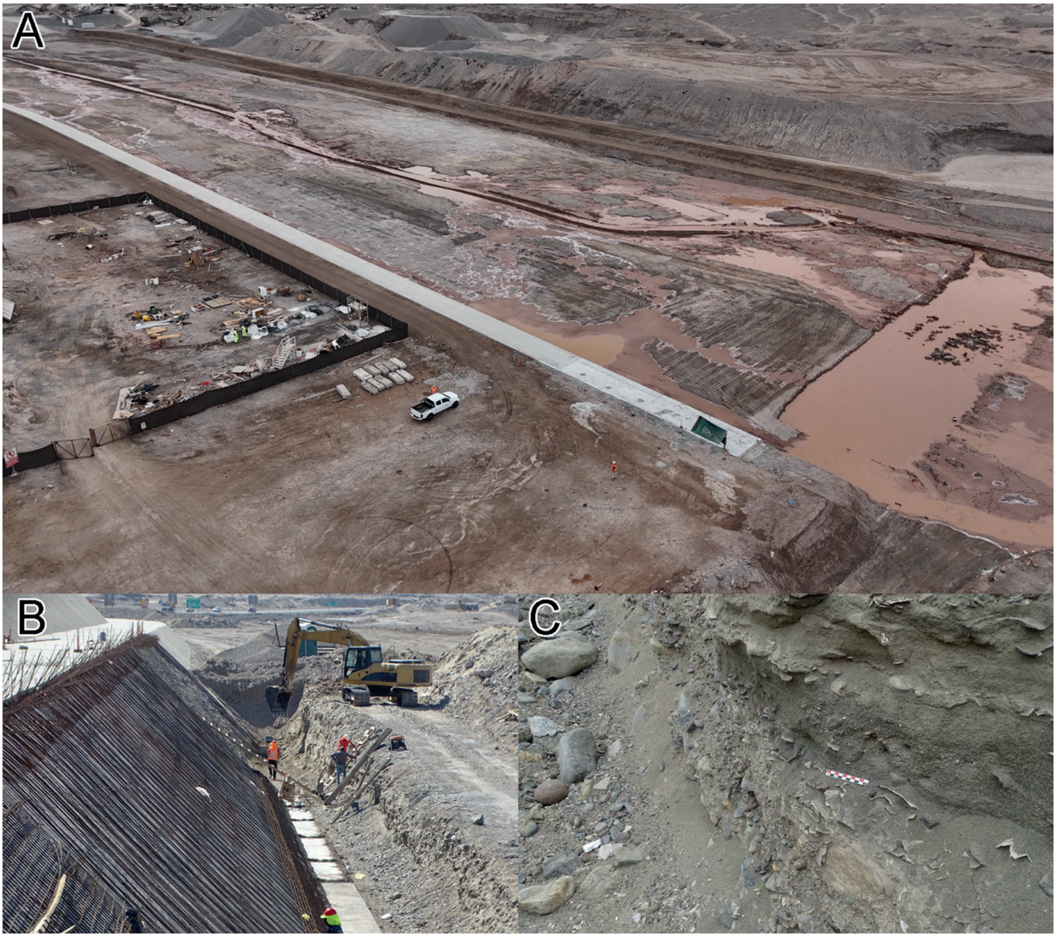

Figure 10 - Exposure of shelly beds found during public works excavations, Río Salado. A) Aerial view following rainfall 02/2026. B) River floodwall construction. C) Fossiliferous outcrop

DISCUSSION

Historical accounts record the presence of 'shelly beds' (*conchuela*) outcropping within the marine terraces identified by Darwin and others during the 19th century. While these beds were widely accepted as evidence of marine terrace uplift, their relative age remained a point of debate, except for Pleistocene deposits containing extant species. The comparison of these historical observations with recent findings reinforces Darwin's theory of 'slow mutation' and gradual uplift through the presence of beds at varying elevations. However, the discovery of an unreported fossil locality containing whale remains now allows for more complex taphonomic interpretations beyond simple coastal elevation —found at approximately 34 m.a.s.l.—by contrasting them with those recorded at similar terrace features further south in Caldera and further north at Pan de Azúcar (Table 2).

The stratigraphic sequences identified along 108 linear kilometers between Pan de Azúcar and Caldera have preserved small hidden outcrops within several bays; with a trend where the shelly beds seem to be

Table 2. Comparative geological and paleontological features of Neogene and Quaternary units in Atacama.

Features	Bahía Inglesa (Caldera)	Estratos de Caldera (Coastal Area)	Pan de Azúcar (Terraces)
Pectinids	*Dietotenhosen hupeanus* (Abundant)	*Argopecten purpuratus* (Abundant)	*Chlamys* spp. (Fragmentary)
Index Fossils	*Otodus megalodon*, cetaceans, penguins	*Mesodesma donacium*, *Concholepas* sp.	Scarce fish, *Chorus* sp, and bird remains
Formation	Bahía Inglesa (High thickness)	Estratos de Caldera (Marine terraces)	Depósitos de Terrazas Marinas Pleistocénicas
Main Facies	Deep to shallow marine	Littoral/Shoreline (8 levels of terraces)	Shallow marine terraces
Abundance	Massive shell beds (Coquinas)	Continuous fossiliferous beds	Scattered fossiliferous lenses
Conservation	High (articulated specimens)	High (well-preserved shells)	Mostly molds and calcified shells
Age	Middle Miocene - Pliocene	Pleistocene – Holocene	Pleistocene

thicker and more abundant in the south and thinner in the north, specifically, this new Chañaral finding allows for a direct comparison between competing geological theories. These findings contrast 19th-century 'gradualism' with modern catastrophic deposition theories. While Darwin focused primarily on the elevation of the marine beds as evidence of slow, steady uplift, these new data emphasize the depth and complexity of a record that remained shielded from the anthropogenic impacts—such as mining sedimentation— mixed with natural ones such as recurrent floods and tsunamis that have since altered the regional landscape.

