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ARTÍCULOS/ARTICLES

Changes of sub-fossil chironomid assemblages associated with volcanic sediment deposition in an Andean lake (38°S), Chile

Cambios en las asociaciones sub-fósiles de quironómidos, producto de la depositación de sedimentos volcánicos en un lago andino (38°S), Chile

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ABSTRACT

Chironomid assemblages and sedimentological parameters (grain size, organic content, mineralogy) of a short sediment core from Lake Galletué (38°41' S, 71°17' W) were analysed. The sedimentary record includes one volcanic ash (tephra) layer, which has a completely different composition than the host sediment in terms of organic content, grain size, and mineralogy. According to the geochronology (^{210}Pb and ^{137}Cs), this ash layer corresponds to the eruption of Llaima Volcano in 1956-

1957. The tephra deposition had an impact on chironomid assemblages producing, among other changes, an increase in *Parakiefferiella* and a decrease in *Ablabesmyia,* although no noticeable change was detected in the diversity index. When compared with other studies, our results also show an impact in terms of the presence of chironomid head capsules within the tephra. The presence of these head capsules could result from the effects of percolation, since the coarse grain size of the tephra particles provides large interstitial spaces. The recovery in the abundances of some taxa after the tephra input, suggests the lake is probably restoring the conditions prevailing before the tephra fall.

Key words: chironomids, lake sediments, tephra layer, southern Chile.

RESUMEN

Se analizan las asociaciones de restos sub-fósiles de quironómidos y los parámetros sedimentológicos de un núcleo sedimentario del lago Galletué (38°41' S, 71°17' O). Es evidente en este núcleo la presencia de un estrato de sedimentos volcánicos (tefra) de una composición distinta en el contenido deµmateria orgánica, en el tamaño de partícula y en la mineralogía, respecto de los sedimentos del lago. De acuerdo a la geocronología isotópica (^{210}Pb y ^{137}Cs), los sedimentos de esta tefra podrían corresponder a la erupción del volcán Llaima de 1956-1957. Por otra parte la depositación de esta tefra también provocó un cambio en las asociaciones de quironómidos, siendo evidente el aumento de *Parakiefferiella* y la disminución de *Ablabesmyia* dentro del estrato de tefra. Si bien nuestros resultados, al igual que estudios previos, registran un cambio en las asociaciones de quironómidos debido a la entrada de sedimentos volcánicos, un aspecto diferente es la presencia de cápsulas cefálicas dentro de la tefra. Una posible explicación a tal diferencia podría ser la percolación de los restos de quironómidos por los espacios intersticiales de la tefra. La recuperación en la abundancia de algunos taxa luego de la depositación de la tefra, sugiere que el lago restablecería las condiciones existentes previo a la caída de la tefra.

Palabras clave: quironómidos, sedimento lacustre, estrato de tefra, Chile.

INTRODUCTION

Chironomids (Insecta: Diptera) have been used extensively,µmainly in the northern hemisphere, to study the past climate, trophic status of lakes, oxygenation levels, and water quality, among others (Walker 1987, Walker et al. 1991, Walker et al. 1995, Heinrichs et al. 1997, Olander et al. 1997, Brooks & Birks 2000, 2004, Brooks et al. 2001, Larocque et al. 2001, Little & Smol 2001, Quinlan & Smol 2001, Adriaenssens et al. 2004). These insects make good paleolimnological indicators because they are abundant inµmany water bodies, the larval head capsules preserve well in sediments, and the winged adult stages are highly mobile, enabling them to disperse over wide areas (Brooks 2000, massaferro & Brooks 2002). Despite their usefulness as environmental indicators, chironomids are rarely used as such outside of the Northern Hemisphere, especially not in southern South America, where only a few studies focus on this insect group.

