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Effects of fluoride intoxication on teeth of livestock due to a recent volcanic eruption in Patagonia, Argentina

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ABSTRACT

Flueck WT, Effects of Fluoride intoxication on teeth of livestock due to a recent volcanic eruption in Patagonia, Argentina, Onl J Vet Res., 17 (4): 167-176, 2013. The Puyehue-Cordon Caulle volcanic eruption deposited large amounts of tephra (ashes) on about 36 million ha of Argentina in June of 2011. Tephra were considered chemically innocuous based on water leachates, surface water fluoride levels were determined to be safe, and livestock losses were attributed to inanition and excessive tooth wear. To evaluate chronic effects on livestock, mandibles from animals that died after August 2012 were evaluated. Clearly, these tephra caused dental fluorosis, with bone fluoride levels reaching up to 3,253 ppm. Among sub-adults, tephra caused pathologic wear of newly emerging teeth, with extremely rapid ablation of entire crowns down to underlying pulp cavities. Although initial analyses of water and tephra were interpreted not to present a concern, ruminants as a major component of the affected landscape were shown to be highly susceptible to fluorosis, with average bone level increasing several fold during the first 15 or more months of exposure to tephra. Fluorosis in domestic livestock due to volcanic eruptions has not yet been reported, yet the described impact will affect morbidity, predation susceptibility, body growth, reproductive success and longevity, with associated impact on livestock production systems.

Keywords: livestock, dental fluorosis, fluoride, pathology, teeth, tephra, volcanic eruption.

INTRODUCTION

The Puyehue-Cordon Caulle volcanic eruption (PCCVE, 4 June 2011) produced plumes 15 km high, and deposited large amounts of tephra (ejected solid matter) in Chile and over about 36 million ha in Argentina (Figure 1; Gaitán et al. 2011; Mohr Bell and Siebert 2011). Winds deposited layers of tephra 5 cm thick at 240 km distance, but it also reached Buenos Aires, 1400 km away (Wilson et al. 2012). Volcanic eruptions may emit toxic levels of fluoride, impacting animals in the surroundings (Cronin et al. 2000, 2003), but generally, fluorosis has raised concerns principally regarding industrial pollution or use of fertilizers (Kierdorf et al. 1996; Richter et al. 2010). A recent local example was the Lonquimay volcano eruption (1988, 200 km north of PCCVE), where fluorosis in livestock occurred within weeks (Araya et al. 1990). Immediately after the PCCVE, analyses of tephra revealed mainly O, Si, Al, Fe, Na and K (Buteler et al. 2011; Hufner and Osuna 2011).

Although initial concerned about fluorosis, based on incidences from other Chilean volcanoes, only fluorine-containing microbubbles that may turn into fluorohydric acid upon contact with water were suggested to possibly occur in tephra (Bermúdez and Delpino 2011). Moreover, water-soluble extracts from tephra revealed low fluoride levels (0.7 ppm; Hufner and Osuna 2011), surface water analyses from both countries revealed low fluoride levels, and overall water consumption was considered without risk for humans and animals (DGA 2012; Wilson et al. 2012). Still, livestock losses in the region receiving tephra were high, but attributed to inanition, rumen blockage and excessive tooth wear, rather than to known toxic elements (Wilson et al. 2012). Apparently only one Chilean analysis was conducted on fluoride levels in forage plants and animal tissues from the PCCVE: forage fluoride levels were >3-fold higher than accepted levels, while levels in tephra and blood from livestock were also elevated (Araya, cited in Flueck and Smith-Flueck 2013). Given these observations in Chile and overt fluorosis documented from the nearby 1988 eruption, reasons for absent fluorotic cases from PCCVE remained elusive.

