Geologica Acta, Vol.10, Nº 1, March 2012, 43-47
DOI: 10.1344/105.000001709
Available online at www.geologica-acta.com

^{14}C dating of the last Croscat volcano eruption (Garrotxa Region, NE Iberian Peninsula)

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ABSTRACT

In this shortnote, we present the results of a geochronological study of the last eruption in the volcanic region of the Garrotxa (NE Iberian Peninsula). Four ^{14}C analysis of organic matter contained in palaeosols located under volcanic pyroclastic fall deposits of the Croscat volcano were made. The samples gave ages between 13160 and 15710 years cal BP, and are in accord with our palynological analysis and climate reconstruction at that time. The ages that we report are the youngest obtained for volcanic activity in the Iberian Peninsula.

KEYWORDS **Geochronology. Carbon-14. Croscat volcano. Quaternary. Olot. Spain.**

INTRODUCTION

The volcanic region of the Garrotxa (Olot) is located in the NE Iberian Peninsula (Fig. 1) and is part of the magmatic activity of the European rift which goes through the French Central Massif, the Rhine Valley and Eiffel in Germany (e.g., Araña et al., 1983). The volcanic activity around Olot is probably the most recent of the peninsula, and the Croscat volcano has been traditionally considered as being the youngest judging from stratigraphic and geomorphologic observations (Fig. 2). There have been very few age determinations of the quaternary volcanism in the Garrotxa area. The combination of a young age, low K volcanism, and the lack of carbonised remains have so far precluded dating by the Ar-Ar or ^{14}C techniques. The only geochronological information of the Croscat volcano is one analysis of thermoluminescence carried out on the basanite flow from the secondary cone of the Croscat volcano, called "La Pomareda", resulted in 11.500 ±1.100 years BP (Guérin et al., 1986). Here we report the findings of palaeosols related to the Croscat volcano and these allow dating with radioactive isotopes for the first time. Aside from an increased understanding of the regional evolution of the volcanism in the Garrotxa and European rifts, robust knowledge of the youngest activity has implications for the classification of the area as volcanically active or not (those with eruptions older than 10000 years; e.g., Smithsonian Global Volcanism Program).

OUTCROPS AND SAMPLING

Dating of carbonaceous plant matter produced by the volcanic eruption itself has not been possible in the volcanic region of the Garrotxa, because remains of this type have not been found either under lava flows or under the pyroclastic fall deposits of volcanoes attributable to a period in which the use of ^{14}C is possible.

We proceeded to date organic sediments deposited just below the volcanic cone of the Croscat (Fig. 3, 4). The hypothesis is that by dating the palaeosol surface directly below the pyroclastic fall deposit, we would obtain a *terminus ante quem* of this deposit. To find the minimal period of time between the palaeosol and pyroclastic deposit, it was essential to obtain an organic sediment sample at a point with maximum guarantees that erosion of the palaeosol had not occurred. On the other hand, the depth where the pre-volcanic deposit is found (between 12 and 15metres below the pyroclastic mantle) assures that the located carbon is not contaminated by modern carbon, since the volcanic layer fossilizes the material anterior to the eruption.

The area of Pla del Torn, located a few metres to the NE of the volcanic cone of the Croscat, fulfilled the necessary conditions. The Pla del Torn is a closed, concave depression corresponding to a volcanic complex prior to the eruption of the Croscat volcano formed by the volcanoes of the Puig de Martinyà, Mallola and Torn, and filled by pyroclastic mantle emitted by this volcano.

Physiographically, this area was not very prone to major erosion before the eruption of the Croscat volcano. As a result, its sedimentary record has undergone little change and, at the same time, the shape of a depression has favoured the accumulation of sediments that are potentially rich in organic matter. Two samples of palaeosol beneath the pyroclastic mantle of the Croscat were obtained using rotation drilling and complete core recovery at Pla del Torn: the first (Torn-06) to a total depth of 16.80 metres and the second (Torn-07) to a depth of 25 metres. In the first sample, the material obtained from the analysed palaeosol was located at a depth of 15 metres, while in the second the edaphic zone was intercepted at 12.30 metres. The samples obtained in Torn-07 were of such a poor quality that subsequent ^{14}C analysis was not possible and they could not be used (Table 1).

