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Rapid communication

Reply to Vogt's comments on the paper “Fibrous-clay mineral formation and soil evolution in Aridisols of northeastern Patagonia, Argentina” by P.J. Bouza, M. Simón, J. Aguilar, H. del Valle and M. Rostagno

Pablo José Bouza

Centro Nacional Patagónico, CONICET, Boulevard Brown s/n, 9120, Puerto Madryn, Chubut, Argentina

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Vogt's comments emphasize the potential influence that the cryogenic processes could have had on the genesis of the soils analyzed in this study. We really appreciate her comments. Indeed, we took into consideration and cited one of her studies dealing with cryogenic processes and sepiolite formation. However, our results led us to conclusions different to the ones held by Vogt.

In the following paragraphs we address some aspects of her comments.

In relation to the cryogenic processes that affected the sandy gravel deposits (*Rodados Patagónicos*), in the description of the study area we mentioned the main morphological features such as the presence of fossil ice-wedged casts and the three-dimensional reticulate structure. We did not analyze the incidence of the cryogenic processes as our study dealt with the genesis of fibrous-clay minerals in soil horizons above the layers presenting cryogenic structures. Our study was focused in those horizons that represent the transition to the *Rodados Patgónicos* (RP) in which most of the cryogenic structures and processes were described by Vogt and del Valle (1994).

With respect to the terms “column and window,” they are used synonymously with “three-dimensional reticulate structure” produced by thermal contraction as described by Trombotto (1998).

We agree with Vogt's comments that the fractures in the gravels could be explained by “shattering (cryoclasty) with the fractures being filled afterwards by calcite.” In the manuscript there is a mistake that we overlooked. We originally wrote “gravels and fragments of them.” It was afterward changed by the English translator to “...gravels and fragmented them.”

The conclusions that we present on the genesis of clay minerals are totally supported by the results. The relationship between the physical, chemical mineralogical and micromorphological properties as well as the results of the submicroscopic and microanalysis allowed us to infer the paleoenvironmental conditions prevailing during the formation of the clay minerals.

The pedogenic origin of the carbonate accumulations in the calcic horizon was inferred by the presence of the following features:

1. Matrix nodules, floating coarse mineral components and micritic calcite nodules surrounded by circum-granular cracks as observed in the analysis of thin-sections. These characteristics indicate an *alpha*-type microstructure (physico-chemical origin) and displacive micritic calcite crystallization by evaporation from supersaturated soil solution (Wright, 1990; Jacks and Sharma, 1995). Subsequent microsparitic crystallizations were frequently observed on the edges of petrocalcic crust fragments. For more details see Fig. 4a–c in the original manuscript.
2. Another pedogenic feature observed, is the typical lenticular crystals of pedogenic-gypsum in the PV2 soil. The lenticular habit of gypsum also indicates high Ca^{2+}/SO_4^{2-} ratios of the soil solution and relatively high temperatures during its growth (see Porta, 1998). The multiple lenticular crystallitic aggregates intergrown in the micritic matrix mentioned on page 41 may be the result of rapid evaporation of the solution migrating through the soil (Watson, 1985). For more details, see Fig. 4d in the manuscript.
3. Taking into account the field observations and chemical analyses, we showed that as pedogenetic calcium carbonate content increases the following clay transformation and neoformation occurred: illite–smectite → smectite → palygorskite → sepiolite, which is highly time-dependent (Bachman and Machette, 1977; Monger and Daugherty, 1991). On the other hand, the association of calcite, fluorite, sepiolite, and opal-CT found in the petrocalcic horizon would indicate a successive precipitation of these minerals and an alkalinization mechanism during the evaporation processes (Jacks and Sharma, 1995; Barbiéro and Van Vliet-Lanoë, 1998; Chernet et al., 2001). In a thorough review of “Palygorskite and Sepiolite,” Singer (2002) did not make reference to thermic conditions favorable for these mineral formation. He does mention

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E-mail address: bouza@cenpat.edu.ar.