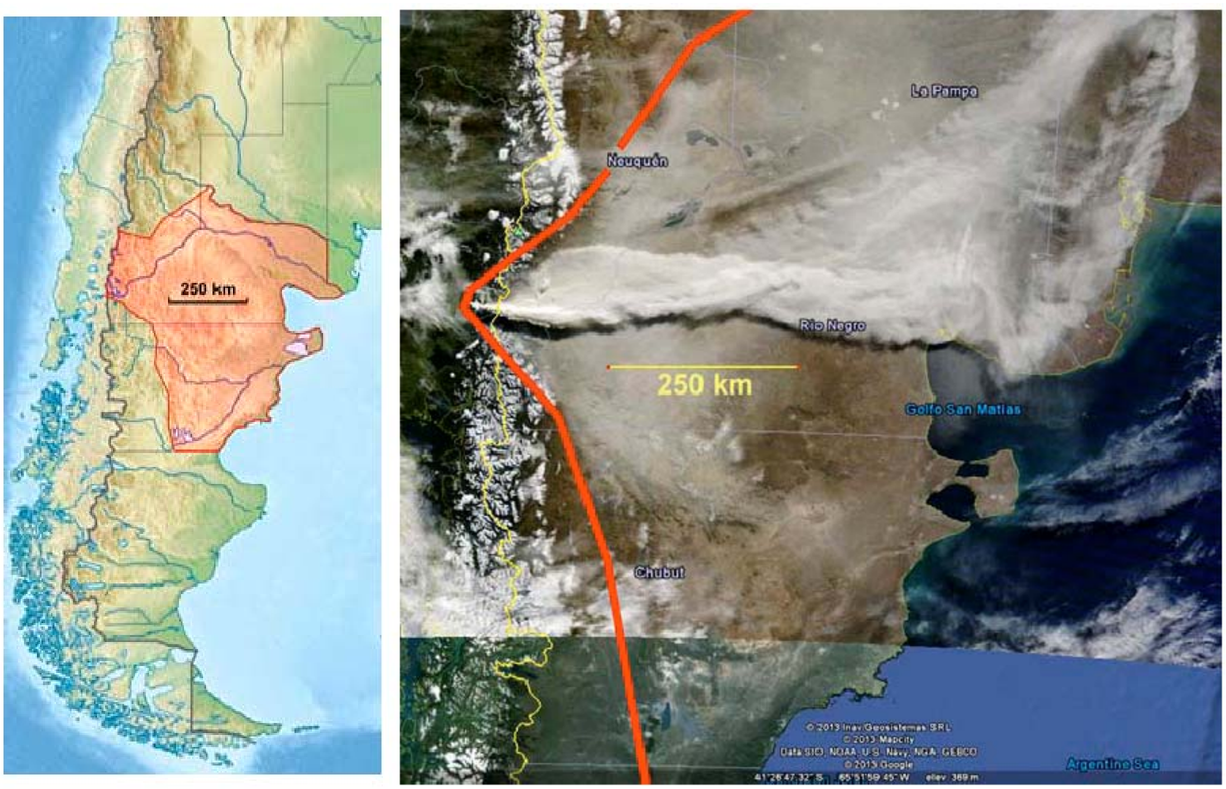

Figure 1. Distribution of tephra deposited from the Puyehue-Cordon Caulle volcanic eruption, showing the Moderate Resolution Imaging Spectroradiometer image of 13 June 2011, http://earthobservatory.nasa.gov. The red line marks the limit of deposition,

principally in the Provinces of Neuquen, Rio Negro, and Chubut (Bermúdez and Delpino 2011; Gaitán et al. 2011; Mohr Bell and Siebert 2011)

Soon after the PCCVE, livestock became weak and hundreds of thousands died; causes were attributed to emaciation from lack of forage. In surviving individuals, excessive tooth wear, attributed to abrasive tephra, was noted within 2 months, and currently evokes the application of artificial dentures to extend the life of hoofstock. Although toxic effects among livestock had not yet been reported, a recent study on wild red deer (*Cervus elaphus*) at 100 km from PCCVE provided the first evidence that the tephra produced severe dental fluorosis in deer (Flueck and Smith-Flueck 2013). This report presents evidence that livestock also succumbed to the effect of excessive fluoride exposure via tephra from the PCCVE.