According to Di Traglia et al. (2009) the Croscat volcano eruption started with fissural Hawaiian activity,

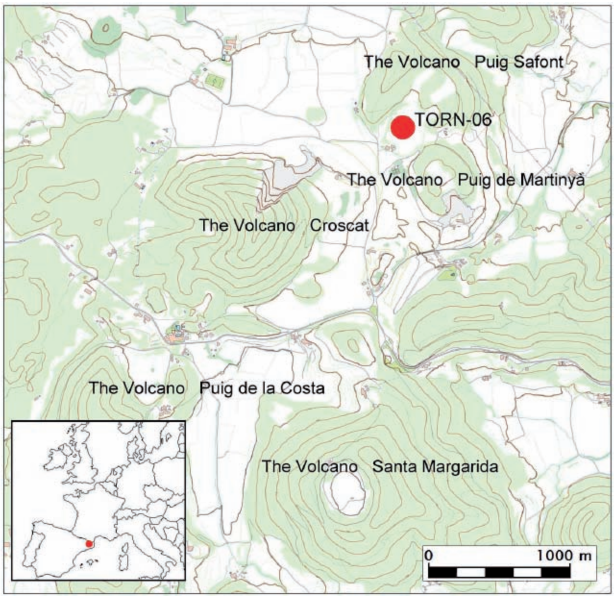

FIGURE 1 | Geographical location of the Croscat volcano.

FIGURE 2 | Photograph of the Croscat volcano.

shifted to Strombolian explosions, after which the magma interacted with a shallow aquifer system, promoting the first phreatomagmatic phase. The arrival of a relatively gas-rich, more primitive magma, possibly decompressed by the preceding phreatomagmatic activity, drove three violent Strombolian phases, producing widespread tephra blankets. The activity subsequently shifted into a second, larger phreatomagmatic phase. The eruption ended with the emission of a lava flow and consequent breaching of the western side of the cone. Bubble number density values in scoria cone products of the Croscat complex reveal that ascent rate initially increased at the end of the Strombolian phase, became constant during the violent Strombolian phase, and finally decreased until the end of the eruption. The stratigraphy and erupted volumes suggest that the duration of the eruption was of a short to average range of scoria cone eruptions (Cimarelli et al., 2010), i.e., during several months.

METHODS

Radiocarbon dating was applied on a sequence of four sediment samples at different depth in the column obtained from the palaeosol located beneath the volcanic deposit (Fig. 5). The four samples were analysed with the ^{14}C AMS method in the Beta Analytic Radiocarbon Dating Laboratory (Miami, Florida), calibrated dating (Reimer et al., 2004). The material to be dated varied: organic sediment was used for the three higher ones, whereas a concentration of palynological residues was used for the lower one. The difference in matter required a difference in pre-treatment. The three higher ones were pre-treated with an acid wash, whereas the lower one received an acid/alkali/acid pre-treatment.

RESULTS

The results obtained from calibrated dating of the four samples were, from bottom to top in the sequence: 16.030-15.410 years cal BP, 14.110-13.780 years cal BP, 13.410-13.160 years cal BP and 13.270-13.040 years cal BP (95% probability) (Fig. 6). The age results are internally consistent: both the radiocarbon age and the calibration data go from oldest to most recent as they move up through the strata, and they are very similar in age. Only the dating that corresponds to 15.10 is slightly more distant from the rest. This could be the result of the different pre-treatment applied to the sample, but it could also be due to the sedimentation rate, given that this sample is 20cm apart from the highest sample (Fig. 7).

The four samples are significantly different from each other, so the dated sequence indicates a sedimentation rate. The upper part of the silt-clay level of the Torn-06 sample (14.90m) was very probably deposited between 13.270-13.040 years cal BP (95% probability). Thus, the eruption took place, possibly at the end of the fourteenth millennium cal BP, or at least at the beginning of the thirteenth millennium cal BP. This dating confirms a recent age for the Croscat eruption.

PALYNOLOGICAL ANALYSIS AND CLIMATE RECONSTRUCTION

Pollen analysis of several samples was carried out to the time of the eruption, corresponding to the upper part of the Torn-06 sample. For palynological analysis, only samples that were potentially from lacustrine sediments were used. In total, 12 samples (between 14.90 and 16.50m) were analysed, of which only four provided optimum results

FIGURE 3 | Field photograph of the level of silts and clays beneath the pyroclastic mantle of the Croscat volcano.

