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RESEARCH ARTICLE

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Snow algae of the Sierra Nevada, Spain, and High Atlas mountains of Morocco

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Summary Snow algae (Chlorophyta) are reported from the Sierra Nevada mountains in southern Spain and the High Atlas mountains of Morocco. Populations of the snow algae *Chlamydomonas* sp., coloring the snow orange-red, were collected from Pico de Veleta, Spain, while snow samples from Mt. Neltner in the High Atlas mountains, contained resting spores of an orange-green colored *Chloromonas* sp. Other microbes observed in snow samples include bacteria, fungi, heterotrophic euglenids, diatoms, nematodes, and heterotrophic mastigotes (flagellated protists). This is the first report of snow algae from the Sierra Nevada mountains of Spain and from the Afro-alpine environment.

Key words *Chlamydomonas* · *Chloromonas* · Snow algae · Algal distribution · Alpine environments

Introduction

Populations of cryophilic microalgae collectively known as snow algae, mostly from division Chlorophyta or green algae, are known to inhabit polar and alpine snow worldwide [6, 13]. While reports of snow algae are widespread, there are mountainous snow covered regions from which snow algae have not been described. For example, it was not until recently that the first report of snow algae from the Himalaya was recorded [23]. The global distribution of common snow algal species has been a paradox [7, 20]. Why are snow algal assemblages so similar worldwide? As Coleman [3] states, “No open body of freshwater remains devoid of algae for much longer than the first gust of wind”. Thus, we hypothesized that if snow algae were present in the Pyrenees mountains in northern Spain [13], then the same species might be present in the mountains of southern Spain and Morocco.

Snow algae are found in mountainous and polar regions that maintain regular and adequate snow accumulations [13]. Blooms of snow algae occur in snow packs that are in the melting stage, with resting spores normally found near the surface of melting snow [6]. Dense populations impart a red, green, or orange color to the snow [6, 13]. While snow algae bloom in cold meltwaters, they spend the majority of the year dormant on soil or rock substratum. Because red-colored snow algae generally inhabit open areas above tree line, they are exposed to high levels of ultraviolet (UV) light and indeed appear adapted to a high UV environment [21].

The first observations of red snow are attributed to Aristotle in the third century BC [1, 13]. It was not until 1819 that Bauer [2] attributed the coloration to a dense population of microbes present in snow meltwaters. The most comprehensive work of snow algae is that by Erzsebet Kol [13], who summarized her life’s work of four decades of research with reports from Europe, North America, South America, Greenland, Asia including Japan, and Antarctica. Snow algae are also reported from the Snowy Mountains of Australia [15], New Zealand [20], and even Papua New Guinea [14]. Until this investigation, Africa was the only continent with no reports of snow algae [5, 6, 20].

Materials and methods

Snow samples were collected 27 May–2 June near the snow line between 2800–3000 m at Pico de Veleta, Spain, and 3100–3200 m at Mt. Neltner, Toubkal region, Morocco (Fig. 1). Melting snow packs less than 1 m in depth were inspected for signs of discoloration or indications of algal populations. Snow samples were aseptically collected and transferred into Whirl pak™ bags. Samples were kept cool in an ice chest during transport to the Autonomous University of Madrid, where they were examined using light microscopy three days after collection. Samples were maintained on ice and in the dark until a more detailed examination was done at the authors home universities, 5–7 days after collection. Individual cells and populations were characterized by phase contrast light microscopy (10003), and by Nomarski differential interference contrast optics (DIC). Photomicrographs were made at 400–10003 through a Nikon Microphot. Algal populations were not tabulated because cells were embedded in debris and mucilage that formed clusters making enumerations unreliable.

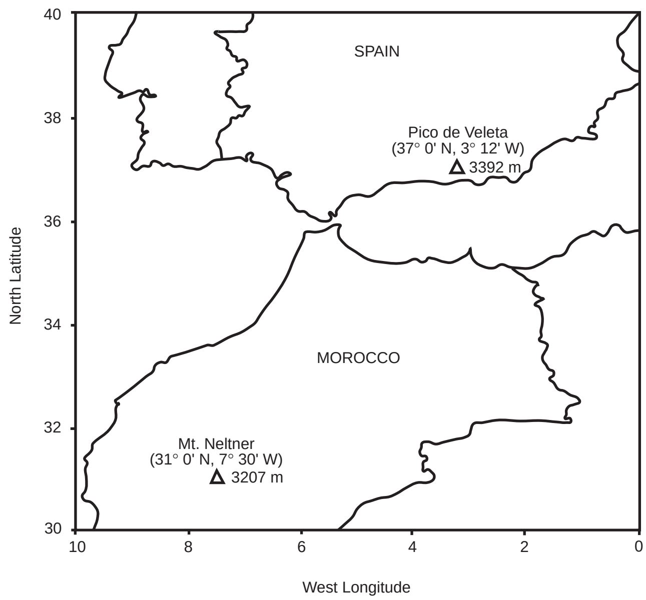

Fig. 1 Snow algae collection sites. Pico de Veleta (3392 m) in the Sierra Nevada of Spain, and Mt. Neltner (3207 m) in the Toubkal region of the High Atlas mountains of Morocco

