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## HIGH ALTITUDE *IN SITU* SURVEYS AND RESEARCHES ON THE SNOW COVER: CASE STUDIES IN ITALIAN AND HIMALAYAN MOUNTAIN RANGES

**ABSTRACT:** PECCI M., *High altitude in situ surveys and researches on the snow cover: case studies in Italian and Himalayan mountain ranges.* (IT ISSN 1724-4757, 2005).

Some snow pack profiles, obtained in the high altitude environment of the Alps, Apennines and Himalaya, are presented, also including measured pH values. The *in situ* surveys regarded namely two issues: 1) the stability of the snow cover, for promoting both the knowledge of the natural risk conditions and the safety of the operators during the development of the activity research, and 2) the pollution within the snow on the field, in order to evaluate the quality of the melting water. The results already obtained during the development of the researches in the Gran Sasso d'Italia and Mount Cho Oyu (Tibetan Himalaya) are compared and discussed with the unpublished ones obtained during field surveys in 2003 at Colle del Lys (Monte Rosa Group) and in the Mount Everest area in spring 2004. The perspective of the creation of a database containing high altitude snow pack profiles and typical pH distribution is also proposed, in order to improve the knowledge of avalanche safety conditions and of pollutants distribution pattern from large scale atmospheric circulation.

**KEY WORDS:** High altitude environment, Pollution of the snow, Snow pack stability, Alps, Apennines, Himalaya.

**RIASSUNTO:** PECCI M., *Rilievi in situ e ricerche nivologiche in alta quota: casi di studio nelle catene montuose italiane e himalayane.* (IT ISSN 1724-4757, 2005).

In questo lavoro vengono presentati i profili della neve al suolo, comprensivi dei valori di pH misurati, realizzati in alcuni siti d'alta quota delle montagne alpine, appenniniche ed himalayane. Tali ricerche hanno riguardato principalmente gli aspetti di stabilità del manto nevoso, sia per quanto riguarda il rischio territoriale, sia la sicurezza degli operatori durante lo svolgimento delle attività di ricerca, e l'inquinamento contenuto nella neve

al suolo, ai fini della valutazione della qualità delle acque. Vengono discussi i risultati già ottenuti nello svolgimento di ricerche effettuate nel gruppo del Gran Sasso d'Italia e dell'Himalaya tibetano (Monte Cho Oyu), a fronte dei nuovi dati ottenuti nel corso delle campagne di rilevamento del 2003 nel gruppo del Monte Rosa (Colle del Lys) e del 2004 nel gruppo del Monte Everest. Viene quindi presentata la proposta di creare specifici database dei profili del manto nevoso e degli andamenti caratteristici del pH nella neve al suolo, relativi all'alta quota, al fine di migliorare le conoscenze relative alla stabilità del manto nevoso e della provenienza degli inquinanti, nell'ambito della circolazione atmosferica globale.

**TERMINI CHIAVE:** Ambiente d'alta quota, Inquinamento della neve, Stabilità del manto nevoso, Alpi, Appennini, Himalaya.

### FOREWARD

The summit area of the studied mountain ranges (fig. 1) has been characterised, in the last decades, by an increasing attention due to the «sensitivity» of the high altitude remote areas, to pollution and, more generally, to the global changes. In fact, changes due to the increasing of the air temperatures are, sometimes radically, modifying the landforms, the landscape and the life conditions of the high mountain environment. The processes, also according to the general retreat of the glaciers, lead to the uplift of the snowline, to the different distribution of snow precipitation and to the permafrost degradation, often generating an increase of rock falls, landslide and avalanches. The higher frequentation of these extreme environments in the last decade, both for research and sportive goals, has increased the risk conditions due to gravitative processes, namely regarding ice falls and avalanches. In the paper the results already obtained during the development of the researches in the Gran Sasso d'Italia (Pecci & alii, 2004), Monte Rosa (Villa & alii, 2001; Villa & alii, 2003) and Cho Oyu in the Tibetan Himalaya (Pecci, 2000) are discussed with the unpublished ones obtained during the recent field surveys in 2003 at Colle del Lys (Monte Rosa Group) and in the Everest area in 2004.

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FIG. 1 - Location of the studied mountain areas. In white line box: Central Himalaya (Mt. Cho, Oyu 8,201 m a.s.l. and Mt. Everest, 8,848 m a.s.l.); in thick black box: Western Alps (Colle del Lys, 4,247 m a.s.l. - Mt. Rosa); in thin black box: Central Apennines (Ghiacciaio del Calderone - Gran Sasso d'Italia, 2,912 m a.s.l.).

## GEOGRAPHIC FEATURES OF THE STUDIED SITES IN HIGH MOUNTAIN RANGES

The Monte Rosa was chosen as it is a fundamental research site since the first drilling in 1996 (Smiraglia, 2000). The Colle del Lys site is located on the Italian slope of the Alps, in the basin of the Ghiacciaio del Lys at 4,247 m a.s.l. The area supplies glacio-chemical data characterised by high temporal resolution, and interesting information on the long range transportation of air mass pollution. Following the first drilling, a second one was carried out during summer 2000 and a third, the last up to now, during summer 2003, coupled with other environmental surveys (Bolzacchini & alii, 2002; Pecci & alii, 2003; Villa & alii, 2001; Villa & alii, 2003).