Specifically in Chile, little is known about the taxonomy and paleo applications of chironomids. Brundin (1983) identified a new sub-family for Chile, Chilenomyiinae, comprising only one species: *Chilenomya paradoxica.* Later, Arenas (1995) studied the composition and distribution patterns of zoobenthos in the Biobio River, identifying 25 chironomid taxa; the genus *Cricotopus* occurred throughout the river. Andersen (1996) described a new chironomid species, *Monodiamesa mariae,* from southern Chile (Los Palos River; 45°23' S, 72°41' W).

Recently, massaferro et al. (2002) found 49 chironomid taxa at Laguna San Rafael National Park (46° S). The subfamily Orthocladiinae was clearly predominant, followed by Tanypodinae, Podonominae, and Chironominae. In another work, massaferro & Brooks (2002) carried out the first study of sub-fossil chironomid assemblages in Chile at Laguna Stibnite (46°25' S, 74°24' W), relating chironomid assemblages to environmental changes developed during the Late Quaternary. The authors found 34 chironomid taxa that reflected environmental changes throughout the Late-glacial and the Holocene.

Only a few references address the impact of volcanic eruptions on chironomid assemblages and other aquatic biota in South America (Massaferro & Corley 1998, massaferro et al. 2005), although Eastwood et al. (2002) found that volcanic eruptions can have substantial impacts on natural ecosystems and that volcanic depositions provide an opportunity to evaluate species interactions and ecosystem resilience (Lotter & Birks 1993, Barker et al. 2000).

Some studies, mainly in the Northern Hemisphere, have focused on evaluating ecosystem responses to volcanic impacts. Birks & Lotter (1994) described the changes in diatom assemblages after a tephra deposition near Laacher See volcano, Germany. Changes in diatom production were found in British Columbia as an effect of tephra deposition (Hickman and Reasoner 1994). Heinrichs et al. (1999) reported changes in chironomid assemblages at Kilpoola Lake (British Columbia) after the deposition of an ash layer, and Tsukada (1967) found decreased abundance of *Tanytarsus genuinus* after two events of volcanic sediment deposition in Lake Nojiri, Japan. Recently, massaferro et al. (2005) used chironomid assemblages to reveal short term environmental changes in Lakeµmorenito of the Argentinean Patagonia (41° S, 71° W), with volcanism being the most important factor affecting the chironomids.

The principal aim of this study was to record the changes in chironomid assemblages after a volcanic event (tephra layer) using a short sediment core from Lake Galletué (Region IX); this is the first study of sub-fossil chironomid assemblages from an Andean lake in Chile. The study of how a volcanic event could affect chironomid assemblages is important as it allows us to disentangle this response from other environmental impacts.

MATERIAL AND METHODS

Study site

Lake Galletué (Fig. 1) is located at 38°41' S, 7I° 17' W in central Chile at an altitude of 1,150 µm. It is approximately 26 km from the nearest city, Lonquimay. The lake has a surface of 12.5 km^2 and the maximum depth is 45 m. It is an oligotrophic, monomictic temperate lake with summer stratification (Parra et al. 1993). The lake experiences a steep seasonal gradient in air temperature with extremes of -6.0 °C in winter and 28.9 °C in summer. Annual average precipitation is 1,900 mm with a maximum of 3,018 mm and a minimum of 1,180 mm (Parra et al. 1993).