Results and Discussion

A two day reconnaissance of Pico de Veleta, Spain, snow yielded only one snowfield that maintained a visibly red color on the snow surface imparted by the algae. This was after surveying numerous areas with varying slope and water availability for visual signs of snow algae. The snowfield had a north facing exposure and a slope between 15–20 degrees, and was not unlike other snow fields that had no signs of snow algae as observed by Hoham and Blinn [7] in the American Southwest. Light microscopy of snow samples revealed orange-red aplanospores (Fig. 2). Cells were spherical and measured between 25–40 mm in diameter and often appeared encompassed by a halo of translucent mucilage to which debris adhered. These cells were morphologically similar to snow algae belonging to *Chlamydomonas nivalis* [12, 18] which has been described from Spain [13]. However, the color of our samples was more orange-red rather than blood-red so typical of *C. nivalis*. Thus we have designated our samples as an unidentified species of *Chlamydomonas*.

Resting spores of snow algae were observed in Mt. Neltner snow from the High Atlas mountains of Morocco (Fig. 3). These cells were oval, 20 3 25 mm, and appeared to have orange-colored pigments at each pole. These cells, with flange-like extensions on the outer wall, are similar to *Scotiella*-like cells reported as resting spores in species of *Chloromonas* from snow [8–10]. However, the markings here appear different from those found in other species of *Chloromonas* described from snow. While this appears to be a previously unreported species of *Chloromonas*, it can not be confirmed. These algae were observed in sparse populations in all six snow samples collected.

Other microorganisms observed in the Moroccan snow samples included rod shaped bacteria, micro-fungi, heterotrophic euglenids, ciliates, diatoms, nematodes, and heterotrophic mastigotes (flagellated protists). Bacterial associations with snow algae have been reported in previous studies [21, 22], as have more complex microbial communities involving algae, yeasts, ciliates, and bacteria [11].

The Sierra Nevada range is not part of a continuous chain of mountains and is geographically set between the semi-arid Spanish lowlands to the north and the Mediterranean Sea to

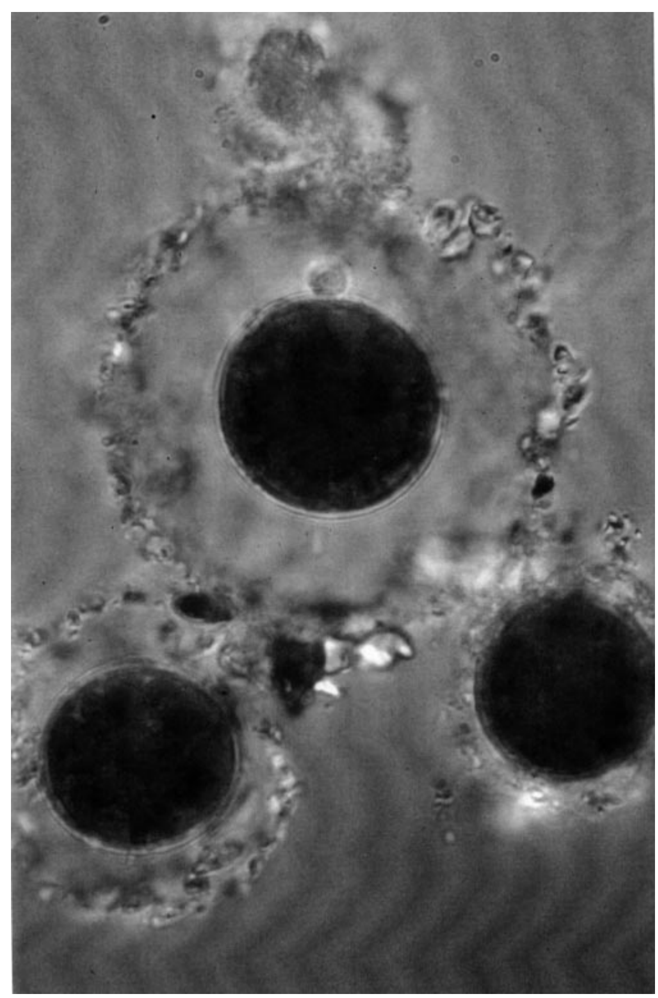

Fig. 2 Snow algal cells *Chlamydomonas* sp. (10003) collected from Pico de Veleta (Spain) are spherical, red in color, 25–30 mm in diameter, and encapsulated by a thick cell wall. A sphere of debris generally surrounds each cell

