COMMENT

Comment on Reply to Comment of Finger *et al.* (2013) on: 'Evidence for an Early-Middle Miocene age of the Navidad Formation (central Chile): Paleontological, paleoclimatic and tectonic implications' of Gutiérrez *et al.* (2013, Andean Geology 40 (1): 66-78)

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In their answer to our Comment (Finger *et al.*, 2013), Le Roux *et al.* (2013) misunderstand several of our remarks and present what we view as flawed arguments, principally their case for a shallow-marine environment for part of the Navidad Formation. We do not wish to see this exchange evolve into an endless discussion, but we feel obligated to clarify some points. We think this is necessary because of history and importance of the Navidad Formation as the reference for the marine Miocene of Chile. Here we also expound upon some concepts relevant to the distinction between shallow-and deep-marine environments.

1. Age of the Navidad Formation

Finger *et al.* (2013) agrees with Le Roux *et al.* (2013) that at least part of the Navidad Formation was deposited during the Early Miocene, although we have some doubt about the reliability of younger radiometric ages derived from pumice clasts because the isotopic signature could have been slightly altered during transport (Finger *et al.*, 2013). The negative opinion of biostratigraphy expressed by Le Roux *et al.* (2013), however, must be addressed because the

discipline plays vital roles in geologic correlation and our understanding of earth history.

We agree with some of the problems encountered with biostratigraphy that were pointed out by Le Roux *et al.* (2013). Pitfalls of this science have been recognized for a long time, and they have been described in detail in several texts (*e.g.*, Miall, 1999). One of the problems is that a fossil species is recognized according to its original description, which is typically of the specimen designated and illustrated as its holotype. Every paleontologist recognizes the subjectivity involved in identifying a form that differs slightly from the holotype they most closely resemble. As with most uncertainties stemming from using a single approach to decipher a complex problem, they can often be recognized and possibly resolved when they are part of a multidisciplinary approach, and as relevant empirical data becomes available. For instance, imagining an example similar to that of the coelacanth presented by Le Roux *et al.* (2013), no geologist would give credit to a Sr or K-Ar Miocene date obtained from a sedimentary succession containing fossils of rudists in living position, ammonites, and plesiosaurs because an immense number of observations indicate that

those taxa went extinct in the Cretaceous-Palogene boundary. The results of other age-dating methods can orient the paleontologist toward published faunas of the indicated age, which is particularly helpful in identifying species that may be difficult to distinguish among the collected specimens. In the case of the Navidad Formation, different methods produced inconsistent results that indicated Early, Middle, and Late Miocene or younger ages (Finger *et al.*, 2013 and references therein), with all previous studies on the planktic foraminifera having identified species indicative of Late Miocene or younger ages (Dremel, in Herm, 1969; Martínez-Pardo and Osorio, 1964; Cecioni, 1970; Ibaraki, 1992; Finger *et al.*, 2007).

The global framework for planktic foraminiferal biostratigraphy, on the other hand, is based on extensive data gathered over several decades from a countless number of outcrop and borehole sections, many millions of specimens, and integration with other microfossil biostratigraphies (*e.g.*, calcareous nannoplankton), magnetostratigraphy, and the absolute time scale. Those sequences, especially deep-sea cores, are often rich in planktic foraminifers, continuous, and span multiple ages, which is in stark contrast to the Navidad material. For these reasons, Finger *et al.* (2013) dismissed the proposition by Gutiérrez *et al.* (2013) that the planktic foraminifera reported by Finger *et al.* (2007) appeared 10 to 20 Myr earlier in the Southeast Pacific than elsewhere in the global ocean.

Chronostratigraphic dating based on isotopic ratios is not immune to problematic results. For example, Wyss *et al.* (1996) emphasizes the problems of overlapping radiometric ages between the Abanico and Farellones formations, whereas Flynn *et al.* (2008) noted that 'the Cura-Mallín and Trapa Trapa formations radiometrically dated at Laguna del Laja are substantially younger (by more than ~10 million and ~5-10 Myr, respectively) than the same formations in Argentina'. Le Roux *et al.* (2004) dated the marine Coquimbo Formation as Miocene to Pliocene and noted some problems derived from the Sr ages. For example, they obtained Sr dates of 7.3, 5.4, and 5.2 Ma from the same bed and concluded that the older age (7.3 Ma) must belong to a reworked fossil, which also exemplifies that age-related assumptions are not exclusive to biostratigraphic studies. In the case of the Navidad Formation, Le Roux *et al.* (2013) recognize the problems with Sr dating indicated by Finger *et al.*

(2013), principally the ages that defy the stratigraphic order of the samples (*e.g.*, one of them being 3.3 My older than that from the underlying bed; figure 3 in Gutiérrez *et al.*, 2013). However, they contradict themselves when they admit that Gutiérrez *et al.* (2013) did not mention the Sr date of 12.1±0.7 Ma (in Encinas, 2006), which was obtained from specimens thought to be *Neogloboquadrina acostaensis* (Finger *et al.*, 2007), because it was too old, even though the maximum global age for this species (10.9 Ma) is only 0.5 My younger. Their argument is even more illogical because they had considered that this and other Navidad species of planktic foraminifers had first appeared in the South East Pacific in the Early Miocene (Gutiérrez *et al.*, 2013).

In summary, no geologic dating method is immune to pitfalls that can result in inaccurate age determinations. Sr dates must be taken with caution as diagenesis can modify the original $^{87}Sr/^{86}Sr$ ratio (DePaolo, 1986), which is a likely explanation for the aberrant ages of 12.1±0.7 and 31.5±0.6 reported by Encinas (2006). The use of a scanning electron microscopy (SEM) to recognize diagenetic alteration, and additional means of age-dating are advisable.

2. Sedimentary environment of the Navidad Formation

Le Roux *et al.* (2013) discuss old and new data in favor of a shallow-marine environment for at least part of the Navidad Formation. Their arguments are based principally on the presence of shallow-marine invertebrates and taphonomy. They also provide some new sedimentological data to support their interpretation.

2.1. Taphonomy

The most important arguments employed by Le Roux *et al.* (2013) to support a shallow marine environment for the Navidad Formation are derived from taphonomic analysis, most notably the good preservation of some of the marine invertebrates and terrestrial leaves and insects. They interpret those specimens as *in situ* and counter our interpretation of displacement by turbidity currents by claiming that they are not conductive to good preservation because they have velocities 'exceeding 120 km per hour and extreme turbulence capable of breaking telegraph cables'.

Not all of the Navidad Formation was deposited in deep water, as this unit includes some shallow-marine facies (Encinas *et al.*, 2008) and we have doubts on our previous interpretation of some of the sections of this unit as deep-water sedimentary facies (Finger *et al.*, 2013). Regardless, we consider the taphonomic arguments of Le Roux *et al.* (2013) ungrounded, as studies have reported well-preserved displaced fossils in gravity-flow deposits, such as molluscs (Walker, 2001), and even delicate leaves (Zavala *et al.*, 2012), insects (Gaudant and Busquets, 1996), and pterosaur wing bones (Hilton, 2003). Also, relatively slow turbidity current velocities of 3.6 to 10.8 km/h have been recorded, such as on the Amazon Fan (Pirmez *et al.*, 2000), and high-speed flows that can snap submarine cables are exceptional (*e.g.*, Fine *et al.*, 2005). Sediment can also be transported to deep-water by other kinds of gravity flows, such as debris or sandy debris flows where grain movement is minimum (*e.g.*, Shanmungan, 2000).

As noted by Zavala *et al.* (2012), a common mistake among geologists is to consider the presence of terrestrial plant remains as an indication of a nearshore, shallow marine environment. Plant debris, including wood and leaves (either fragmented or whole), are very common in turbidites (Zavala *et al.*, 2012 and references therein). Sedimentary displacement can be extensive, as turbidity currents can transport plant remains more than 300 km and migrate to water depths of 4,000 m, as reported in the Zaire submarine valley seaward of the Congo River mouth (Khripounoff *et al.*, 2003). As Zavala *et al.* (2012) explain in their seminal paper, the main problem in transporting plant debris to deep-water substrates is their low density (0.09-0.55 g/cm^3). Classic turbidity currents (termed I turbidites by Zavala *et al.*, 2012) have an overall tendency to lose lighter plant materials that stay suspended and get left behind by the main flow. On the other hand, turbidity currents derived from hyperpycnal flows (termed E turbidites by Zavala *et al.*, 2012) force lighter material, such as mud and plant remains derived from fluvial discharge, to sink and travel basinward (Zavala *et al.*, 2012). Thus, the occurrence of well-preserved, occasionally complete, leaves in some strata of the Navidad Formation is not evidence of a shallow marine environment or *in situ* deposition as purported by Le Roux *et al.* (2013). In fact, the Matanzas, Pololos, and Centinela floras (stratigraphically indicated in Gutiérrez *et al.*, 2013,

figure 3; this work, figure 1) all show abundant and well-preserved leaves but the Gutiérrez *et al.* (2013) scheme has the Matanzas flora at the base of the Navidad Formation, whereas the other two correspond to the upper part of this unit, which according to these authors was deposited at the top of a deepening-upward succession. More importantly, as noted by Finger *et al.* (2013) but not mentioned by Le Roux *et al.* (2013), the leaf-rich successions of the Navidad Formation include sedimentary facies, ichnofacies, and microfossils typical of deep-marine environments (Figs. 1 and 2). We therefore interpret the Navidad Formation leaf-bearing strata as deposited by E turbidity currents (*sensu* Zavala *et al.*, 2012) that originated from hyperpycnical flows.

Decapod crustaceans inhabit all ocean depths (Feldmann *et al.*, 1991); thus, the presence of unidentified, articulated crabs in strata of the Navidad Formation is not necessarily indicative of shallow-marine deposition. Furthermore, the displacement of live crabs from shallow- to deep-water by gravity flows is not uncommon, and it is possible for them to colonize and bioturbate the new substrate, although they commonly die rapidly due to anoxia (Fig. 6.7 in Buatois *et al.*, 2002).