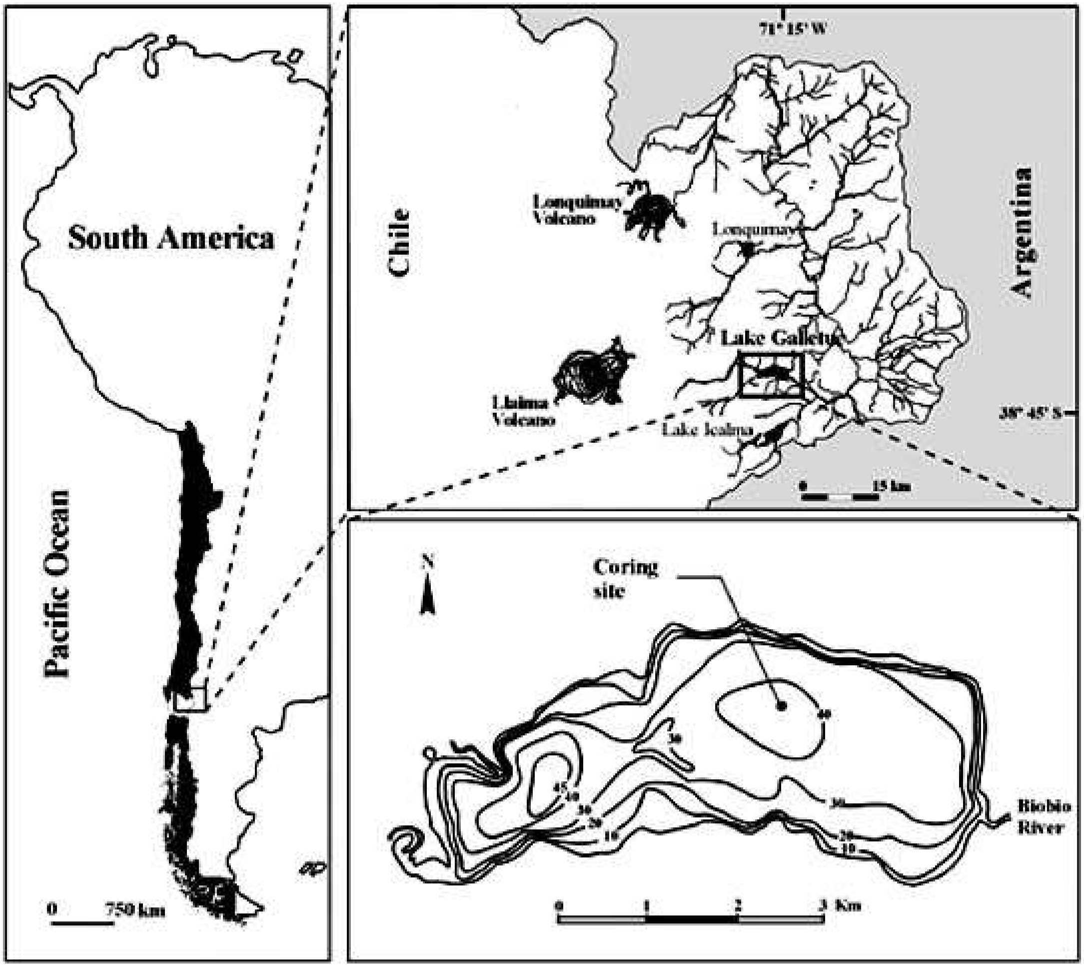

Fig. 1: Study site indicating the location of Lake Galletué.

Área de estudio indicando la localization del lago Galletué.

According toµmardones et al. (1993), different vegetational associations are found in the Lake Galletué watershed. A typical temperate rainforest composed mostly of *Nothofagus pumilio* (Poepp. & Endl.), *Nothofagus dombeyi* ((Mirb.) Oerst.), and *Araucaria araucana* ((Mol.) K Koch) covers the north-north eastern portion of the watershed, with upper levels of this forest reaching 35 to 50µm high. The mid-levels are composed mainly of young individuals of the same species, whereas the understorey is dominated by *Berberís* spp. (michay), *Drimys winteri* var. andina, and the Chilean bamboo *Chusquea* sp. (quila). The east-south eastern section of the watershed is covered with a high prairie grassland, called "coironal" that covers important areas of the prairie next to the lake and grows in a cushion form called "champas".