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Table 1
Chronological data of Puerto Madryn profile from del Valle and Beltramone (1987)

Horizon	Depth (cm)	Age (yr BP)	Δ^{13}C
A	0–40	5440±160	−4.8±0.2
2Bk[b]	40–47	24,300±950	−8.7±0.2
3Ck[c]	>47	36,500±2500	−3.7±0.3
Inner part of the fossil–ice wedge cast (Ck)[a,c]		22,700±500	
Outer part of the fossil–ice wedge cast (Ck)[a]		27,200±800	

[a] Corte and Beltramone (1984).
[b] Drying horizon associated with a previous cryoturbation (?).
[c] Cryoturbated horizon.

that sepiolite and palygorskite occur almost exclusively in soils with xeric, ustic, and aridic moisture regimes (Singer, 2002), but no reference is made to cryogenic conditions. Vogt and Larqué (1998) mention the presence of sepiolite in fossil, carbonate-free, ice-lenses that were present in the gravel deposit (Rodados Patagónicos) in the Puerto Madryn area, 50 km east of the ER soil as described in Bouza et al. (2007). Vogt and Larqué (1998) used X-ray diffractometry and infer the presence of sepiolite by the detection of "a minor peak at 12 Å which suggests sepiolite," however, no X-ray diffractogram was shown that would allow readers to draw their own conclusions. In addition, we considered that this evidence showing the presence of sepiolite was not sufficient, because the identification of this fibrous clay mineral requires at least two treatments: 1) Mg-saturated, air dried; and 2) Mg-saturated ethylene glycol solvated.

4. In the soil horizon of the soils studied, we did not find cryogenic features such as vesicular, laminar and lenticular microstructure as those described by Bunting (1977), FitzPatrick (1984) and Van Vliet-Lanoë (1985). The laminar (platy) structures that we described are petrocalcic crusts. We did not find a laminar structure formed by cryogenesis processes, characterized as having a sharp upper surface impregnated with fine materials (FitzPatrick, 1984). In addition, we did not observe lenticular aggregates with capping of fine material on top and depletion of fine material at their base that are caused by frost action (Stoops, 2003), nor did we find silt cappings on the surfaces of the gravels formed by the filling of a pre-existing space created by ice (FitzPatrick, 1997).

As mentioned above, we did find evidence of recent carbonate precipitation. Under this condition, it is not recommended to use ^{14}C dating due to contamination with young carbon.

In the exposure studied by Corte and Beltramone (1984) and del Valle and Beltramone (1987) close to Puerto Madryn, the ^{14}C dating in carbonate samples were later reinterpreted by Vogt and del Valle (1994). These authors concluded that the carbonate was formed in a periglacial environment during the last glacial maximum (LGM, ~18–22 kyr BP). Table 1 shows the original data as presented by del Valle and Beltramone (1987), and it can be seen that the carbonate in the 3Ck horizon is 36,500±2500 yr BP. This would represent a minimum age due to possible contamination and because it falls close to the confidence limit for the ^{14}C dating. Curiously, the carbonate in the fossil-ice wedge cast (presumably beneath the 3Ck horizon) is younger than that present in the 3Ck, indicating a probable rejuvenation. We believe that the carbonate was precipitated before the LGM episode. In relation to the carbonate origin, the δ^{13}C contents (Table 1) are similar to the data provided by Cerling and Quade (1993) for pedogenic carbonates of different soils.

As mentioned in the manuscript, the soil environment that is favorable for smectite–palygorskite transformation was found at the textural transition between the fine materials of subsurface horizons and the coarsest deposit of RP. This is where temporary waterlogging occurs, as described by Yaalon and Wieder (1976) for arid soils of Israel. If we consider that this transformation could have taken place between 120,000 and 300,000 yr BP (Bachman and Machette, 1977, Monger and Daugherty, 1991), then these soils could have been formed in the warm period between 186,000 and 242,000 yr BP (OIS 7) (Bouza et al., 2005). On the other hand, the Pleistocene marine terraces, located 28 km to the SSE of the PV1 soil, that are composed of gravels with fossil bivalves shells (genus *Mytilus*), presented a Th/U age between 115,000±5000 and 137,000±14,000 yr BP and represents the culmination of the Last Interglacial OIS 5e (Rostami et al., 2000). These gravel deposits, with a lower pedogenic carbonate, present no evidence of cryogenesis as those detected in the RP soils (ER, PV1 and PV2).

In conclusion, the carbonate accumulation, the fossil–ice wedge casts, and the other cryogenic features recorded in the RP of our study area would be much older than the LGM. Similar conclusions about the cryogenesis and pedogenic carbonate ages in the RP were stated by Trombotto (2002) and Douglass and Bockheim (2006), respectively.

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