Well-preserved shallow-water molluscs have been found in turbidites and other kind of gravity-flow deposits (*e.g.*, Aalto and Miller, 1999; Walker, 2001). As an example for the Navidad Formation, molluscs in a massive sandstone with abundant floating intraclasts have excellent preservation (Nielsen and Frassinetti, 2003, figures 8, 11; Finger *et al.*, 2007, figures 12 B, E, M). Le Roux *et al.* (2013) purport 'the fact that the sediment matrix within their shells is the same as that of the surrounding host' is further evidence of an *in situ* molluscan fauna, but it only indicates that the fossils were not reworked from older strata. We do not envisage why it should be considered as indicative of *in situ* deposition as gravity flows typically displace their entire load (*i.e.*, sediment and fossils) downslope. In addition, if the molluscs were alive when transported, their shells would not be infilled with sediment from their original environment unless that sediment was also displaced.

Le Roux *et al.* (2013) indicate that 'it would be hard to imagine delicate insect body parts surviving transport by a turbidity current'. The presence of insects in any marine deposit is considered exceptional as they are usually destroyed not only by currents or waves
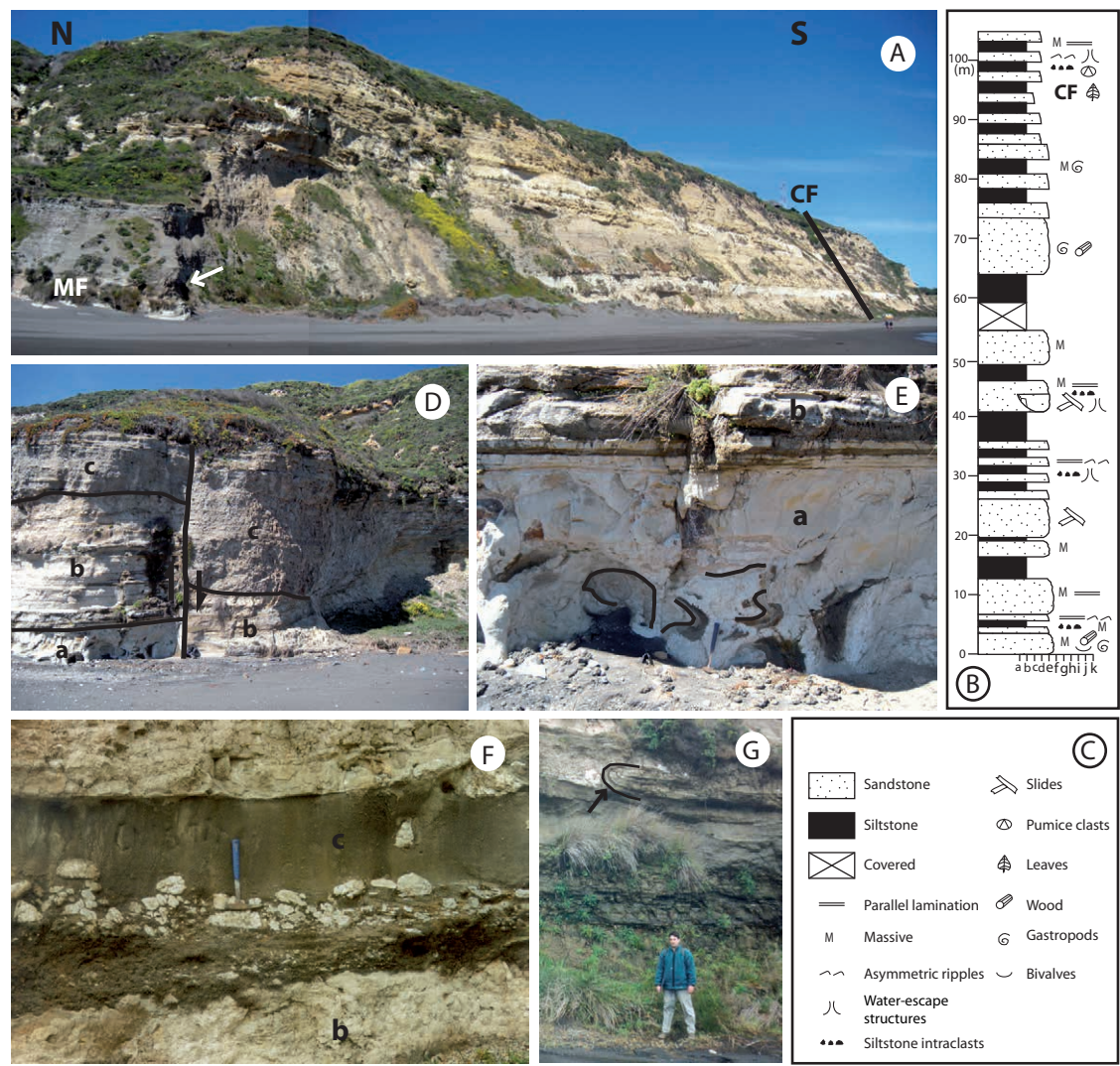
FIG. 1. **A.** Coastal cliff north of Matanzas showing a succession of horizontal sandstone and siltstone. **CF:** strata bearing Centinela flora (Troncoso and Encinas, 2006); **MF:** strata bearing Matanzas flora (leaves are most abundant in base of cliff ~25 m to the north; Troncoso, 1991 and Gutiérrez *et al*., 2013). Black line indicates location of column in B, the upper part of which is not visible. The location of picture F is indicated by an arrow; **B.** Representative column of the Matanzas cliff (modified from section MAT of Encinas, 2006) showing alternating sandstone and siltstone and the location of the Centinela flora (CF) strata at the top; **C.** Legend of column shown in B; **D.** Basal part of cliff succession ~25 m north of exposure shown in A. **a:** massive tuffaceous sandstone with distorted (rolled) stratified intraclasts; **b:** turbidites; **c:** sandstone, massive at base and stratified at top; **E.** Detail of intervals a and b shown in left part of D. The general shape of some of the distorted stratified intraclasts is partially delineated; **F.** Detail of intervals b and c (location in A). Interval c shows an erosive contact overlain by a massive sandstone with abundant siltstone intraclasts, some of them floating, and also containing shallow-water molluscs, shark teeth, bathyal foraminifera, and psychrospheric ostracodes. From Encinas *et al*. (2008); **G.** Basal part of the Matanzas succession exposed north of A. Arrow points to a partially delineated slump.

but by biological activity (*e.g.*, scavenging, bacterial decomposition), or diagenesis (Martínez-Delclós *et al*., 2004). Although the explanation by Le Roux *et al*. (2013) for their preservation seems logical, it is flawed because remains of delicate terrestrial insects have been found in marine turbidites elsewhere (*e.g.*, Gaudant and Busquets, 1996). Gutiérrez *et al*. (2013) and Le Roux *et al*. (2013) purport that the

FIG. 2. Strata bearing the Pololos (**A** and **B**), Boca Pupuya (**C** and **D**) and Centinela (**E**) floras. Locations of these floras are indicated in Gutiérrez *et al*. (2013); Troncoso (1991) and Troncoso and Encinas (2006). **A.** Rhythmically interbedded tufacceous sandstone and siltstone at Cerro Los Pololos. Encircled hammer is at the location of photo B; **B.** Slump showing important soft-sediment folding. The folds structure is partially delineated but difficult to follow due to intense deformation; **C.** Succession of tuffaceous sandstone and siltstone north of Boca Pupuya. The lower part of the section is composed mainly of massive and parallel-laminated sandstone and shows soft-sediment folding (partially delineated), while the upper part comprises rhythmically interbedded sandstone and siltstone. Intraclasts (**i**) are locally abundant; **D.** Succession of parallel-laminated sandstone overlain by rhythmically interbedded sandstone and siltstone at Boca Pupuya. A large sheared flame is in lower half of succession. Other flames are indicated (**f**). Intraclasts (**i**) are abundant in some beds. Upper half of succession includes some disrupted beds (**d**); **E.** Rhythmically interbedded tuffaceous sandstone and siltstone at Cerro Centinela. Encircled hammer for scale.

insect remains in the Navidad Formation are in strata deposited in a tranquil, shallow-marine setting. We cannot respond fully to this assertation because they neither describe the locality or sedimentary facies of their material. However, the arthropods shown by Le Roux *et al.* (2013, their figure 2) are original body parts that appear to have been extracted when processing for pollen. According to entomologists, figures presented by Le Roux *et al.* (2013) represent an oribatid mite (figure 2.1), a trichogrammatid wasp (figure 2.2-2.4) and lepidopterid scales (figure 2.5-2.6) (written communications, M. Elgueta and A. Polaszek, 2013). All of them still exist, so they could be contaminants. We observed insects on outcrops of the Navidad Formation and occasionally found them in rock samples processed for microfossils. Thus, it remains for Le Roux *et al.* (2013) to present convincing evidence that their presented insects are indeed fossils. If this is the case, it would be valuable to describe them more fully, as there is almost no fossil record for Cenozoic terrestrial arthropods in Chile.

2.2. Shallow-marine invertebrate species

Another argument presented by Le Roux *et al.* (2013) in favor of a shallow-marine environment for the Navidad Formation is based on the presence of marine invertebrate species indicative of shallow-marine sandy and rocky settings. They claim some of the fossils dispersed in the rock are *in situ*. They also question the transport of species characteristic of rocky coasts by turbidity currents by considering it unlikely that they could have been displaced from the shoreline and down a continental shelf that typically has a low gradient (0.1°).