The typical composition of this association isµmarked by the predominance of *Festuca scabriuscula* (Phil.), *Acaena sericea* (Jacq.fil.), *Baccharisµmagellanica* (Radin), and *Rumex acetosella* (Linnaeus). This community of low vegetation can be also mixed with *Nothofagus antárctica* (G. Forster, Oerst.) and *A. araucana* forests. In the wetland zones near the lake, Juncaceae and Ciperaceae species occur together with the herbaceous genera *Trifolium,µmelilothus,* and *Caltha* (Mardones op. cit.). These communities indicate the lake has relatively pristine vegetation in its surrounding areas.

Sampling and physical analysis

A Lowrance X-16 echo sound profiler was used to locate the maximum depth of the lake and a 17-cm sediment core was retrieved using an Uwitec gravity corer with a plexiglass tube (6 cm diameter). Later, the core was sliced at 1 cm intervals.

In order to assess the lithology, the core was x-rayed (at 50 kV and 26-30 mA s^{-1}) following the method outlined by Axelsson (1983). The x-ray inspection clearly identified a high reflectance sediment layer, which was separated for mineralogical analysis. The chemical composition (major elements) of this sediment layer was determined using an electron microprobe (Cameca SX50) at the Centre d'Analyse par microsonde pour les Sciences de la Terre, Louvain-la-Neuve University (CAMST). The accelerating voltage was 15 kV and the beam current was 20 nA. Counting times were 20 sec for all elements.

For grain size analysis, samples were sieved at 4.0 and 1.0 phi units in order to separate the sample into fine (mud) and coarse (sand) fractions. Grain size was analyzed using an Elzone 282 PC Coulter Counter particle analyzer. The organic content in each layer was estimated by loss on ignition (LOI) following theµmethod described by Boyle (2002).

Geochronology

The age of the core was determined through the activity of ^{210}Pb. The gammaspectrometricalµmeasurements were done using an HPGe detector with a 0.5µmm beryllium window and an energy resolution of 570 eV at the level of 122 eV. The detector and theµmeasuring geometry were calibrated with certified referenceµmaterial (RGU-1, RGth-1, RGK-1) from the International Atomic Energy Agency (IAEA). Once the activity of each sample was obtained, the age models CIC and CRS (Appleby & Oldfield 1978) were evaluated in terms of age-depth profile and coherency with the peak in ^{137}Cs activity. The CIC was theµmost adequateµmodel. The estimated age was validated with the peak in ^{137}Cs activity, which was observed around 1963, when large quantities of this isotope were released into the atmosphere from nuclear weapons tests (Longmore et al. 1983).

Chironomids

For the chironomid analysis, 4 ml of wet sediment were deflocculated in 10 % KOH for 15 minutes at 70° C and passed through a 90 *im* sieve. Later, the remains were transferred to a Bogorov counting tray and head capsules were picked out with entomological forceps. Each head capsule was dehydrated in 80 and 100 % ethanol and then mounted, ventral side up, in euparal. The insects were identified using a Zeiss microscope (25, 40, or 100 x) and the keys of Hofmann (1971), Wiederholm (1983), Epler (2001), Paggi (2001), and Rieradevall & Brooks (2001).

The relative abundance of each taxon was presented as a percentage of the total abundance in each centimetre using the programs TILIA and TILIA GRAPH. To distinguish different associations along the profile, a stratigraphically constrained sum-of-squares cluster analysis (CONISS) was applied. Zonation was applied when examining major differences in CONISS groupings; their significance levels were evaluated with a one-way analysis of similarities (ANOSIM), with zones as factors using the program Primer E.v. 6.12 (Clarke & Gorley 2005). This analysis tests for differences among factors using permutation and randomizationµmethods based on the similarity matrix Bray-Curtis (Clarke et al. 2005). At the same time to determine which taxa were theµmost important in to contribute to the differences among the groups, we used the similarity percentage procedure (SIMPER; Primer v.5, Clarke & Gorley 2001) on transformed variables. In order to relate chironomid assemblages to environmental variables, ordination analyses were performed using the programs CANOCO and CANODRAW. Chironomid diversity and equitability were estimated through the Shannon index, using the program BioDiversity v2.

