Journal of Glaciology, Vol. 40, No. 134, 1994

Correspondence

The Editor,
Journal of Glaciology

SIR,

Glaciers in Picos de Europa, Cordillera Cantábrica, northwest Spain

Cordillera Cantábrica, trending east–west, is located in the northwest of the Iberian Peninsula and lies 25–60 km from the Bay of Biscay coast. In its eastern part, in the area known as Picos de Europa Massif, are the highest peaks of the Cordillera (about 2600 m). This massif is formed almost totally by calcareous rocks. Duje and Cares Rivers, flowing from the divide between the Cantabrian and Atlantic basins, cross Picos de Europa and divide them into three units known from east to west as: Macizo Oriental (Eastern Massif), Macizo Central (Central Massif) and Macizo Occidental (Western Massif) (Fig. 1). Proximity to the sea, that at present is causing major cloud cover and abundant precipitation, contributed to the formation of glaciers during Pleistocene times, their activity producing a characteristic landscape. In spite of intense karstification, there are still many signs of glacial activity, especially in the higher areas of the Massif, which constitute a glaciokarst, where erosional forms prevail over deposits.

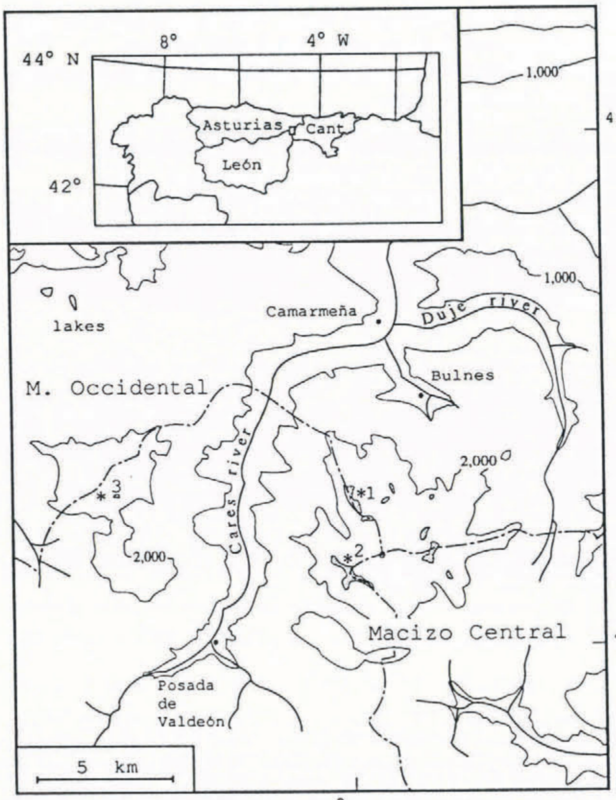

Fig. 1. Location of the main snow patches of Picos de Europa: 1, Jou Negro; 2, Llambrión; 3, Neverón de la Forcadona. Stippled areas are above 2500 m.

BACKGROUND

Geomorphological studies of Cordillera Cantábrica and recognition of its glacial and periglacial features date from the beginning of the present century (Hernández Pacheco, 1914; Obermaier, 1914). Traditionally, it was recognized that in Picos de Europa there are only perennial snow patches (Clark, 1981; Fernández Rodríguez, 1992).

Until now, the only glaciers found in the Iberian Peninsula were located in the Pyrenees (Serrat, 1980). This author considered that the snow line in Picos de Europa was 800 m lower than in the Pyrenees although, for Clark (1981), this massif would have developed glaciers with a slight climatic deterioration.

GLACIAL ICE

In this letter, the presence of glacial ice in the Macizo Central, in the form of glaciers of small dimensions, is reported for the first time. They were formed from the wastage of larger glaciers that were partially covering the uplands of the Macizo Central during the Little Ice Age.