As we mentioned previously, we cannot affirm that all of the fossils in the Navidad Formation were transported to deep-water because this unit presents shallow- and deep-marine facies. However, the arguments presented by Le Roux *et al.* (2013) to demonstrate shallow-water deposition are again invalid because any coastal or land-derived organism has the potential of being transported into deeper water by a gravity flow (*e.g.*, Feldmann *et al.*, 1991; Bernet *et al.*, 2000; Hilton, 2003; Zavala *et al.*, 2012) and deep-water organisms can also be displaced farther downslope (Miller, 2008). For example, rocky shoreline invertebrates, including barnacles, have been recorded in deep-water turbidites off the Canary Islands (Goldstrand, 1998). As proposed by Encinas

et al. (2008) for the Navidad Formation, displacement from shallow- to deep-water is enhanced if the continental shelf is narrow, which means the heads of submarine canyons will be near the coast (Goldstrand, 1998). Some of the rocky shoreline species found in this unit occur in conglomerate beds interbedded with turbidites and thin siltstone beds (*e.g.*, section SBP in Encinas, 2006), indicating that the fossils were transported at least below fair-weather wave base and not near the coast.

Molluscs in the Navidad Formation (which are not only entire but also fragmented) are commonly concentrated in lenses. We concur with Le Roux *et al.* (2013) that this does not indicate long distances of transport. Some of these beds, however, show sedimentological and paleontological evidence of deep-water deposition. An example is the bed at the base of the Matanzas section, where classic turbidites are overlain by a massive sandstone containing large floating intraclasts shallow-water molluscs, shark teeth, bathyal foraminifera, and psychrospheric ostracodes. Isolated mollusc fossils are also dispersed throughout the sedimentary rocks in the Navidad Formation. Yet, this is not evidence of *in situ* deposition nor did we observe the molluscs oriented into living position. Although well-documented as a rich fauna, molluscs in the Navidad Formation are not particularly common relative to the amount of the unit that is exposed. Their distribution is intermittent and they are not present in many beds regardless of lithology, which argues against the generalization that deposition was *in situ*.

2.3. Microfossils

Finger *et al.* (2013) discussed the reliability of bathyal (*i.e.*, at least >200 m) paleodepths indicated by benthic foraminifers. Le Roux *et al.* (2013) argued that 'Lipps (1993) maintained that deep water benthic foraminifers have shown great evolutionary stability only after 15 Ma and especially after the Late Miocene, in which most of the extant benthic species appeared. There is thus no guarantee that Early Miocene species inhabited the same water depths as their successors'. We consider their argument as illogical. The comment by Lipps is misinterpreted by Le Roux, as it does not state anything about foraminiferal depth distributions before and after 15 Ma, but only refers to the fact that the majority of modern species appeared after that time (personal communication, J.H. Lipps,

2013). Many modern species of benthic foraminifers that live at bathyal depths first appeared in the Late Oligocene-Early Miocene, by which time the opening of the Drake Passage, thought to have been ~41 Ma (Scher and Martin, 2006), most likely enabled the modern stratification of the South Pacific Ocean in which cold Antarctic waters sink progressively deeper as they migrate northward. In addition, there is no evidence to suggest a mass migration of those new species from shallow- to deep-water around 15 Ma. The fact that 36 (11%) of the bathyal species found in our study have been recorded as provincially extant is also misconstrued by Le Roux *et al.* (2013), as those species are significant and sufficient for our paleodepth interpretation. To clarify that percentage, in the Navidad Formation there are 63 extant species of foraminifera that have been recorded only at bathyal depths, 36 of which have been recorded off south-central Chile (Finger, 2013). The number of bathyal species in the unit is substantially greater when modern distributions elsewhere are considered. In addition, most of the Neogene benthic foraminifera recovered from ODP Site 1237, drilled in the Nazca plate off Perú at a water depth of 3,212 m (Mix *et al.*, 2003), are identical or similar to those we reported from the Navidad Formation (Finger *et al.*, 2007; Finger, 2013). This finding provides independent evidence that those species lived at bathyal depths in the Pacific during the Early Miocene making unlikely that all of them lived at shallow water during the same period.

Another argument favoring bathyal deposition for the Navidad Formation is the presence of psychrospheric ostracodes (Finger *et al.*, 2007; Finger *et al.*, 2013). These species characterize cold water masses, usually are at a depth of at least 500 m, although they can occur shallower at high latitudes and in areas of strong upwelling (Benson, 1975). Le Roux *et al.* (2013) misunderstand these concepts when they argue that psychrospheric ostracodes 'cannot be used to infer water depths of more than 500 m, as this ignores the effect of upwelling'. First, the 500 m water-depth is the usual minimum (upper depth limit), not the maximum, in the bathymetric range of these organisms. Second, Le Roux *et al.* (2013) apparently assume that coastal upwelling occurred in the Navidad basin during the Early Miocene, but there is no supporting evidence, such as an abundance of phosphate or diatoms, in the Navidad Formation (Finger *et al.*, 2007).

2.4. Sedimentology

Finger *et al.* (2013) presented sedimentological evidence of deep-marine deposition for most of the Navidad Formation. In their rebuttal, Le Roux *et al.* (2013) clearly misunderstood some of our arguments, do not clarify some of their comments, and commit some errors worthy of discussion.

Many of the Navidad exposures exhibit sedimentary features characteristic of gravity flow deposits, whereas typical shallow marine facies, although locally present, are uncommon (Encinas, 2006; Encinas *et al.*, 2008; Finger *et al.*, 2013). Le Roux *et al.* (2013) claims that 'the absence of hummocky cross-bedding in the Navidad Formation is also not an indication of deep-water, as these structures are nowhere common'. In fact, we do not refer exclusively to this particular sedimentary structure, but to those of all shallow-marine facies typical of wave-, river-, or tide-dominated coastal systems, such as trough or planar cross-bedding, hummocky cross-stratification, flaser bedding, and herringbone cross-stratification. Cross-bedding is a very common feature in any kind of shallow-marine setting (*e.g.*, Bhattacharya, 2006; Clifton, 2006), but it is rare in the Navidad Formation. The only shallow-water structure mentioned by Le Roux *et al.* (2013) is wave ripple marks, which they correctly note cannot form in deep-water. We only observed what could be symmetrical ripple marks in a section along the eastern shore of the Punta Perro peninsula (section PPE in Encinas, 2006); however, they are poorly preserved and we are inclined to interpret them as current ripple marks. If they are confirmed to be wave ripple marks, it would merely indicate that this particular section was deposited at shallow-water. Yet, it is not clear if Le Roux *et al.* (2013) refer solely to the PPE section (*sensu* Encinas, 2006) or if they found wave ripples elsewhere in the Navidad Formation, as Gutiérrez *et al.* (2013) indicate the presence of 'wave ripples in the sandstones' and Le Roux *et al.* (2013) mention their occurrence in some of the sandstone packages (*e.g.*, Punta Perro). We cannot ascertain these reported features because Le Roux *et al.* (2013) do not indicate their exact location or provide convincing photodocumentation.

Among the deep-water indications we (Finger *et al.*, 2013) presented is that observed at Punta Perro, where granitic boulders scattered atop a thick siltstone succession are associated with a synsedi-

mentary breccia composed of large stratified blocks of siltstone and sandstone (Fig. 3). As indicated by Finger *et al*. (2013), large boulders (commonly termed as olistoliths) offshore are typically derived from shelf-margin failure (commonly triggered by earthquakes) and displaced downslope by mass movements such as block slides, debris avalanches, debris flows, and hyperconcentrated flows (Lucente and Pini, 2003; Festa *et al*., 2010). We believe the large stratified blocks in the associated breccia at Punta Perro (Fig. 3) were ripped-up from the substrate by the boulders as they moved downslope. Le Roux *et al*. (2013) confused these boulders with those found in the basal conglomerate of the Navidad Formation exposed on the western edge of the Punta Perro peninsula (*e.g.*, Tavera, 1979; Encinas *et al*., 2006). The boulders referred to by Finger *et al*. (2013) are located near the mouth of the Rapel River, north of the basal conglomerate.

Another argument Le Roux *et al*. (2013) use against deep-water deposition states that 'most turbidite successions worldwide are very homogeneous' and the Navidad Formation consists instead of 'heterogeneous sandstone packages of 30-40 m' interbedded with 'siltstone-shale packages'. They interpret these as characteristically deltaic based on the 'many similarities between the deposits of prograding deltas and submarine slope fans', noting features such as 'the presence of coarsening-upward successions and of shifting distributary channels'. They further their case with an interpretation of a seismic line 'modified from Contardo *et al*., 2008' (Fig. 3 in Le Roux *et al.*, 2013) where they observe '3 prominent sandstone packages that might represent delta platform deposits alternating with siltstone-shale packages that show what appear to be westward-sloping, prograding beds possibly reflecting delta slope sedimentation'.