RESULTS

Physical parameters

The radiograph of the Lake Galletué sediment column is depicted in Fig. 2A. A clear high reflectance sediment layer (white area) present between 7 and 12 cm indicates higher density than in the rest of the core. A first visual inspection revealed coarse, dark, irregular, and very sharp particles, probably belonging to a tephra layer. According to the microprobe analysis, the chemical composition of this tephra corresponds to basaltic andesite with 54.29 % $Si0_2$ and 4.32 % $Na_20 + K_20$.

The organic content (LOI) follows a trend related to the tephra layer (Fig. 2B), with a noticeable decrease in the section of core where the tephra layer is evident (7-12 cm). The highest organic content (17.2 %) was found at 6 cm, and the lowest (2.3 %) at 10 cm (within the volcanic layer). The lower organic content in the volcanic layer is due to its inorganic nature.

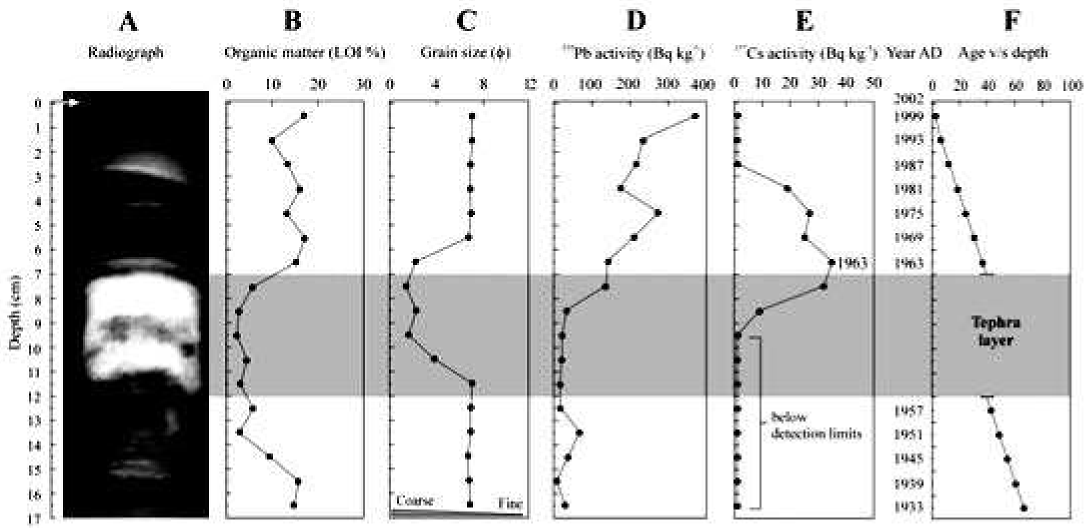

Fig. 2: Physical parameters of Lake Galletué sediment core. (A) X-rays, (B) organic matter, (C) grain size, (D) ^{210}Pb activity, (E) ^{137}Cs activity, and (F) age versus depth profile.

Parámetros físicos del núcleo sedimentario del lago Galletué. (A) rayos-x, (B) materia orgánica, (C) tamaño medio, (D) actividad de ^{210}Pb, (E) actividad de ^{137}Cs y (F) perfil edad versus profundidad.

Grain size analysis (Fig. 2C) shows an increase in particle size in the tephra layer, passing texturally from silt to sand (mean size 6.83 phi = 8.8 µm to 2.16 phi = 223 µm). a more detailed description of the grain size of this tephra is presented in Fig. 3, where two populations of particle sizes are evident. The coarser population corresponds to the tephra layer, with a mean size around 600-900 µm, and the finer population belongs to the host sediment with a diameter below 63 µm. Also, the circular diagrams indicate that the lower sample (11-12 cm) has the highest proportion of mud. Below the tephra layer, the sediment is composed mainly of silt (Fig. 2C).