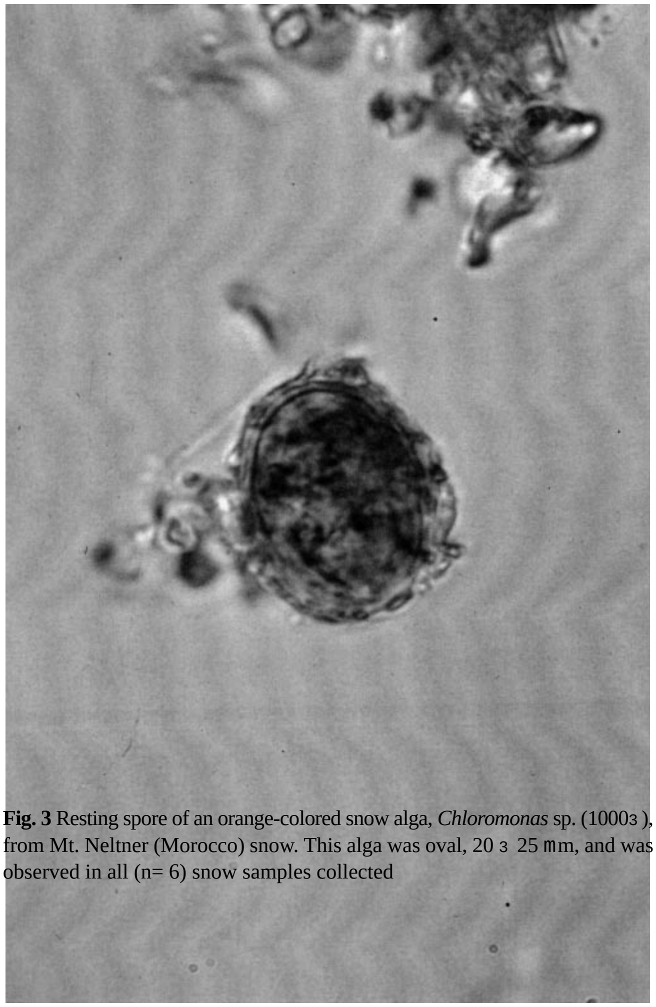

Fig. 3 Resting spore of an orange-colored snow alga, *Chloromonas* sp. (1000×), from Mt. Neltner (Morocco) snow. This alga was oval, 20 × 25 μm, and was observed in all (n= 6) snow samples collected

the south. The High Atlas are northern Africa's tallest mountains, and are likewise bound by the arid desert of the western Sahara. At one point in time (Pangea), the High Atlas were adjacent to mountain ranges in eastern North America near the Equator [17]. It is debatable, however, whether the ranges would have supported snow algae at that time due to uncertainties in elevations in these ranges, and if temperatures would have been cold enough to support such life forms [16].

While *Chlamydomonas* sp. in red snow are reported from mountainous regions worldwide, they are absent from other snow covered mountains that appear to be a suitable habitat. For example, *C. nivalis* is conspicuously absent in alpine snow from areas above tree line in the northeastern USA, even though the alga is commonly found in the western USA throughout the Sierra Nevada [19] and the Rocky Mountains [6, 7], despite prevailing winds that might carry algal spores in an easterly direction from western to eastern North America. Many species of snow algae have become isolated in individual ranges [7, 11, 20]. During the Oligocene and Miocene periods (40–20 mya, at the beginning of the Ice Ages), contiguous orogenic belts that linked the North American and European plates may have provided a contiguous habitat for ancient snow algae.

Chlamydomonas sp. is commonly reported as airborne inoculum due to their heavy cell wall and gelatinous sheath that can withstand desiccation [3]. While the inoculation of algal resting spores by wind is a probable mechanism of snow algal distribution, we would like to suggest that Late Cenozoic era mountain building and glaciation events of the Oligocene and Late Miocene periods (40–20 mya) [4] may have provided a more contiguous alpine-snow habitat suitable for snow algae. This possibility would facilitate more widespread dispersion and may help to explain some of the peculiarities of today's snow algal distributions after the retreat of glaciers.