That turbidite successions are typically homogenous is a common misconception among geologists. Posamentier and Walker (2006) remark that 'deep-water deposits commonly are complex and consequently do not neatly fit any single facies model'. According to these authors, deep-marine successions consist of a variety of lithofacies (*e.g*., turbidites, structureless sandstones, pebbly sandstones, conglomerates, slumps) organized in different architectural or depositional elements (including slope channels and canyons, channels, overbank deposits, splays, and mass-transport complexes). Amalgamated massive

sandstones without mudstone partings may be characteristic of shallow-water environments, but they can also form thick successions in deep-water, as is the case for the 200 m succession of the Annot Sandstone in France (Posamentier and Walker, 2006, p. 404). This does not demonstrate that all the sandstone intervals in the Navidad Formation were deposited in deep-water (in fact, we suspect that some of the sandstone strata at Punta Perro are shallow-water deposits). However, many of the massive sandstones that are common in the Navidad Formation are interbedded with turbidites and display features typical of gravity flow deposits, such as large flutes, thin siltstone partings, water escape marks, sheared flames, floating clasts (ranging to >1 m in diameter), and rip-up siltstone clasts (Fig. 1F). The Navidad Formation is not, as purported by Le Roux *et al*. (2013), composed exclusively by thick packages of sandstone interbedded with siltstone. It comprises these and other lithofacies that vary in thickness from a few centimeters for turbidites to ~25 m for massive sandstones (Encinas, 2006; Encinas *et al*., 2008). We observed this, for example, in the coastal bluffs at Matanzas (Fig. 1) where, according to Gutiérrez *et al*. (2013), the entire Navidad Formation is exposed. We also disagree with the interpretation by Le Roux *et al*. (2013) that these sandstone-siltstone packages were deposited in a deltaic environment. Deltaic cycles typically range from a few meters to a hundred meters in thickness and are characterized by a succession of coarsening-upward facies showing a transition from the muddier facies of a prodelta to the sandier facies of a delta front (Bhattacharya, 2006). Although some of the Navidad Formation may be of deltaic origin, most sections of this unit, including those of the Matanzas bluffs (Fig. 1) do not show features characteristic of that environment. We did not observe any clear coarsening-upward arrangement at any scale, and sedimentary structures typical of shallow-marine environments (*e.g.*, cross-bedding) are rather uncommon. The individual sandstone and siltstone intervals vary widely in thickness, their contacts are typically abrupt, and they commonly show sedimentary structures typical of gravity-flow deposits. Distributary channels on deltaic environments, on the other hand, usually occur on the delta plain, whereas those observed in the Navidad Formation contain fossils characteristic of open-marine settings. Regarding the seismic profile depicted in figure 3 of Le Roux *et al*. (2013), which they credit to Contardo
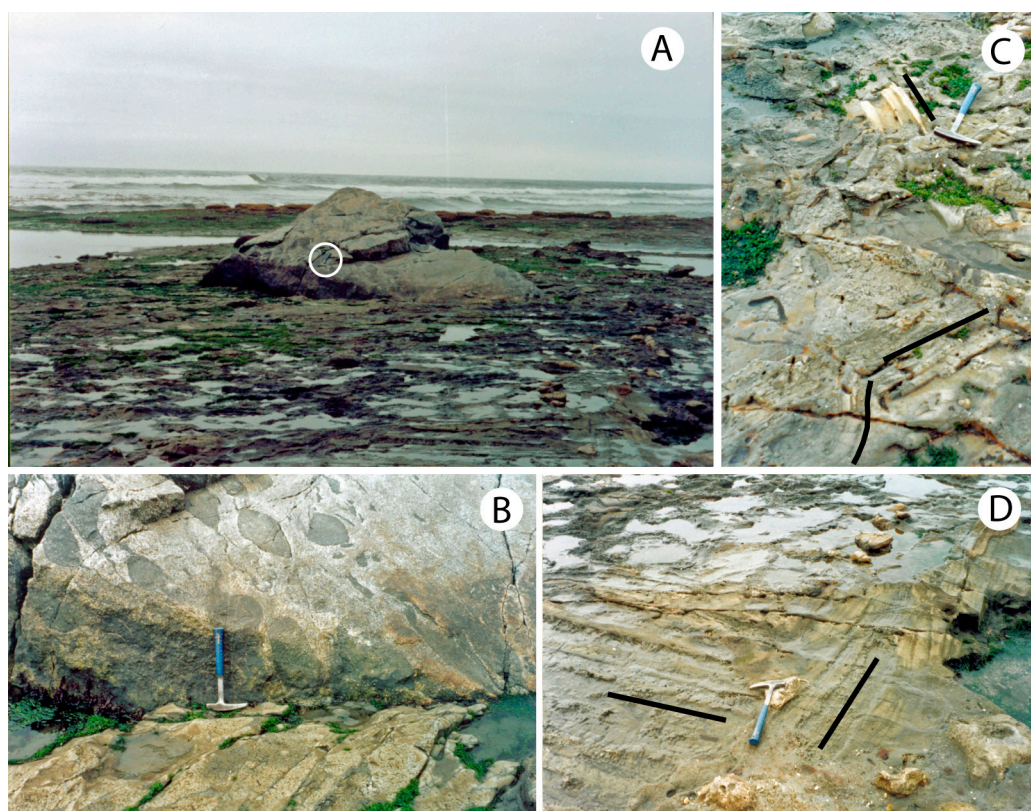
FIG. 3. **A.** Large granitic boulder associated with siltstone and sedimentary breccia near the mouth of the Rapel River at Punta Perro. Other boulders of smaller size occur in the succession but are not visible in photo. Encircled hammer for scale. **B.** Detail of siltstone onlapping boulder, demonstrating that the megaclast is embedded in, and therefore contemporaneous with, the sedimentary succession. **C.-D.** Details of associated breccia composed of large stratified blocks of siltstone and sandstone showing different orientations (partially delineated).

et al. (2008), we were surprised to find out that it is not the same part of Line VG02-18 shown in the indicated source, but is the eastward extension of it. Le Roux *et al*. (2013) assume that the entire analyzed succession in that profile corresponds to the Navidad Formation, but there are no wells drilled offshore in this area to confirm this. In fact, Beicip-Franlab (1996) offer an alternative interpretation of a seismic profile made by ENAP in the same area, which indicates the presence of three marine sequences (Upper Cretaceous, Eocene, Oligocene-Miocene) that show a regional dipping of tectonic origin, not prograding clinoforms. Even if the entire profile were to correspond to the Navidad Formation, we do not comprehend how Le Roux *et al.* (2013) were able to recognize different lithologies in the seismograph. Further, according to the scale shown in the profile, the thickness of the three siltstone packages they identify vary from ~100 to 300 m, while that of the three sandstone packages is ~30-40 m. This contradicts Gutiérrez *et al.* (2013), who state that the Navidad Formation has a total thickness of 220 m and no siltstone or sandstone interval in the Matanzas section (Fig. 1) exceeds ~10 m. More importantly, two of the three subhorizontal reflectors interpreted by Le Roux *et al*. (2013) as 'prominent sandstone packages' actually correspond to the multiple reflections of the upper bed that can be observed in the uninterpreted seismic profile (Fig. 4).

2.5. Paleoseeps

As another feature favoring deep-water deposition, Finger *et al.* (2013) mention the presence of the hydrocarbon paleoseep in the Navidad Formation that was described by Contardo and Mena (2012).
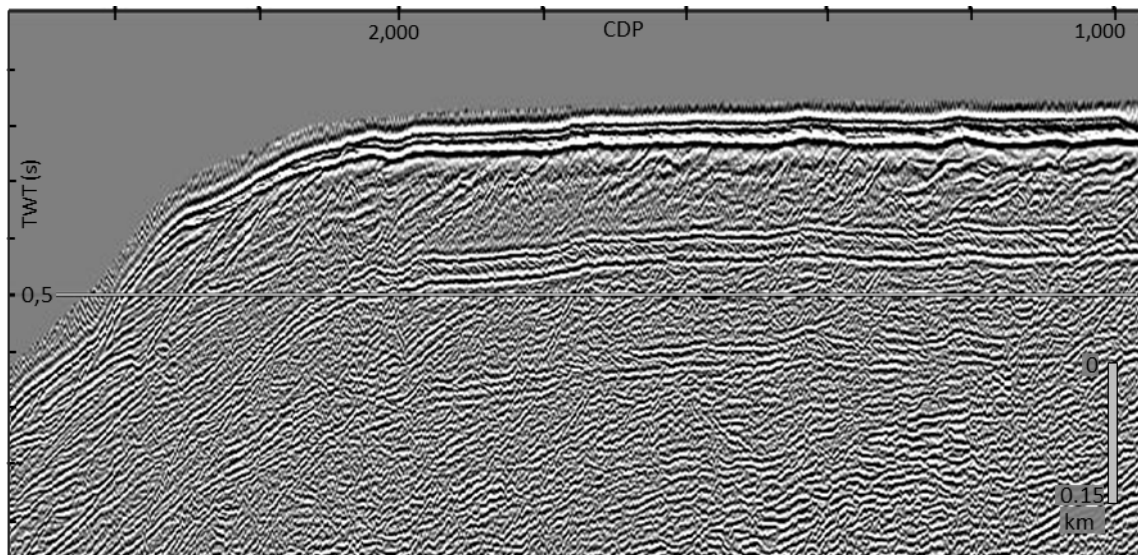
FIG. 4. Uninterpreted seismic line that Le Roux *et al*. (2013, figure 3) analyzed. The line is located east of line VGO2-18 (location in figure 1 of Contardo *et al*., 2008). It can be observed that two of the three subhorizontal reflectors interpreted by Le Roux *et al*. (2013) as 'prominent sandstone packages' actually correspond to multiple reflections of the upper bed. They have lower amplitudes than primary reflection due to loss of energy. **TWT:** two-way traveltime; **CDP:** common depth point.

Le Roux *et al*. (2013) dismiss this by stating that 'such seeps can occur in any sedimentary succession where hydrocarbons accumulate' and that 'the isotopic characteristics described by Contardo and Mena (2012) indicate a paleoseep, not deep water'. Certainly cold seeps are widespread and occur on tectonically active and passive margins. Seep communities are known from depths of <15 m (Montagna *et al.*, 1987) to >7,400 m in the Japan Trench (Fujikura *et al*., 1999). However, seep sites are usually located at depths below 300 m (Sibuet and Olu-Le Roy, 2002) and they differ in both source and form from those in shallower water (Levin, 2005). The trophic web at a shallow water seep is based on photosynthesis, but seep communities at bathyal and abyssal depths rely on chemosynthesis. Cold seeps fueling chemosynthesis-based benthic communities have been observed in deep sea areas ranging between 400 and 6,000 m (Sibuet and Olu-Le Roy, 1998). Isotopic signatures of $\delta^{13}C$ also differ between deep and shallow marine environments. Seep samples recovered from deep water are characterized by exceptionally light $\delta^{13}C$ signatures (*e.g.*, -40‰ to -50‰ on the Black Ridge) (Van Dover *et al*., 2003; Campbell *et al*., 2008), while those at shallower seeps have less ^{13}C depleted signatures (*e.g.*, -16‰

and -20‰) (Dando *et al*., 1991). Deep-water seeps are also characterized by the presence of authigenic carbonate, mostly of microbial origin (Barbieri and Cavalazzi, 2004), that forms mounds, platforms, or other structures (Levin, 2005). In contrast, aerobic methane oxidation occurs in the presence of oxygen and leads to production of CO_2 and carbonate dissolution. For that reason, the optimal conditions for carbonate mound precipitation and preservation require low-energy, anaerobic environments, and deep water. Under these conditions, the carbonate mound can grow to a height of ~300 m associated with fossil venting as in the Porcupine Bight, Rockall Trough (van Weering *et al*., 2003; Levin, 2005).