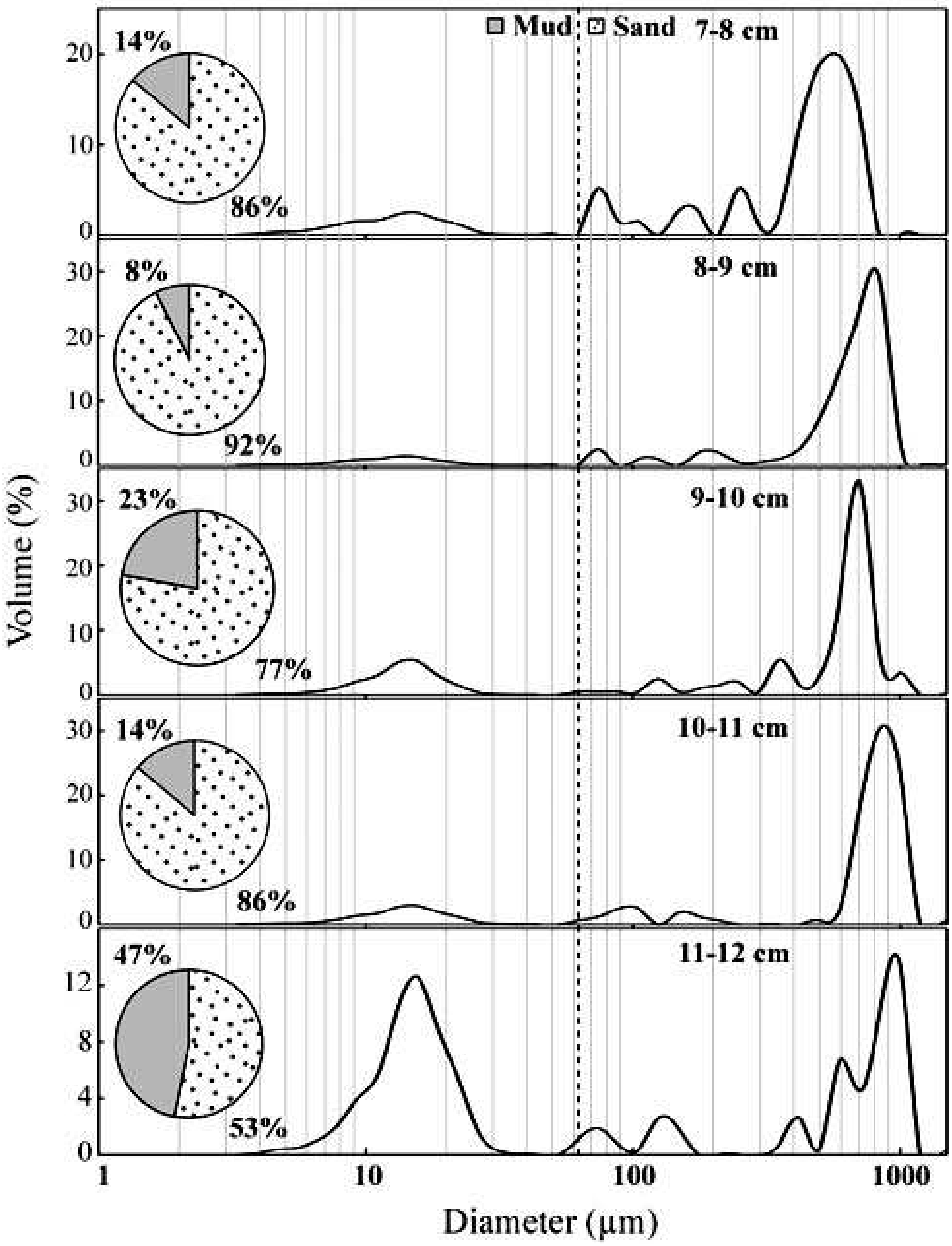

Fig. 3: Grain-size distribution of the five centimetres where the tephra layer is evident; pie diagrams indicate sand-mud proportion. The lower sample (11 cm) has the highest proportion of mud, reflecting the initial mixing of tephra particles (coarse) with the host sediment (fine).