At present, the largest glacier is that in Jou Negro, located at the base of the highest summit of Picos de Europa (Torre de Cerredo, 2651 m). Glacial ice occupies the bottom of a cirque with a northeast aspect, that is well protected from solar radiation by the surrounding crests situated to the east, south and west (Figs 2 and 3). Resting against the cirque walls, at a certain distance from the ice and facing the north-northeast, there is an arcuate push moraine. According to the nomenclature established in the Catalan Pyrenees by Bru and others (1985), this moraine could be subactual, corresponding to the historic post-glacial phase. This relation between glacial ice and terminal moraine in Jou Negro is

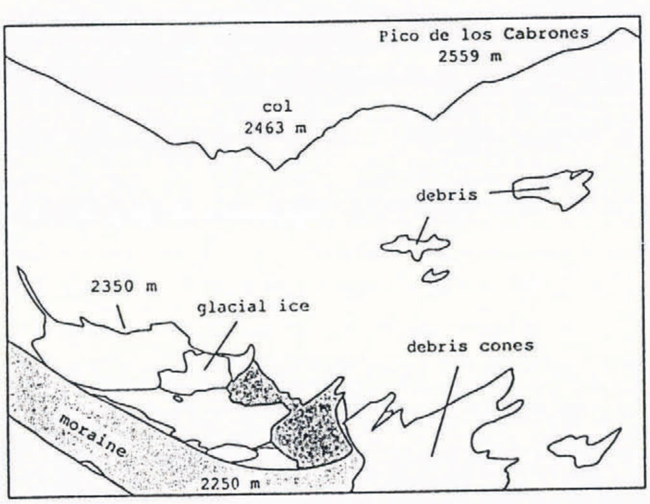

Fig. 2. Sketch from Figure 3.

Fig. 3. General view towards the south of the relict glacier of Jou Negro (Macizo Central). The highest peak of the massif (Torre de Cerredo, 2651 m), outside the photograph, lies just to the left of the margin (taken on 20 September 1992).

comparable to that described by Serrat (1980) in Madaleta Massif (central Pyrenees), where important glacier retreat took place from the 19th century until 1957. According to Serrat, the best-developed moraines, formed in the 19th century, are separated from the present glacier margins.

Besides Glaciar Jou Negro, it is possible that there is glacial ice beneath the northeast snow patch of Torre de la Palanca and the snow patch of Llambrión, both in the Macizo Central. Some snow patches in the Macizo Occidental could also have ice cores, such as Neverón de la Forcadona, on the north face of Peña Santa de Castilla, although the altitudes of the summits here are slightly lower than in the Macizo Central.

It is not surprising that glacial ice has not been seen until now in Picos de Europa as it is usually beneath a layer of snow and firn that acts as an insulator. Due to the low precipitation during the last few years, ablation exceeded precipitation, causing melting of most of the snow and firn. As a result, the ice cores have been exposed in recent summers. In September 1992, Glaciar Jou Negro was discovered by one of the authors (González Suárez).

The preservation of these small glaciers in Picos de Europa can be attributed to heavy precipitation, in the form of snowfall and the permanence of this snow favoured by low solar radiation. As perennial snow-cover provides insulation, ablation was considerably reduced, and this allowed the continued existence of the glacial ice. The present state of these glaciers is not known, although future surveys will enable us to establish whether they are stable or whether they are retreating.

ACKNOWLEDGEMENT

The authors thank T. J. Chinn for helpful comments on the manuscript.

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1 July 1993 and in revised form 2 August 1993

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SIR,

Comments on "Subglacial floods and the origin of low-relief ice-sheet lobes" by E. M. Shoemaker

Shoemaker (1992) proposed that gently sloping lobes of the Laurentide ice sheet (e.g. Mathews, 1974; Beget, 1986) were not steady-state features due to ice movement over weak, deformable sediment, but rather were transient features whose advance was triggered by giant subglacial floods of water, moving in a meters-thick sheet, released from subglacial storage. Although there is much geological evidence for episodic advance of gently sloping ice-sheet lobes (e.g. Clayton and others, 1985; Clark, 1993), Shoemaker's proposed explanation is untenable, because thick water sheets are unconditionally unstable to formation of channels (Walder, 1982). In the remainder of this commentary, I elaborate this criticism and also remark on other problems in Shoemaker's discussion of subglacial hydrology.

Nye (1976, p. 207) briefly considered whether an outburst flood might take the form of a water sheet. He concluded this was unlikely for two reasons. First, unless both the ice surface and the bed have no lateral slope whatsoever, water flowing in a sheet tends to be driven into channels. Secondly, lateral variations in water-sheet thickness tend to be accentuated by concomitant variations in frictional melting of the basal ice. Nye's remarks on the latter issue motivated my analysis (Walder, 1982), demonstrating that sheet flow is unconditionally unstable to formation of channels. I went on to present a heuristic argument that the effect of bed roughness might nevertheless allow sheets up to a few millimeters in thickness to be quasi-stable. Weertman and Birchfield (1983) subsequently argued that channelized flow itself is unstable if all meltwater is subglacially derived, due to the supposed inability of channels to