On the slope off south-central Chile, localities of active methane seeps have been identified by their characteristic carbonate and biota recovered in bottom samples from depths of 350 to 1,000 m (Sellanes *et al*., 2004, 2008; Quiroga y Levin, 2010). In addition, high-resolution geoacoustic data have revealed cold-seep areas off central Chile at upper-slope depths of 600 to 1,000 m, and they include both active and fossil methane seeps (Klaucke *et al*., 2012). To date, the only shallow-water seep site documented from the Chilean margin is that at Mocha Island off central Chile. Jessen *et al*. (2011) studied the intertidal and

subtidal gas seepage system at four main sites. They found that stable carbon isotopic signatures extracted from tissues of marine benthic organisms indicate a predominantly photosynthesis-based food web, although some specific taxa yielded lower isotopic ratios that suggest assimilation of methane-derived carbon, whose trophic structure and food source is analyzed by Sellanes *et al.* (2011).

For the Navidad Paleoseep (PSN), Contardo and Mena (2012) obtained mean $\delta^{13}C$ values around -40‰ (in carbonate samples) and one of -29.5‰ PDB (Pee Dee Belemnite) from a lucinid bivalve shell, which is consistent with the low values reported from deep-water hydrocarbon seeps in both modern and ancient seeps (Levin, 2005; Campbell *et al.*, 2008).

The Miocene PSN is also characterized by an authigenic carbonate mound and contains a variety of fossils, including lucinids bivalves, gastropods, tube worms, microbialites, and teredolites. Although lucinids are not restricted to seep environments (in fact, *Lucinoma promaucana* occurs in sandstones throughout the Navidad Formation), numerous species of this genus have been reported from Late Jurassic to Pliocene paleoseep deposits worldwide (Kiel, 2013; Campbell *et al.*, 2008). Seep related lucinids have been registered as dominant around 300 to 1,700 m (Levin, 2005; Taylor and Glover, 2006).

3. Tectonosedimentary evolution and sequence stratigraphy of the Navidad basin

Le Roux *et al.* (2013) remark on the sedimentary evolution of the Navidad basin, the tectonic setting during deposition of the Neogene marine units that crop out in this area, and the relative sea level changes that took place during the basin filling. One of our interpretations they question is the 'dramatic' paleodepth of 1,500 m indicated in Finger *et al.*, (2007) and Encinas *et al.*, (2008) on the basis of benthic foraminifera. They alternatively propose that this unit comprises alternating packages of siltstones deposited at 200-300 m depth (which places them on the upper slope) during marine transgressions, and sandstones deposited at shallower depths during regressions. How they arrived at those maximum depths is not evident.

Finger *et al.* (2013) and Finger (2013) explain the inherent uncertainties involved in determining paleodepths on the basis of extant foraminiferal species. Thus, we realize that some of our species

may have had shallow upper depth limits in the Early Miocene. However, we think it would be most unlikely that any significant number of the species we consider as bathyal depth indicators inhabited the shelf during that time interval, as we discussed before. Thus, it is probable that the depositional environment for part of the Navidad Formation was at least a few hundred meters deeper than the maximum paleodepth of 300 m proposed by Le Roux *et al.* (2013). Furthermore, several studies on convergent margins show that a paleodepth of 1,500 m is not necessarily 'dramatic' as defined by Le Roux *et al.* (2013). For example, work derived from DSDP-ODP projects demonstrate that several Pacific margins where the subject of 4-5 km of water-depth increase during the Neogene (*e.g.*, Von Huene and Scholl, 1991; Clift and Vannucchi, 2004; references therein). In addition, Buret *et al.* (1997) studied a Neogene marine succession in the Hikurangi forearc of New Zealand that had a history somewhat similar to that of the Navidad basin, reaching water paleodepths of ~1,000 m in the Middle to Late Miocene before rising to shelfal depths in the Pliocene. According to the reasoning of Le Roux *et al.* (2013) the water-depth determinations of that study should be reliable because they were based on foraminifera younger than 15 Ma. A point of major disagreement with Le Roux *et al.* (2013), however, is their interpretation of the Navidad Formation as alternating packages of siltstones and sandstones, the former deposited at 200-300 m depth as a consequence of marine transgressions, and the latter deposited during marine regressions. As clarified above, this unit is not simply composed of just large packages of shallow-water sandstones and deep-water silt-stones but by several different facies in which these lithologies occur. It would be hard to imagine that the abrupt and repetitive changes between sandstones and siltstones seen in several sections such as that of Matanzas (Fig. 1) reflect water-depth shifts on the order of ~200 m. Although we agree that some lithological changes in the Navidad Formation are likely related to sea-level changes, deposition of sandstone and siltstone in most sections is better explained by alternating gravity flows and settling of fine-grained particles. Yet, the Navidad Formation is not exclusively formed by deep-water facies as mentioned above. Because it overlies a Paleozoic or Upper Cretaceous basement and underlies the shallow-marine Licancheu Formation (Encinas *et al.*,

2006), it necessarily has to record a transgressive-regressive cycle. Unfortunately, there is no complete section of the Navidad Formation that includes the basal and upper contacts of this unit and from which its complete sedimentary evolution can be studied. The sedimentary environment of the upper part of the Navidad Formation is difficult to interpret because it is partially covered by vegetation. The basal contact of the Navidad Formation is clearly exposed only at Punta Topocalma and Cerro Guanaco (sections TOP and GUAN in Encinas, 2006) but those successions are short. The conglomerate containing large granitic blocks on the west side of the Punta Perro peninsula is thought to be the basal Navidad Formation (*e.g.*, Cecioni, 1978; Tavera, 1979; Encinas *et al.*, 2006), but this eludes confirmation because its contact with the basement is not exposed. Yet, the boulder conglomerate is seen in the intertidal platform but not in the nearby bluffs, which instead consist of a succession of sandstone and siltstone with local facies (*e.g.*, slumps) characteristic of deep-water settings (figure 8 in Encinas *et al.*, 2008). We now consider this is probably due to displacement by faulting parallel or oblique to the coast, as inferred by Cecioni (1970, 1978). In summary, the Navidad Formation comprises shallow- and deep-water facies but their relationship is difficult to ascertain because individual sections are separated by incised valleys or faults.

Another point of interest is the cause of the marine transgression associated with the deposition of the Navidad Formation. Based on previous studies on convergent margins, Encinas *et al.* (2008) proposed subduction erosion as the most probable cause of subsidence in this area. By this process, basal tectonic erosion removes the underside of the upper plate causing its thinning and margin subsidence. Von Huene and Scholl (1991) proposed that subduction erosion could explain the presence of Miocene unconformities in the margins of Perú and Japan that were carved near sea level and presently occur at a depth of more than 4,000 m. This process also has been considered to be the cause of Neogene subsidence of several Pacific margins, such as those of New Zealand (Buret *et al.*, 1997), Costa Rica (Vannucchi *et al.*, 2001), and Guatemala (Vannucchi *et al.*, 2004). Thus, subduction erosion seems to be a reasonable mechanism to explain Miocene subsidence of the Navidad basin. Yet, Le Roux *et al.* (2013) discard this notion because 'subduction erosion according

to this theory would have been the direct effect of a decrease in the sedimentation rate in the oceanic trench caused by an increasingly dry climate' and the Navidad region was subjected to high rainfall during the Early Miocene (*e.g.*, Hinojosa and Villagrán, 2005). However, trench sedimentation rates are not solely related to regional climate, as they are also influenced by the relief of the overriding plate. For example, there are several margins dominated by tectonic erosion that are located in regions of high rainfall (Clift and Vannucchi, 2004). Subduction erosion is a complex process and what drives it is not well understood. Based on their global study of convergent margins, Clift and Vannucchi (2004) state that tectonic erosion 'is favored in regions where convergence rates exceed 6 ± 0.1 cm yr^{-1} and where the trench sedimentary cover is <1 km'. Accordingly, Melnick and Echtler (2006) proposed that 'a low-relief Andes resulted in a sediment-starved trench, which, in addition to high plate-convergence rates, caused subduction erosion of the south-central Chilean margin during the Miocene'. Thus, a wet climate is insufficient reason to discard the notion that subduction erosion drove the Early Miocene subsidence of the Navidad basin. Regardless, we now consider that another possible mechanism for that subsidence is extension caused by negative rollback of the subducting slab. According to Muñoz *et al.* (2000), this occurred in south-central Chile at ~25-24 Ma as a consequence of the transient steepening of the subduction angle during the transition from a more oblique South America-Farallón convergence to a more rapid and near normal South America-Nazca convergence. The erroneous assumption that the Navidad Formation was deposited during the Late Miocene-Early Pliocene gave Encinas *et al.* (2008) reason to discard this mechanism because they figured negative rollback would have resulted in the onset of widespread extension. Instead, a major tectonic compressive phase is well documented in the Andean Cordillera during that time (references in Encinas *et al.*, 2008). Given the Early Miocene age that, for the most part, is now agreed upon for the Navidad Formation (Nielsen and Glodny, 2009; Gutiérrez *et al.*, 2013; Finger *et al.*, 2013; Finger, 2013), we no longer exclude negative roll-back as a possible cause.