FIGURE 4 | Field photograph of the pyroclastic level. Located on top of the level of dated silts and clays.

TABLE 1 | Results of the age determination using ^{14}C dating (in years)

Sample Torn-06 (depth in meters)	15,10	15,05	15,00	14,90
Conventional radiocarbon age	13 260 + 50 BP	12 090 + 60 BP	11 420 + 60 BP	11 260 + 60 BP
2 sygma calibrated result (95% probability)	16 030 -15 410 cal BP	14 110 -13 780 cal BP	13 410 -13 160 cal BP	13 270 -13 040 cal BP
Intercept radiocarbon age / calibration curve	15 710 cal BP	13 950 cal BP	13 270 cal BP	13 160 cal BP
Laboratory / number	Beta-225 760	Beta-244 068	Beta-245 869	Beta-245 868

(between 15.00 and 15.20m). The samples were treated according to the Goeury and Beaulieu technique (1979), without acetolysis (Girard and Renault-Miskovsky, 1969), and according to the protocol set out in Burjachs et al. (2003).

The pollen spectrum reveals an open landscape (Fig. 7), with AP values between 72.2 and 28.5%. This plant landscape was made of meadows/steppes covered with grasses (Poaceae), Asteraceae and *Artemisia*, where groups of trees could be found (*Quercus* spp., *Acer* spp, *Castanea*-type) in the sheltered areas of the warmest microclimate, a symptom of the beginning of thawing once the Last Glacial Maximum had passed. On the other hand, the presence of mesophiles, *Quercus*, *Acer* and *Corylus*, as well as riverside trees (*Ulmus*, *Alnus* and *Salix*) indicate an increase in rainfall, which is also demonstrated by the presence of hygro-hydrophytes (Cyperaceae, *Alisma* and *Typha-Sparganium*, where we could also include Apiaceae).

According to isotope dating, this period belongs to the 'GI-1c' event of Walker et al. (1999), focused on the classic interstadial complex of Bölling-Alleröd from Tardiglacial. Subsequently, the increase in *Pinus* in the 15.00m sample would indicate the drop in temperature in the 'GI-1b' event. These results confirm this chronological period and the results that we have obtained by absolute ^{14}C dating.

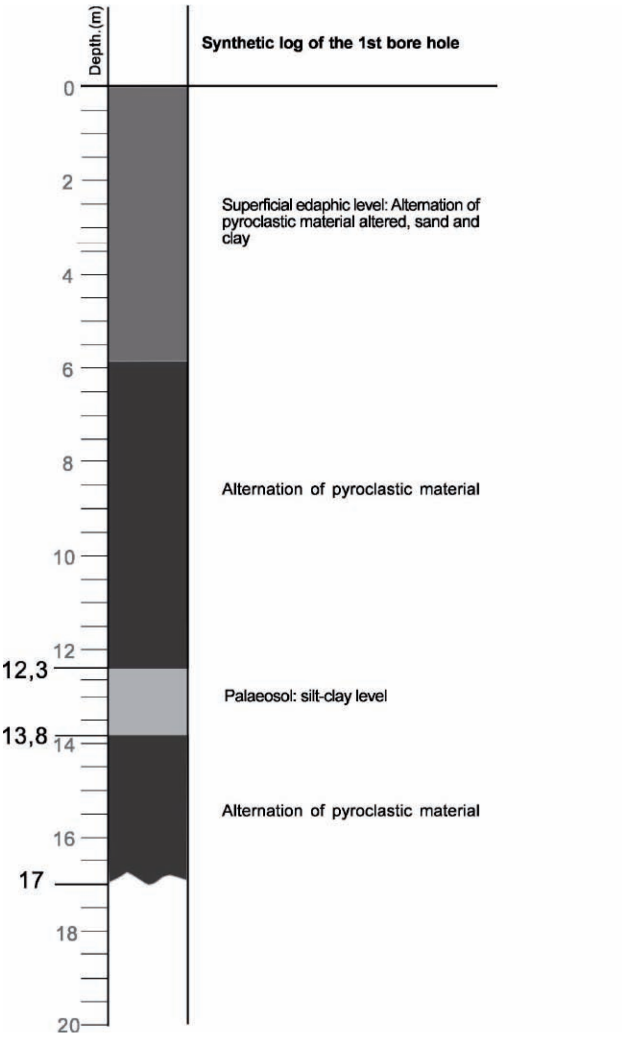

FIGURE 5 | Synthetic column of the material used in the 1st survey (volcà del Croscat).