Distribución del tamaño medio de los sedimentos en los cinco centímetros donde es evidente la tefra. Los diagramas circulares indican la proporción arena/fango. El centímetro inferior (11 cm) tiene la proporciónµmás alta de fango, reflejando la mezcla inicial de las partículas de tefra (gruesas) con el sedimento lacustre (fino).

The activity of ^{210}Pb and ^{137}Cs are presented in Fig. 2D and 2E, respectively. The activity of ^{210}Pb shows a general decreasing trend toward the deepest part of the core. However, some reversal of the ^{210}Pb activity can be seen in centimetres 2, 3, and 4 with respect to the first and fifth centimetres. ^{210}Pb activity is highest (375 Bq kg^{1}) in the first cm and lowest at 16 cm (8.0 Bq kg^{-1}). The total ^{210}Pb inventory in the core reached 2,351 Bq kg^{-1}, indicating that the total flux of ^{210}Pb to the sediments is 73.2 Bq m^{-2} yr^{-1}. The ^{210}Pb profile reveals an evident relationship with the stratigraphy, as ^{210}Pb activity decreased after the tephra deposition. This drop could be explained by a dilution of ^{210}Pb due to an abrupt input of volcanic sediments into the lake. The uniform mineralogical composition of the tephra layer implies that this input had the same origin and was generated in a relatively short period of time (Fig. 2F).

The ^{137}Cs activity (Fig. 2E) is detectable as of 4 cm (19.0 Bq kg^{1}) and peaks at 7 cm (35.0 Bq kg^{1}). From 10 to 17 cm, the activity is not detectable. According to Longmore et al. (1983), the peak in ^{137}Cs activity probably represents the year 1963, when this radioisotope was released in large quantities during nuclear weapons tests. There is good agreement between the ^{137}Cs and ^{210}Pb profiles.

Chironomid assemblages

A total of 23 chironomid taxa (sub-families Chironominae, Tanypodinae, Orthocladiinae, Podonominae) were identified in the sediment column of Lake Galletué. Theµmost important sub-family in terms of abundance was Chironominae, composed of the tribes Tanytarsini (25.7 %) and Chironomini (11.4 %), and reaching 37.1 % of the total. The second sub-family in importance was Tanypodinae (29.1 %), followed by Orthocladiinae (27.1 %). The sub-family Podonominae had a very low abundance (0.3 %). Unidentified remains represented 6.3 % of the total. Two different groups of Tanytarsini (types A and B) were distinguished based on differencesµmainly in the shape of antennal pedestal. Type A is characterized by an antennal pedestal with a low and rounded spur, whereas Type B has an antennal pedestal with a longer rounded spur at an obtuse angle to the pedestal.

The chironomid assemblages in the Lake Galletué sediments are presented in Fig. 4. Using CONISS analysis, three zones were distinguished in the chironomid assemblages. Zone I (17-12 cm) before the impact of the tephra layer, Zone II (12-6 cm) during the impact, and Zone III (6-1 cm) after the impact. The one way ANOSIM analysis, indicated significant differences among the taxa abundances of the zones identified by CONISS (ANOSIM, R_{Global} = 0.36, P = 0.001) and in the paired comparisons ($R_Z$onesiiMi$^{=}$ 0.41, P = 0.002, Rzonesµm-i = 0-44, P = 0.002). The SIMPER analysis showed that theµmost important taxa in to determinate differences among zones were *Parakiefferiella, Ablabesmyia,* Tanytarsini types A and B, *Cricotopus/Orthocladius* and *Macropelopia* (Table 1).