Le Roux *et al.* (2013) make some comments about the sedimentary evolution and sequence stratigraphy of the Navidad basin that we wish to clarify. The

Navidad Formation is overlain by shallow-marine strata of the Licancheu, Rapel, and La Cueva formations (Encinas *et al.*, 2006). The architecture and sedimentary evolution of the basin is difficult to interpret because there are no complete sections where all four units are exposed, and their basal contacts can be observed at only a few locations. However, Encinas *et al.* (2006), noted that all these formations overlie each other or, locally, rest over a Paleozoic or Mesozoic basement. The basal strata of the Rapel and La Cueva formations are transgressive conglomerates overlying bioturbated surfaces that, in terms of sequence stratigraphy, represent co-planar surfaces of lowstand erosion and transgressive ravinement (Buatois and Encinas, 2006; Encinas *et al.*, 2006). We did not observe a transgressive lag or a bioturbated surface between the Navidad and Licancheu formations, but the characteristics of this contact are difficult to study because it is partially obscured by vegetation. However, near the town of Rapel, the Licancheu Formation records the beginning of the transgression in the form of barnacles attached to the upper surface of the subjacent Paleozoic basement (Tavera, 1979; Encinas *et al.*, 2006). Independently of the exact maximum water-paleodepth reached during deposition of the Navidad Formation, Le Roux *et al.* (2013) concord with us that part of this unit was deposited in deep-water. It can therefore be deduced that at the time of Navidad deposition, the paleocoast must have been located east of the outcrops of this unit exposed near the town of Navidad, although not necessarily very far away (*e.g.*, in north Chile, the 2,000 mbsl contour is only ~20 km west of the Mejillones Peninsula). In the Rapel area, it appears that erosion of the Navidad Formation exposed the basement prior to the transgression that deposited the Licancheu Formation. In support of this, Melnick and Echtler (2006) noted that in the Arauco area there is an angular unconformity between the Ranquil Formation (which correlates with the Navidad Formation) and younger shallow-marine deposits (Melnick and Echtler, 2006). Thus, it seems plausible that the Navidad Formation had a similar history in which it was deformed, uplifted, and partially eroded before deposition of the Licancheu Formation. Le Roux *et al.* (2013), however, propose an alternative explanation when they consider the Neogene succession of the Navidad basin as, 'a typical onlap situation, therefore indicating large-scale marine transgression that continued the deepening

trend proposed by us for the Navidad Formation'. If the Navidad basin had been filling during a widespread and continuous marine transgression, and the paleocoast during deposition of the Licancheu Formation had been located east (inland) of the Navidad Formation, covering the formerly emerged basement, then the younger units would represent a progressively deepening sequence. In contrast, sedimentological evidence clearly indicates that the Licancheu, Rapel, and La Cueva formations were deposited in shallow-marine settings (Encinas, 2006; Encinas *et al.*, 2006).

4. Stratigraphy of the Navidad Basin

Le Roux *et al.* (2013) make some considerations on the stratigraphy of the Navidad Formation and other Neogene marine units in the area. They state that the Lo Abarca Formation 'may have a questionable correlation with the Navidad Formation' and further support the stratigraphic scheme proposed by Gutiérrez *et al.* (2013) in which the Navidad Formation is divided into a lower unit composed of 'coarse- to medium-grained sandstone interbedded with lenticular, pebbly sandstones', and an upper unit consisting on 'fine- to very fine-grained sandstones intercalated with shales and claystones'. They also propose bundling the Neogene formations (Navidad, Licancheu, Rapel, and La Cueva) in the Navidad area as the Darwin group.

Encinas *et al.* (2006) correlated the Lo Abarca and the Navidad formations based on their overlapping ages and similar facies. However, the temporal equivalence was based in the erroneous Late Miocene-Early Pliocene age presented for the Navidad Formation. In light of the new data that confirms an Early Miocene age for at least part of the Navidad Formation (Gutiérrez *et al.*, 2013; Finger *et al.*, 2013; Finger, 2013), and a late Middle Miocene-Pliocene? age for the Lo Abarca Formation (Encinas *et al.*, 2010), we concur with Le Roux *et al.* (2013) that the two units are not correlative. We still differ, however, in the Gutiérrez *et al.* (2013) division of the Navidad Formation into a coarse-grained lower unit and a fine-grained upper unit. As pointed out by Finger *et al.* (2013), their stratigraphic scheme is based solely on the Punta Perro-Matanzas sections, but does not consider those where the Navidad Formation contacts the overlying Licancheu Formation. On the other hand, although we assume that Gutiérrez (2011)

did careful mapping, we doubt if their correlation between the Punta Perro and Matanzas areas is accurate because of facies repetition and the separation of the sections by the mouth of the Estero Navidad (Finger *et al.*, 2013). We are particularly perplexed as to how Gutiérrez *et al.* (2013) correlated the boulder conglomerate that is considered the base of the Navidad Formation (*e.g.*, Tavera, 1979; Encinas *et al.*, 2006) since it crops out at Punta Perro but not Matanzas. Further, a well drilled by ENAP in the vicinity of the town of Matanzas indicates that, unless there is a major fault in the area, the succession of horizontal strata exposed in the coastal cliff is underlain by at least 100 m of the Navidad Formation (Encinas *et al.*, 2006). On the other hand, neither the sections measured by Encinas (2006) at Matanzas (Fig. 1) nor the composite column of Gutiérrez *et al.* (2013) display a lower, coarse-grained unit and an upper, fine-grained unit that indicate the deepening-upward succession proposed by Gutiérrez *et al.* (2013). On the contrary, these columns show a continuous and repetitive succession of alternating sandstone, siltstone, and minor conglomerate. In addition, the base of the Matanzas succession (Fig. 1), considered by Gutiérrez *et al.* (2013) as the basal part of the Navidad Formation, displays several siltstone intervals, deep-water facies (*e.g.*, turbidites, slumps, and massive sandstones with large rip-up clasts, figure 1), and it has a microfauna that includes bathyal benthic foraminifera and ostracodes. The scheme of Gutiérrez *et al.* (2013) is not readily observed in the two sections that have the basal Navidad Formation superjacent to the basement, as the column at Cerro Guanaco (GUAN in Encinas, 2006) shows a succession of conglomerate and sandstone that is ~60 m thick, while that at Punta Topocalma (TOP in Encinas, 2006) is a mere ~5 m overlain by siltstone and minor sandstone. This demonstrates that the stratigraphy of the Navidad Formation is a complex issue and lithological correlation of disparate sections must be taken with caution because of lateral facies changes.

Finally, we agree with the proposal of Le Roux *et al.* (2013) to bundle the four Neogene successions in the Navidad area as a group. In fact, the Darwin Group was first proposed by Encinas *et al.* (2006) in the draft of the manuscript first submitted, but the journal editor advised against using a name that does not correspond to any locality in the area.

5. Conclusions

The Navidad Formation consists of shallow- and deep-marine facies whose stratigraphic relationships are difficult to determine because there is not a single section that records the totality of this unit and individual sections are separated by incised valleys or faults. Refinement of the stratigraphy and sedimentary evolution of this unit thus remains elusive, and some interpretations are still contested. We do not believe the Navidad Formation should be divided into a lower, coarse-grained unit, and an upper, fine-grained unit, thus forming a deepening-upward succession, because this is not evident at Matanzas.

We interpreted many of the sections as deep-water deposits because they exhibit sedimentary facies characteristic of gravity-flow deposits and contain bathyal species of foraminifers and ostracodes. Additionally, the environmental conditions required for authigenic carbonate deposition, their chemosynthetic associated communities and preservation of the Navidad Paleoseep are distinctive of deep water. Because paleoecological inferences based on the modern faunal data have inherent uncertainties, we cannot ascertain that the Navidad Formation was deposited at specific water depths; however, the presence of a significant number of deep-water species of foraminifera and ostracodes, many of which are extant, constitutes a strong argument favoring deposition of their samples well below the shelf-slope break.

Although we do not discard that some of the fossils in the Navidad Formation occur in shallow-marine facies, many arguments favoring shallow-water deposition are weak. Good preservation of terrestrial and nearshore species in this unit does not confirm their shallow-water deposition, as studies elsewhere have found well-preserved marine invertebrates, leaves, and terrestrial insects in turbidites. The occurrence of invertebrate species indicative of shallow-marine sandy and rocky settings is not a valid argument either because several studies have demonstrated that gravity flows can transport these organisms into deep-water, especially in settings were the continental shelf is narrow and the submarine canyon heads are located near the coast. Many of the leaf-rich successions of the Navidad Formation, as well as several concentrations of marine invertebrates, show facies characteristic of gravity-flow deposits and contain bathyal foraminifera and psychrospheric ostracodes.

We discard the notion that the Navidad Formation is simply composed by alternating packages of siltstones deposited at water depths of 200-300 m during marine transgressions, and sandstones deposited at shallower depths during regressions because these lithologies alternate repetitively, vary widely in thickness, and occur in a variety of facies, especially those most often associated with gravity-flow deposits.

References

Aalto, K.R.; Miller, W. III. 1999. Sedimentology of the Pliocene upper Onzole Formation, an inner-trench slope succession in northwestern Ecuador. Journal of South American Earth Sciences 12: 69-85.

Barbieri, R.; Cavalazzi, B. 2004. Microbial signatures in fossil chemosynthetic carbonates. *In* General Assembly of the European Geosciences Union, No. 1. European Geophysical Research Abstracts 6: EGE 04-A-04792. Niza.

Beicip-Franlab. 1996. Petroleum exploration play types in the sub-andean basins. Beicip-Franlab 2: 136 p.