ACKNOWLEDGMENTS

For the realization of this note we could count on the interesting contributions and annotations of Mr F. Costa, Mr S. Scaillet and M. Ort, who we would like to thank for orienting the contents of this text.

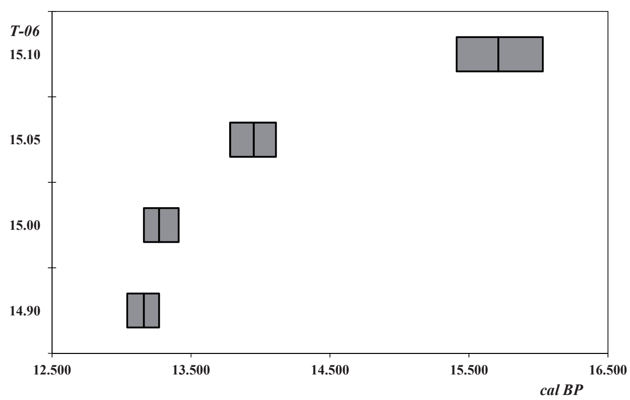

FIGURE 6 | Graphic representation of the relation among ^{14}C datings carried out in Pla del Torn.

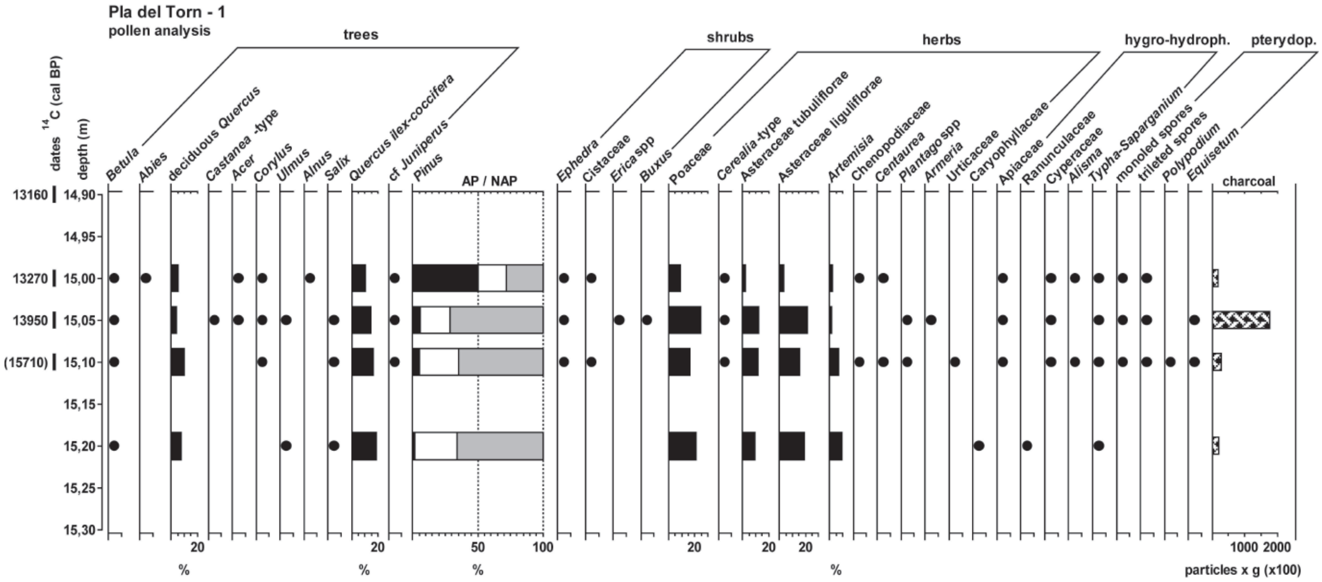

FIGURE 7 Pollen diagram of selected taxa from the Pla del Torn deposit. The black dots indicate a presence of less than 1%. Pinus curve is overlaid on AP.

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Manuscript received January 2010;
revision accepted December 2010;
published Online September 2011.