Historical Discrepancy: Navidad vs. Atacama Formations

Darwin formally described the Navidad Formation (Central Chile, 34° S) in 1846, identifying it as a reference for Miocene marine beds. Also, he described the Coquimbo Formation (Norte chico, 31° S). However, when he observed the younger shell beds and *conchuela* in the north, he lacked a formal equivalent. Recent findings along the Río Salado and Ruta 5 highway likely belong to Pleistocene Estratos de Caldera or the Pan de Azúcar sequences, which were only defined at the end of the 20th century to categorize the specific Pliocene and Pleistocene records of the Atacama region (Marquardt *et al*, 2000; Godoy and Lara, 1998). Since Darwin's first studies, these younger strata have been recognized by their fossil content too, because the taxa are practically indistinguishable from those currently living today. Conversely, those older Miocene formations such as Navidad are different in its taxa composition. Therefore, the following comparative table is presented here to illustrate these features (Table 3).

Whale remains have also been identified within the shelly beds at Chañaral. This fossil discovery provides a likely analogue to the younger strata of the Cerro Ballena Member (Bahía Inglesa Formation), a site renowned for mass strandings of baleen whales and other marine mammals (Pyenson et al., 2014).

On the other hand, the *Conchuela* beds require specific stratigraphic clarification. Darwin's observations typically conflated the Estratos de Caldera (the Pleistocene sur-

Table 3. Summary of geological units and their relevance to historical paleontological observations.

Unit	Age	Primary Lithology	Significance for these finds
Estratos de Caldera / Pan de Azúcar (Qlp)	Pleistocene	Marine terraces, sands, silts, and coquinas	Represents the fossiliferous "layer b" (Philippi) and the "conchuela" surfaces documented by Darwin; often overlies older units.
Bahía Inglesa Formation	Miocene – Pliocene (16 – 2 Ma)	Fossiliferous sandstones, coquinas, and marls	Hosts world-class marine vertebrate bonebeds (e.g., Cerro Ballena); consistent with fossil whale occurrences.
Coquimbo Formation	Pliocene – Pleistocene (5 – 0.5 Ma)	Calcareous sandstones, coquinas, and conglomerates	A key historical reference for Darwin and Philippi; represents the extensive shell-rich terraces of the semi-arid north.
Navidad Formation	Miocene	Sandstones and siltstones	Darwin's original type-locality; serves as the historical baseline for Neogene marine correlations in Chile.

face terraces he walked upon) with the much older Bahía Inglesa Formation. It should be noted that while the surface shells—whether archaeological (conchales) or from exposed fossil beds (conchuela)—were historically harvested for lime (*cal*), the deeper subsurface shelly beds (Qlp) remained obscured. These hidden stratigraphical horizons were only recently revealed when distinct lenses and levels were exposed during excavations for the Defensas Fluviales del Río Salado public works project, which runs parallel to the Ruta 5 highway along the northern side of Chañaral.

Finally, with regard to tectonic implications, modern dating of the Estratos de Caldera—using 21Ne cosmogenic exposure—reveals an average uplift rate of ~0.28 mm/year over the last 860,000 years (Quezada et al., 2007). This provides a precise modern measurement for the 'gradual elevation' that Darwin could only hypothesize during his 1835 observations.

CONCLUSIONS

Linking the observations of 19th-century naturalists—including Charles Darwin, the hydrographic surveyors like Fitzroy, Vidal Gormaz, and the accounts of Rodulfo Philippi—with modern findings, a clear pattern of coastal evolution emerges. Chilean localities like Chañaral have been sites of rapid change, where urban growth, industrial consumption, and natural disasters (such as earthquakes and floods) have frequently obscured or eroded the geological record. These recent discoveries validate the "gradual uplift" theories of 1835 while adding a new dimension of catastrophic preservation. This study reaffirms that monitoring public works is a critical tool for modern Natural History, enabling the reconstruction of scientific heritage that early pioneers could only witness as surface features.

Ultimately, the "missing" *conchuela* of Chañaral is a consequence of urbanization and historical local consumption rather than geological absence. The 2024 discovery of intact shell beds and cetacean fossils nearby—unearthed beneath Ruta 5 highway— confirms the foundational observations of naturalists such as Darwin, Domeyko and Philippi, while adding a previously unrecorded paleontological locality to the region's history.

This research demonstrates that urban toponyms (e.g., *Calle Conchuela*) serve as reliable indicators, providing vital clues to locate and assess "hidden" geological heritage while reconstructing the decline of what was once most likely a thin, prominent surface outcrop.

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