MATERIALS AND METHODS

Study area

The study area is located in the northeastern portion of Patagonia, between 40°18' - 41°14' S and 69°30' - 71°13' W. The topography to the west is primarily mountainous with most features formed by glacial processes. The majority of soils originated from volcanic processes and are young. The dominant climate is temperate with main precipitation occurring April-September and snow falling frequently during June-September. There is an abrupt precipitation gradient from west to east due to the Andean orography, resulting in a strongly defined vegetation structure and floristic composition. The western portion of the study area is between 900-1,200 m elevation and represents the ecotone between forests and steppe. Patches of forests are characterized by *Nothofagus antarctica* and *Austrocedrus chilensis* at lower elevations, replaced by *Nothofagus pumilio* at higher elevations. Forest patches at lower elevations alternate with wet grasslands with abundant growth of herbaceous plants whereas at high elevation they are replaced by grass-dominated steppe of *Stipa speciosa* var. *major* and *Festuca pallescens*, with variable occurrence of brush species including *Mulinum spinosum*, *Berberis* spp. and *Colletia spinosissima*. Riparian areas also contain galleries of trees including *Lomatia hirsuta*, *Maytenus boaria* and *Schinus patagonicus*. The eastern portion of the sampled area is dominated by rangeland.

Animal samples

Samples consisted of bones, principally mandibles, collected on five ranches in different areas. Death resulted mainly from slaughter for human consumption, with some due to predation. Mandibles were inspected for the stage of dental eruption and wear patterns. The exposure to tephra began on 4 June 2011, and samples stem from animals that died after about August of 2012. As the time of death was estimated by ranch personnel, the dates for some older samples, particularly related to predation, were likely estimated as too recent.

Determination of fluorine concentrations

Samples were obtained from mandibles (n=24) by removing 0.5 g from the ventral ridge at the level of molar M1 in most cases. One sample consisted of ribs, where a piece of the cortical layer was removed. Fluorine concentrations were determined in the Laboratorio de Biología Ósea (Universidad Nacional de Rosario, Rosario, Argentina;

Rigalli et al. 2007). Samples were ashed at 550° C, acid labile fluorine was isolated from 50 µg of sample by isothermal distillation, and the sample was treated with phosphoric acid 98% w/w at 60° C for one day. During this time, hydrofluoric acid released from samples was recovered by sodium hydroxide placed in the cup of the distillation chamber. Subsequently, the sodium hydroxide trap was adjusted to pH 5.5 with acetic acid 17.5 mol/L. Standards ranging from 10^{-3} – 10^{-6} mol/L were simultaneously processed.

Total fluorine was measured by direct potentiometry using an ion selective electrode ORION 94-09 (Orion Research Inc, Cambridge MA, USA) and a reference electrode of Ag/AgCl. Duplicate samples were analyzed, resulting in coefficients of variation of <3.5%, and the results are presented as the mean, expressed as ppm in dry bone. In addition, rat bones were analyzed simultaneously: ash of rats treated with NaF averaged 2,317 ppm whereas control rats averaged 11 ppm.

RESULTS

Effects on livestock

Livestock exhibited excessive tooth wear following the PCCVE, being notable in cheek teeth, but particularly in incisive teeth. Prime-aged sheep had incisors evenly worn down to the gums (Figure 2).

Figure 2. Excessive but even wear of incisive teeth in an adult sheep with only root stubs remaining.

Sub-adults also exhibited extreme tooth wear. This was particularly evident on newly emerged incisors which developed under the influence of excess fluoride exposure. The 3 mandibular incisors in sheep emerge such that in the first year only I1 appears, followed by I2 in the next year, and I3 in the third year. In some individuals the wear on the I1 was so advanced that practically all posterior enamel was ablated and the underlying pulp cavity exposed, while incisors 2 and 3 were still milk teeth (Figure 3).