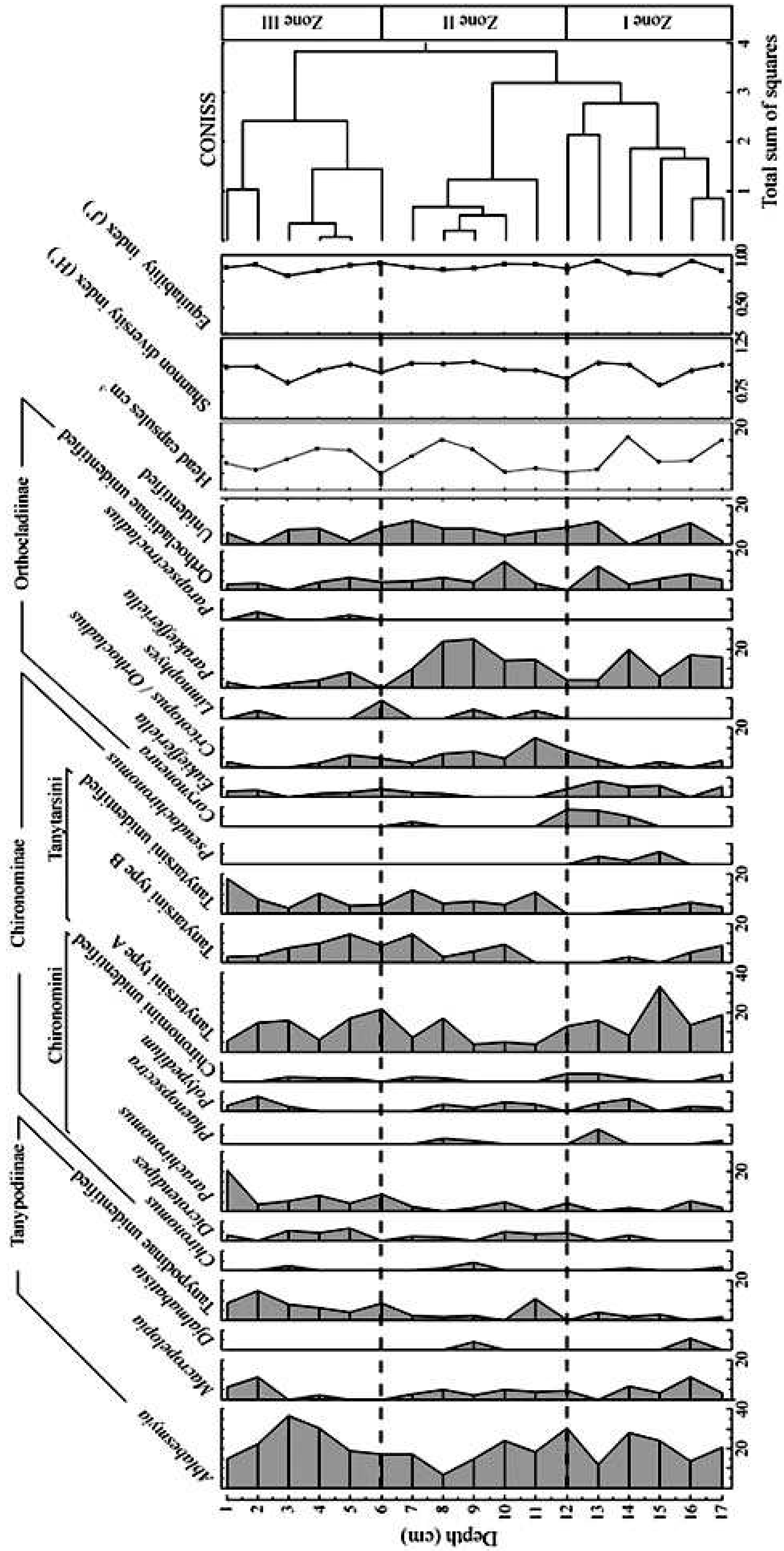

Fig. 4: Chironomid percentage diagram, showing the assemblage structure of Lake Galletué sediments. The stratigraphical division was