Conclusions

Snow algae are now known to inhabit snow from all continents. Red-colored snow algae resembling *Chlamydomonas* (Chlorophtya) were found in snow collected from the Sierra Nevada mountains, Spain. This alga is similar to that encountered by Kol [13] in the Pyrenees mountains that border northern Spain, but differs in color being orange-red rather than blood-red. Snow collected from the High Atlas of Morocco contained a resting spore of *Chloromonas*.

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References

1. Baross JA, Morita RY (1978) Life at low temperatures: ecological aspects. In: Kushner DJ (ed) Microbial Life in Extreme Environments. London: Academic Press, pp 49–50
2. Bauer F (1819) Microscopical observations on the red snow. Quart J Lit Sci Arts 7:222–229
3. Coleman A (1983) The roles of resting spores and akinetes in chlorophyte survival. In: Greta A (ed) Survival Strategies of the Algae. Fryxell: Cambridge University Press, pp 1–20
4. Dott RH, Prothero DR (1994) Cenozoic history. In: Evolution of the Earth (5th edn). New York: McGraw-Hill Inc, pp 474–485
5. Hoham RW (1974) New findings in the life history of the snow algae, *Chlainomonas rubra* (Stein et Brooke) *comb. nov.* (Chlorophyta, Volvocales). Syesis 7:239–247
6. Hoham RW (1980) Unicellular chlorophytes– snow algae. In: Cox ER (ed) Phytoflagellates. New York: Elsevier North Holland, pp 61–84
7. Hoham RW, Blinn DW (1979) Distribution of cryophilic algae in an arid region, the American Southwest. Phycologia 18:133–145
8. Hoham RW, Mullet JE (1978) *Chloromonas nivalis* (Chod.) Hoh. & Mull. comb. nov., and additional comments on the snow algae, *Scotiella*. Phycologia 17:106–107

9. Hoham RW, Mullet JE, Roemer SC (1983). The life history and ecology of the snow alga *Chloromonas polyptera* comb. nov. (Chlorophyta, Volvocales). Can J Bot 61:2416–2429
10. Hoham RW, Kemp K, Fjerdingstad E, Fjerdingstad E (1977) Comparative study of trace elements and nutrients in green snow (Washington, USA) and red snow (Greenland and Spitzbergen). J Phycol 13:30
11. Hoham RW, Laursen AE, Clive SO, Duval B (1993) Snow algae and other microbes in several alpine areas in New England. In: Ferrick M, Pangburn T (eds) Proceedings of the Fiftieth Annual Eastern Snow Conference, Québec, pp 165–173
12. Kawecka B (1981) Biology and ecology of snow algae. 2. Formation of aplanospores in *Chlamydomonas nivalis* (Bauer) Wille (Chlorophyta, Volvocales). Acta Hydrobiol 23:211–215
13. Kol E (1968) Kryobiologie. Biologie und limnologie des Schnees und Eises. I. Kryovegetation. In: Elster HJ, Ohle W (eds) Die Binnengewasser. Stuttgart: E Schweizerbart'sche Verlagsbuchhandlung, 216 pp
14. Kol E, Peterson JA (1976) Cryobiology. In: Hope GS, Peterson JA, Radok U, Allison I (eds) The Equatorial Glaciers of New Guinea, Results of the 1971–1973 Australian Universities' Expeditions to Irian Jaya: Survey, Glaciology, Meteorology, Biology and Paleoenvironments. Rotterdam: AA Balkema, pp 81–91
15. Marchant H (1982) Snow algae from the Australian Snowy Mountains. Phycologia 21:178–184
16. Parrish JT (1993) Climate of the supercontinent Pangea. J Geology 101:215–233
17. Smith AG, Livermore RA (1991). Pangea in Permian to Jurassic time. Tectonophysics 187:135–179
18. Stein J, Brooke RC (1964) Red snow from Mt. Seymour, British Columbia. Can J Bot 42:1183–1188
19. Thomas WH (1972) Observations on snow algae in California. J Phycology 8:19
20. Thomas WH, Broady PA (1997) Distribution of coloured snow and associated algal genera in New Zealand. New Zealand J Bot 35:113–117
21. Thomas WH, Duval B (1995) Sierra Nevada, California, USA, snow algae: snow albedo changes, algal-bacterial interrelationships, and ultraviolet radiation effects. Arc Alp Res 27:389–399
22. Weiss RL (1983) Fine structure of the snow alga (*Chlamydomonas nivalis*) and associated bacteria. J Phycol 19:200–204
23. Yoshimura Y, Kohshima S, Ohtani S (1997) A community of snow algae on a Himalayan glacier: change in algal biomass and community structure with altitude. Arc Alp Res 29:126–137