Figure 3. Excessive tooth wear in sub-adult teeth due to abrasion from volcanic tephra and chemical impact. Note extensive wear on first incisors, with exposed pulp cavity, in presence of milk incisive teeth (except the left permanent I2 which is just emerging)

In older sheep, upon the emergence of I2, the first pair had often already been worn down to the level of the gums, resulting in accelerated unsymmetric wear of I2 (Figure 4a). Upon emergence of I3, both I1 and 2 had frequently been already worn down to the gums with exposure of pulp cavity (Figure 4b, next page).

Fluoride concentrations

Besides the tephra causing excessive mechanical abrasion of teeth, to explore systemic effects, fluoride levels in bones were determined (Table 1). Sheep from site A (41° 05' S, 70° 59' W) averaged 931 ppm of fluoride (range 569-1,502 ppm, n=3). Sheep from site B (41° 00' S, 71° 12' W) averaged 956 ppm of fluoride (range 660-1,216 ppm, n=5). Sheep from site C (41° 17' S, 70° 44' W) averaged 1,160 ppm of fluoride (range 1,072-1,313 ppm, n=4). Sheep from site D (40° 22' S, 69° 32' W) averaged 1,604 ppm of fluoride (range 1,136-2,240 ppm, n=4) in one location, whereas two sheep from another location had 698 and 948 ppm. Two horses from site D had fluoride levels of 880 and 1,198 ppm. Lastly, sheep from site C (41° 15' S, 70° 30' W) averaged 2,431 ppm of fluoride (range 1,449-3,253 ppm, n=5).