Benson, R.H. 1975. The origin of the psychrosphere as recorded in changes of deep-sea ostracode assemblages. Lethaia 8: 69-83.

Bernet, K.H.; Eberli, G.P.; Gilli, A. 2000. Turbidite frequency and composition in the distal part of the Bahamas transect. Proceedings of the Ocean Drilling Program, Scientific Results 166: 45-60.

Bhattacharya, J.P. 2006. Deltas. *In* Facies models revisited (Posamentier, H.W.; Walker, R.G.; editors). Society for Sedimentary Geology, Special Publication 84: 237-292.

Buatois, L.; Mángano, G.; Aceñolaza, F. 2002. Trazas fósiles. Señales de comportamiento en el Registro Estratigráfico. Museo Paleontológico Egidio Feruglio, Edición Especial 2: 382 p.

Buatois, L.A.; Encinas, A. 2006. La icnofacies de *Glossifungites* en el contacto entre las formaciones Navidad (Miembro Rapel) y La Cueva, Plioceno de la Cordillera de la Costa, Chile: su significado estratigráfico-secuencial. Ameghiniana 43: 3-9.

Buret, C.; Chanier, F.; Ferrére, J.N.; Proust, J. 1997. Individualisation d'un bassin d'avant-arc au cours du fonctionnement d'une marge active: la marge Hikurangi, Nouvelle-Zélande. Earth and Planetary Sciences 325: 615-621.

Campbell, K.; Francis, D.; Collins, M.; Gregory, M.; Nelson, C.; Greinert, J.; Aharon, P. 2008. Hydrocarbon seep-car-bonates of a Miocene forearc (East Coast Basin), North Island, New Zealand. Sedimentary Geology 204: 83-105.

Cecioni, G. 1970. Esquema de paleogeografía Chilena. Editorial Universitaria: 143 p. Santiago.

Cecioni, G. 1978. Petroleum possibilities of the Darwin's Navidad Formation near Santiago, Chile. Publicación Ocasional del Museo Nacional de Historia Natural de Chile 25: 3-28.

Clift, P.; Vannucchi, P. 2004, Controls on tectonic accretion *versus* erosion in subduction zones: Implications for the origin and recycling of the continental crust. Review of Geophysics 42: RG2001. doi: 10.1029/2003RG000127.

Clifton, H.E. 2006. A reexamination of facies models for clastic shorelines. *In* Facies models revisited (Posamentier, H.W.; Walker, R.G.; editors). Society for Sedimentary Geology, Special Publication 84: 293-338.

Contardo, X.; Cembrano, J.; Jensen, A.; Díaz-Naveas, J. 2008. Tectono-sedimentary evolution of marine slope basins in the Chilean forearc (33°30'-36°50'S): insights into their link with the subduction process. Tectonophysics 459 (1-4): 206-218.

Contardo, X.; Mena, E. 2012. Evidencias, caracterización e implicancias del primer seep fósil descubierto en la costa emergida de Chile central. *In* Congreso Geológico Chileno, No. 13, Actas: CD-Rom T5: 663-665. Antofagasta.

Dando, P.R.; Austen, M.C.; Burke, R.A.; Kendall, M.A.; Kennicutt II, M.C.; Judd, A.C.; Moore, D.C.; O'Hara, S.C.M.; Schmaljohann, R.; Southward, A.J. 1991. Ecology of a North Sea pockmark with an active methane seep. Marine Ecology, Progress Series 70: 49-63.

DePaolo, D.J. 1986. Detailed record of the Neogene Sr isotopic evolution of seawater from DSDP Site 590B. Geology 14: 103-106.

Encinas, A. 2006. Estratigrafía y sedimentología de los depósitos marinos mio-pleistocénicos del área de Navidad (33º00'-34º30'S), Chile central: implicaciones con respecto a la tectónica del antearco. Ph.D. Thesis (Unpublished), Universidad de Chile: 177 p. Santiago.

Encinas, A.; Le Roux, J.P.; Buatois, L.A.; Nielsen, S.N.; Finger, K.L.; Fourtanier, E.; Lavenu, A. 2006. Nuevo esquema estratigráfico para los depósitos marinos mio-pliocenos del área de Navidad (33°00'-34°30'S), Chile central. Revista Geológica de Chile 33 (2): 221-246. doi: 10.5027/andgeoV33n2-a02.

Encinas, A.; Finger, K.L.; Nielsen, S.N.; Lavenu, A.; Buatois, L.A.; Peterson, D.E.; Le Roux, J.P. 2008. Rapid and major coastal subsidence during the late

Miocene in south-central Chile. Journal of South American Earth Sciences 25: 157-175.

Encinas, A.; Fourtanier, E.; Finger, K.L.; Buatois, L.A.; Le Roux, J.P. 2010. Stratigraphic implications of latest middle Miocene to earliest late Miocene diatoms in the Navidad Formation at Lo Abarca, central Chile (33°30'S). Ameghiniana 47 (4): 527-533.

Feldmann, R.M.; Tucker, A.B.; Berglund, R.E. 1991. Fossil crustaceans: Paleobathymetry of decapod crustaceans. National Geographic Research and Exploration 7: 352-363. Washington.

Festa, A.; Pini, G.A.; Dilek, Y.; Codegone, G. 2010. Mélanges and mélange-forming processes: a historical overview and new concepts. International Geology 52: 1040-1105.

Fine, I.V.; Rabinovich, A.B.; Bornhold, B.D.; Thomson, R.E.; Kulikov, E.A. 2005. The Grand Banks landslide generated tsunami of November 18, 1929: preliminary analysis and numerical modeling. Marine Geology 215: 45-57.

Finger, K.L. 2013. Miocene foraminifera from the south-central coast of Chile. Micropaleontology 59 (4-5): 341-492.

Finger, K.L.; Encinas, A.; Nielsen, S.N. 2013. Comment on 'Evidence for an Early-Middle Miocene age of the Navidad Formation (central Chile): Paleontological, paleoclimatic and tectonic implications' of Gutiérrez *et al.* (2013, Andean Geology 40 (1): 66-78). Andean Geology 40 (3): 570-578. doi: 10.5027/andgeoV40n3-a10.

Finger, K.L.; Nielsen, S.N.; DeVries, T.J.; Encinas, A.; Peterson, D.E. 2007. Paleontologic evidence of sedimentary displacement in Neogene forearc basins of central Chile. Palaios 23: 3-16.

Flynn, J.J.; Charrier, R.; Croft, D.A.; Gans, P.B.; Herriott, T.M.; Wertheim, J.A.; Wyss, A.R. 2008. Chronologic implications of new Miocene mammals from the Cura-Mallín and Trapa Trapa formations, Laguna del Laja area, south central Chile. Journal of South American Earth Sciences 26: 412-423. doi: 10.1016/j.jsames.2008.05.006.

Fujikura, K.; Kojima, S.; Tamaki, K.; Maki, Y.; Hunt, J.; Okutani, T. 1999. The deepest chemosynthesis based community yet discovered from the hadal zone, 7,426 m depth in the Japan Trench. Marine Ecology Progress Series 190: 17-26.

Gaudant, J.; Busquets, P. 1996. Una ictiofauna de la formación de Vallfogona-Unidad del Cadí (Eoceno marino del dominio Prepirenaico Catalán). Batallería 6: 5-18.

Goldstrand, P.M. 1998. Provenance and sedimentologic variations of turbidite and slump deposits at sites 955 and 956. *In* Proceedings of the Ocean Drilling Program (Weaver, P.P.E.; Schmincke, H.-U.; Firth, J.V.; Duffield, W.; editors), Scientific Results 157: 343-360. doi: 10.2973/odp.proc.sr.157.122.1998.

Gutiérrez, N.M. 2011. Diversidad y cambios florísticos durante el Mioceno en Chile central. Masters Thesis (Unpublished), Universidad de Chile: 70 p.

Gutiérrez, N.; Hinojosa, L.F.; Le Roux, J.P.; Pedroza, V. 2013. Evidence for an early-Middle Miocene age of the Navidad Formation (central Chile): paleontological, paleoclimatic and tectonic implications. Andean Geology 40 (1): 66-78. doi: 10.5027/andgeoV40n1-a03.

Herm, D. 1969. Marines Pliozän und Pleistozän in Nord- und Mittel-Chile unter besonderer Berücksichtigung der Entwicklung der Mollusken-Faunen. Zitteliana 2: 1-159.

Hinojosa, L.F.; Villagrán, C. 2005. Did the South American Mixed Paleofloras evolve under thermal equability or in the absence of the Andes during the Tertiary? Palaeogeography, Palaeoclimatology, Palaeoecology 217: 1-23.

Hilton, R.P. 2003. Dinosaurs and other Mesozoic reptiles of California. University of California Press: 356 p. Berkeley.

Ibaraki, M. 1992. Planktonic foraminifera from the Navidad Formation, Chile: their geologic age and paleoceanographic implications. *In* Centenary of Japanese Micropaleontology (Ishizaki, K.; Saito, T.; editors). Terra Scientific Publishing: 91-95. Tokyo.

Jessen, G.L.; Pantoja, S.; Gutiérrez, M.A.; Quiñones, R.A.; González, R.R.; Sellanes, J.; Kellermann, M.Y.; Hinrinchs, K.U. 2011. Methane in shallow cold seeps at Mocha Island off central Chile. Continental Shelf Research 31: 574-581.

Khripounoff, A.; Vangriesheim, A.; Babonneau, N.; Crassous, P.; Dennielou, B.; Savoye, B. 2003. Direct observation of intense turbidity current activity in the Zaire submarine valley at 4,000 m water depth. Marine Geology 194: 151-158.

Klaucke, I.; Weinrebe, W.; Linke, P.; Kläschen, D.; Bialas, J. 2012. Sidescan sonar imagery of widespread fossil and active cold seeps along the central Chilean continental margin. Geo-Marine Letters 32 (5-6): 489-499. doi: 10.1007/s00367-012-0283-1.