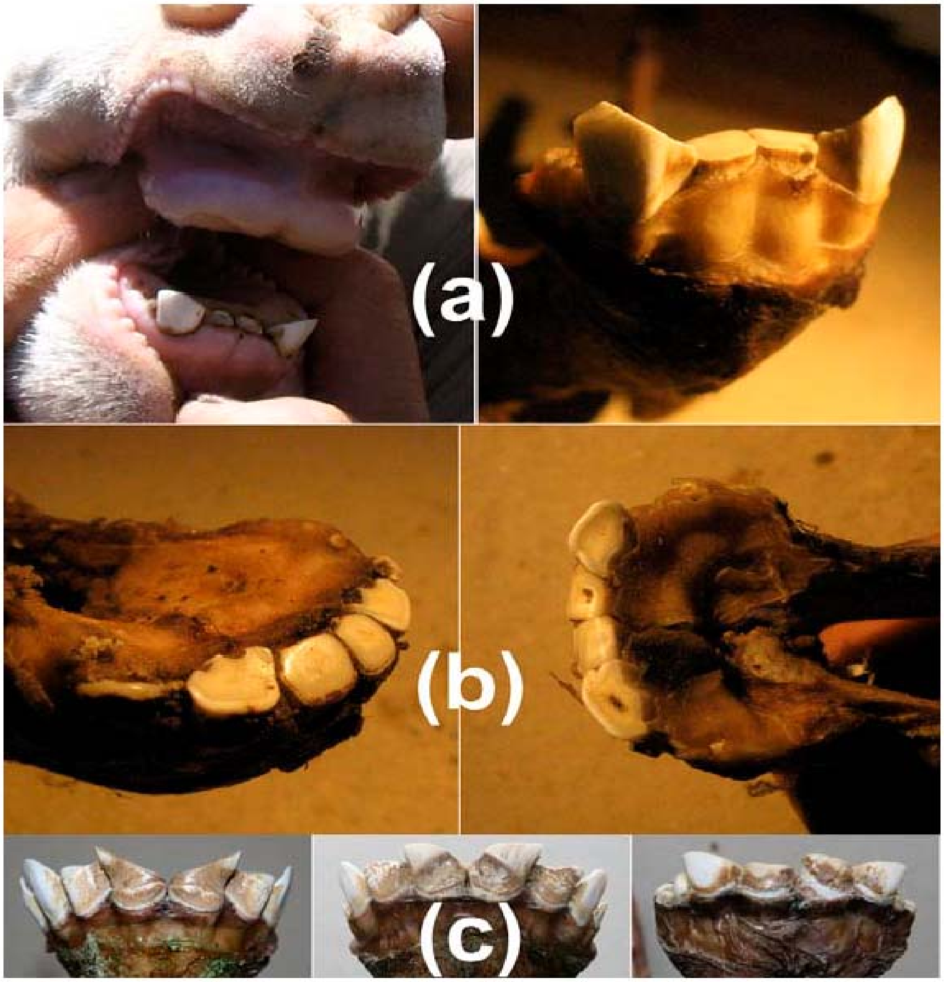

Figure 4. Mandibular teeth of sheep affected by fluorosis following a 2011 volcanic eruption in Patagonia. (a) The first incisors have been worn down to the gum, the nearly fully emerged second incisors show already substantial uneven wear, and the incisor arcade is rendered unfunctional. Note deciduous i3 and c. (b) Left: incisors 1 and 2 are worn down to the gum, the right I3 is just emerging, the remainder are milk teeth. Right: uneven and extensive wear on I1 and I2, exposing pulp cavities, with i3 and c still present. c) Aberrant wear pattern of new incisive teeth in cervids from the same area (Flueck and Smith-Flueck 2013).

Table 1 Fluoride concentrations (ppm) in dry bone from livestock exposed to tephra from the Puyehue-Cordon Caulle volcanic eruption of 4 June 2011, collected from five ranches in Patagonia.

Farm	Species	Age (yrs)	F- (ppm)	Time of death*
A	sheep	3	1502	Jan 2013
A	sheep	>8	723	Jan 2013
A	sheep	>5	569	Jan 2013
B	sheep	adult	1216	Oct 2012
B	sheep	adult	1142	Oct 2012
B	sheep	<1	1061	Oct 2012
B	sheep	adult	701	Oct 2012
B	sheep	<1	660	Aug 2012
C	sheep	2	1313	Dec 2012
C	sheep	>8	1158	Nov 2012
C	sheep	>8	1095	Nov 2012
C	sheep	adult	1072	Dec 2012
D	sheep	2	2240	Nov 2012
D	sheep	>8	1816	Sep 2012
D	sheep	2	1223	Nov 2012
D	sheep	2	1136	Sep 2012
D	sheep	2	948	Nov 2012
D	sheep	2	698	Nov 2012
D	horse	adult	1198	Aug 2012
D	horse	adult	880	Oct 2012
E	sheep	3	3253	Nov 2012
E	sheep	>8	2675	Nov 2012
E	sheep	2	2594	Nov 2012
E	sheep	2	2185	Nov 2012
E	sheep	>8	1449	Nov 2012

* time of death was an estimate by ranch personnel, and dates for some older samples, particularly related to predation, were likely estimated as too recent.

DISCUSSION

General premature tooth wear was omnipresent and due to the abrasiveness of tephra, thus affecting also animals with normally developed teeth. This effect was exacerbated in sub-adults as shown by extremely rapid wear of new teeth, indicating that the biophysical properties of teeth have been affected during their development. As these subadults continue to grow in body size, such advanced wear would likely considerably reduce their morphometric development and health condition, shorten life expectancy, and reduce lifetime reproductive success. Particularly incisive teeth worn down to the gums, with newly emerged lateral incisors, would impair feeding, as these different degrees of wear results in highly uneven incisor arcades with a reduction in functionality (Figure 4a). This aberrant wear pattern is homologous to those observed in cervids in the region (Figure 4c).

In addition to fluoride-induced dental lesions, concomitant occurrence of marked periodontal disease and tooth loss are important factors responsible for reducing the life expectancy (e.g. Schultz et al. 1998). For instance, Garrott et al. (2002) found that the onset of survival senescence in non-affected deer occurred at about 16 years of age with a life expectancy of 25 years, whereas none of the deer with bones averaging 1,711 ppm of fluoride survived beyond 16 years: accordingly, there was a 24% reduction in the potential annual population growth rate. A similar shortening of longevity is expected in livestock affected by the PCCVE.

The bone fluoride levels in livestock from all examined ranches are clearly above the background level of 63 ppm determined in bones from before the PCCVE (Flueck and Smith-Flueck 2013), and are above levels considered normal for livestock (Aiello and Moses 2012). A study in New Zealand showed that lambs shortly after weaning had bone fluoride levels of 160 ppm, which though increase to 2,784 ppm after 3 months of feeding them a diet mixed with fluoride containing soil (Grace et al. 2007). A study on horses in Colorado, USA showed that animals with typical symptoms of fluoride intoxication (dental fluorosis, leg deformations, hyperostosis and other clinical effects) had bone fluoride levels between 587-936 ppm (Macicek and Krook 2008). Therefore, the levels of 880 and 1,198 ppm in two horses in this study indicate that overt pathology is to be expected among equids.

The variations in fluoride concentration *within* a ranch site stem from the fact that lambs born in Oct-Nov will be mainly nursing for the initial months and, therefore, their time of exposure to tephra ingestion was shorter than fully functional ruminants. Similarly, 2-year old had less time of exposure than animals that were functional ruminants at the time of the eruption. Additional factors include the actual time to death, different amounts of tephra deposited according to topography and wind conditions, or different management among corrals like the provision of balanced food to overcome food shortage. Variations *among* these ranches stem from the distance and direction from the volcano, which influenced the particle size and quantity deposited on the area. Differences are also due to the precipitation gradient caused by the orography of the Andes, as drier areas likely take longer to fix particles in the soil column, and aeolic re-deposition is more pronounced which intensifies and prolongs animal exposure to tephra.

Skeletal bone fluoride content commonly increases continuously with age in mammals (Walton 1988). Bone levels of deer collected in this study area before the volcanic eruption averaged 63 ppm of fluoride (Flueck and Smith-Flueck 2013), and bones of fetal deer collected in 2012 averaged only 20 ppm although their mothers already averaged 2,151 ppm. Additionally, based on fluoride levels in one-year old deer (which had been feeding for about 8-9 months), two-year old deer and those 3 years or older, a continued similar exposure to fluoride sources indicates that animals may accumulate about 1,000 ppm per year (Flueck and Smith-Flueck, submitted). It is, therefore, also likely that livestock will continue to accumulate fluoride with associated long term problems of acquiring osteofluorosis. Tephra from the nearby Lonquimay volcano eruption of 1988 caused elevated forage fluoride levels for 2 years of monitoring after the eruption, and high forage levels alone were concluded to be dangerous for animals at least 2 years after cessation of the eruption (Araya et al. 1993). The occurrence of osteofluorotic alterations has been diagnosed in ruminants with fluoride concentrations greater than 4,000 ppm in dry bone (Schultz et al. 1998).

Tephra deposited from PCCVE has been estimated at 100 million tons, spread over some 36 million ha in Argentina. Importantly, tephra layers of even <1 mm resulted in the death of several thousand sheep in New Zealand, mainly from fluorosis (Gregory and Neall 1996; Cronin et al. 2003). Also important is recognizing that due to particle size, tephra deposited farthest from a volcano have highest fluoride levels (Taves 1980; Rubin et al. 1994; Gregory and Neall 1996; Cronin et al. 2003). With regard to possible sources of fluoride, local water has been shown to contain very low levels. Although no information on plant fluoride levels exists, the main source has been suggested to be related to the susceptibility of ruminants due to their food processing: 1) intensive mastication and tephra size reduction (with concomitant excessive tooth wear), 2) thorough mixing of tephra with alkaline saliva at repeated rumination cycles, 3) water soluble extraction in rumen, and 4) further extraction in the acidic abomasum (Flueck and Smith-Flueck 2013).

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