Kiel, S. 2013. Lucinid bivalves from ancient methane seeps. Journal of Molluscan Studies 79 (4): 346-363.

Le Roux, J.P.; Gómez, C.; Fenner, J.; Middleton, H. 2004. Sedimentological processes in a scarp-controlled rocky

shoreline to upper continental slope environment, as revealed by unusual sedimentary features in the Neogene Coquimbo Formation, north-central Chile. Sedimentary Geology 165: 67-92.

Le Roux, J.P.; Gutiérrez, N.M.; Hinojosa, L.F.; Pedroza, V.; Becerra, J. 2013. Reply to Comment of Finger *et al*. (2013) on: 'Evidence for an Early-Middle Miocene age of the Navidad Formation (central Chile): Paleontological, paleoclimatic and tectonic implications' of Gutiérrez *et al*. (2013, Andean Geology 40 (1): 66-78). Andean Geology 40 (3): 580-588. doi: 10.5027/andgeoV40n3-a11.

Levin, L.A. 2005. Ecology of cold seep sediments: interactions of fauna with flow, chemistry and microbes. Oceanography and Marine Biology: an Annual Review 43: 1-46.

Lipps, J.H. 1993. Fossil Prokaryotes and Protists. Blackwell Scientific Publications: 342 p. Cambridge.

Lucente, C.C.; Pini, G.A. 2003. Anatomy and emplacement mechanism of a large submarine slide within the Miocene foredeep in the Northern Apennines, Italy: a field perspective. American Journal of Science 303: 565-602.

Martínez-Delclòs, X.; Briggs, D.E.G.; Peñalver, E. 2004. Taphonomy of insects in carbonates and amber. Palaeogeography, Palaeoclimatology, Palaeoecology 203: 19-64.

Martínez-Pardo, R.; Osorio, R. 1964. Discoastéridos y foraminíferos de la Formación Navidad: nuevos antecedentes para su datación. Sociedad Geológica de Chile, Resúmenes 9: 5-6.

Melnick, D.; Echtler, H.P. 2006. Inversion of forearc basins in south-central Chile caused by rapid glacial age trench fill. Geology 34: 709-712.

Miall, A.D. 1999. Principles of sedimentary basin analysis, third edition. Springer-Verlag Inc.: 616 p. New York.

Miller, W. III. 2008. A *Bathysiphon* (Foraminifera) 'shell bed' from the Cretaceous of northern California, USA: Example of a parautochthonous macro-skeletal deposit in deep-ocean turbidites. Palaeogeography, Palaeoclimatology, Palaeoecology 260: 342-346.

Mix, A.C.; Tiedemann, R.; Blum, P. 2003. Proceedings of the Ocean Drilling Program, Initial Reports 202: 107 p.

Montagna, P.A.; Bauer, J.E.; Toal, J.; Hardin, D.; Spies, R.B. 1987. Temporal variability and the relationship between benthic meiofaunal and microbial populations of a natural coastal petroleum seep. Journal of Marine Research 45: 761-789.

Muñoz, J.; Troncoso, R.; Duhart, P.; Crignola, P.; Farmer, L.; Stern, C.R. 2000. The relation of the mid-Tertiary coastal magmatic belt in south-central Chile to the Late Oligocene increase in plate convergence rate. Revista Geológica de Chile 27 (2): 177-203. doi: 10.5027/andgeoV27n2-a03.

Nielsen, S.N.; Frassinetti, D. 2003. New and little known species of Pseudolividae (Gastropoda) from the Tertiary of Chile. The Nautilus 117: 91-96.

Nielsen, S.N.; Glodny, J. 2009. Early Miocene subtropical water temperatures in the southeast Pacific. Palaeogeography, Palaeoclimatology, Palaeoecology 280: 480-488.

Pirmez, C.; Beaubouef, R.T.; Friedmann, S.J.; Mohrig, D.C. 2000. Equilibrium profile and base level in submarine channels: examples from late Pleistocene systems and implications for the architecture of deepwater reservoirs. *In* Deepwater Reservoirs of the World (Weimer, P.; Slatt, R.M.; Coleman, J.; Rosen, N.C. Jr.; Nelson, H.; Bouma, A.H.; Styzen, M.; Lawrence, D.T.; editors). Society for Sedimentary Geology, Gulf Coast Section. Annual Research Conference, No. 20: 782-805.

Posamentier, H.W.; Walker, R. 2006. Deep-water turbidites and submarine fans. *In* Facies models revisited (Posamentier, H.W.; Walker, R.; editors). Society for Sedimentary Geology, Special Publication 84: 399-520.

Quiroga, E.; Levin, L.A. 2010. *Eunice pennata* (Polychaeta: Eunicidae) en sitios de filtración de metano activos y pasivos del Centro y Sur de Chile (36°-46°S). Anales Instituto Patagonia (Chile) 38 (2): 31-37. Punta Arenas.

Rust, J. 2000. Fossil record of mass moth migration. Nature 405: 530-531.

Scher, H.D.; Martin, E.E. 2006. Timing and climatic consequences of the opening of the Drake Passage. Science 312: 428-430. doi: 10.1126/science.1120044

Sellanes, J.; Quiroga, E.; Gallardo, V.A. 2004. First direct evidences of methane seepage and associated chemosynthetic communities in the bathyal zone off Chile. Journal of the Marine Biological Association of the United Kingdom 84: 1065-1066.

Sellanes, J.; Quiroga, E.; Neira, C. 2008. Megafaunal community structure and trophic relationships of the recently discovered Concepción Methane Seep Area (Chile, 36°S). International Council for the Exploration of the Sea, Journal of Marine Sciences 65: 1102-1111.

Sellanes, J.; Zapata-Hernández, G.; Pantoja, S.; Jessen, G.L. 2011. Chemosynthetic trophic support for the benthic community at an intertidal cold seep site at Mocha Island off central Chile. Estuarine, Coastal and Shelf Science 95 (4): 431-439.

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Shanmugam, S. 2000. 50 years of the turbidite paradigm (1950s-1990s): deep-water processes and facies models-a critical perspective. Marine and Petroleum Geology 17: 285-342.

Sibuet, M.; Olu-Le Roy, K. 1998. Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. Deep-Sea Research II 45: 517-567.

Sibuet, M.; Olu-Le Roy, K. 2002. Cold seep communities on continental margins: structure and quantitative distribution relative to geological and fluid venting patterns. *In* Ocean Margin Systems (Wefer, G.; Billet, D.; Hebbeln, D.; Jorgensen, B.B.; Van Weering, T.J.; editors). Springer-Verlag: 235-251. Berlin.

Tavera, J. 1979. Estratigrafía y paleontología de la Formación Navidad, Provincia de Colchagua, Chile (lat. 30°50'-34°S). Museo Nacional de Historia Natural de Chile, Boletín 36 (5-10): 176 p.

Taylor, J.D.; Glover, E.A. 2006. 'Lucinidae (Bivalvia)-the most diverse group of chemosymbiotic molluscs. Zoological Journal of the Linnean Society 148: 421-438.

Troncoso, A. 1991. Paleomegaflora de la Formación Navidad, Miembro Navidad (Mioceno), en el área de Matanzas, Chile central occidental. Museo de Historia Natural de Chile, Boletín 42: 131-168.

Troncoso, A.; Encinas, A. 2006. La tafoflora de cerro Centinela (Chile, VI Región): vegetación y clima de Chile central a fines del Mioceno-comienzos del Plioceno. Ameghiniana 43 (1): 171-180.

Van Dover, C.L.; Aharon, P.; Bernhard, J.M.; Caylor, E.; Doerries, M.; Flickinger, W.; Gilhooly, W.; Goffredi, S.K.; Knick, K.E.; Macko, S.A.; Rapoport, S.; Raulfs, E.C.; Ruppel, C.; Salerno, J.L.; Seitz, R.D.; Sen Gupta, B.K.; Shank, T.; Turnipseed, M.; Vrijenhoek, R. 2003. Blake Ridge methane seeps: characterization of a soft sediment, chemosynthetically based ecosystem. Deep-Sea Research I 50: 281-300.

Vannucchi, P.; Scholl, D.W.; Meschede, M.; McDougall-Reid, K. 2001. Tectonic erosion and consequent collapse of the Pacific margin of Costa Rica: combined implications from ODP Leg 170, seismic offshore data, and regional geology of the Nicoya Peninsula. Tectonics 20: 649-668.

Vanucchi, P.; Galeotti, S.; Clift, P.D.; Ranero, C.R.; Von Huene, R. 2004. Long-term subduction-erosion along the Guatemalan margin of the Middle America Trench. Geology 32: 617-620.

Van Weering, T.C.E.; Dullo, C.; Henriet, J.P. 2003. An introduction to geosphere-biosphere coupling; cold seep related carbonate and mound formation and ecology. Marine Geology 198: 1-3.

Von Huene, R.; Scholl, D.W. 1991. Observations at convergent margins concerning sediment subduction, subduction erosion, and the growth of continental crust. Reviews of Geophysics 29: 279-316.

Walker, S.E. 2001. Paleoecology of gastropods preserved in turbiditic slope deposits from the Upper Pliocene of Ecuador. Palaeogeography, Palaeoclimatology, Palaeoecology 166: 141-163

Wyss, A.; Charrier, R.; Flynn, J. 1996. Fossil mammals as a tood in Andean stratigraphy: dwingling evidence of Late Cretaceous volcanism in the Soluth Central Main Range. Paleobios 17 (2-4): 13-27.

Zavala, C.; Arcuri, M.; Blanco-Valiente, L. 2012. The importance of plant remains as diagnostic criteria for the recognition of ancient hyperpycnites. Revue de Paléobiologie, Genève Volume spécial 11: 457-469.