The Corno Grande summit (2,912 m a.s.l.) of the Gran Sasso d'Italia range is located in the middle of the Italian peninsula at a latitude of about 42° 30' N and at a distance of about 35 km from the Mar Adriatico and about 135 km from the Mar Tirreno, just in the centre of the Mediterranean area. The main ridge has a W-E direction and can be divided into two sub-chains – the northern and the southern – linked westward by secondary ridges perpen-

dicular to the principal ones. The Ghiacciaio del Calderone fills up the upper cirque of the north-eastern slope of the Corno Grande, between about 2,650 and 2,850 m a.s.l., at present sub-divided into two ice bodies, since the 1999-2000 hydrological year. The glaciological and environmental researches have been performed along a decade of surveys (1994-2004); moreover significant results on the chemistry of snow and ice were obtained during the drilling and survey data campaign of May and June 1999 (Pecci & alii, 2004).

The Cho Oyu (fig. 2) is the sixth highest peak in the world (8,201 m a.s.l.) and is located between the northern (Tibetan) slope and the southern Khumbu Himal region. The studied area is included in the Gyabrag Glacier valley, approximately between 28°05' and 29°00' latitude North and 86°35' and 86°40' longitude East. From the geomorphological point of view, the whole area is characterised and deeply modelled by active glacial and periglacial processes, including avalanches and ice falls. The high-altitude environment and climate are also conditioned by the presence and activity of the inter-tropical convergence zone, with the related rainfall and snowfall abundance, due to the monsoon. The interest of the area is due to the environmental control of Asian air masses pollution. The tibetan slope is, in fact, relatively less known than the southern, where Ev-K<sup>2</sup>-CNR Pyramid is located (Balerna & alii, 2003; Marinoni & alii, 2001a; Marinoni & alii, 2001b; Pecci, 2000).

The study area of the Mount Everest, within the eastern Rongbuk glacier, is located in correspondence of the Advanced Base Camp, just below the North Col, with a geographic location of latitude N 28° 02' and longitude E 86° 57'. All the scientific activities have been performed during the scientific and mountaineering expedition «K2 2004 - 50 anni dopo», developed on the Everest from April to May 2004, in an area relatively poor of environmental data (Jenkins & alii, 1987).

## FIELD SURVEYS

Field activities always included the digging of a snow pit, reaching the bedrock in all the cases, except for the Colle del Lys, where the snow pack is of the order of decades of metres and the surveys involved only the superficial snow cover (340 cm). The operations, according to the methods suggested by the ICSI - International Commission on Snow and Ice, IASH - International Association of Scientific Hydrology and IGS - International Glaciological Society, concerned, from the stability point of view, the whole layering of the snow pack, the mechanical features (profile of the snow pack) and, successively, the sampling of snow for chemical analyses. Many samples were collected for laboratory analyses; on the remaining, except for the samples of the Ghiacciaio del Calderone, the pH was determined *in situ* at the same altitude of the sampling point, in order to evaluate the «true» pH values. In fact the acidity of the snow is different from the acidity of its melting water in which the pH is determined

FIG. 2 - Full-depth slab avalanche (circle) on the northern slope of Mt. Cho Oyu 8,201 m a.s.l., Tibetan Himalaya, just below the snowy ridge, crossed the mountaineering route to the top (arrow).



(Legrand & *alii*, 1982); moreover the equilibrium with CO<sub>2</sub> is different from the sampling point (high altitude) to the sea level of the laboratory (Marinoni & *alii*, 2001a).

## FIELD RESULTS

In order to display and to discuss the survey data, all the snow pack profiles (from the snow stability point of view) are drawn and presented respectively for: Monte Rosa - Colle del Lys (fig. 3), Gran Sasso d'Italia - Ghiacciaio del Calderone (fig. 4), Cho Oyu - Gyabrag Glacier (fig. 5), Everest - Rongbuk Glacier (fig. 6) and Everest - North Col (fig. 7); only in the case of Colle del Lys (Alps) and North Col (Everest) mechanical features are expressed by the result of the «hand test», while in the other three cases by the results of the penetration test of a «Swiss rammsonde». Moreover a synthetic «global» pH distribution diagram of fig. 8 have been drawn for each study area. At the moment, snow cover profile surveys and pH measures represent the only operations capable to characterise, directly *in situ* and at high altitude, the snow cover with the aim of the study (safety and knowledge of risks and environmental condition).

The profile of each site shows on the left the mechanical trend with the depth, in term of snow strength, coupled with the temperature profile; the right side includes the layering and classification of the snow, in terms of snow humidity, grain shape and size, snow hardness, obtained from the «hand test», and snow density.

The diagram of the distribution of the pH has been carried out using the values measured on the samples collected during the same operations necessary for the snow cover profile, digging a snow pit. The values have been measured directly *in situ* with field electronic pHmeters, characterised by precision of  $\pm 0.015$  pH and resolution of 0.01 pH, except for the values of the Ghiacciaio del Calderone, obtained from laboratory tests, also due to the relative lower altitude in comparison to the other cases. The pH values are drawn versus the thickness of the snow cover, given. In this way the behaviour of the superficial snow cover is given in terms of chemical-environmental response.

## DISCUSSION

Considering and comparing figs. 3, 4, 5, 6 and 7, the following issues can be discussed:

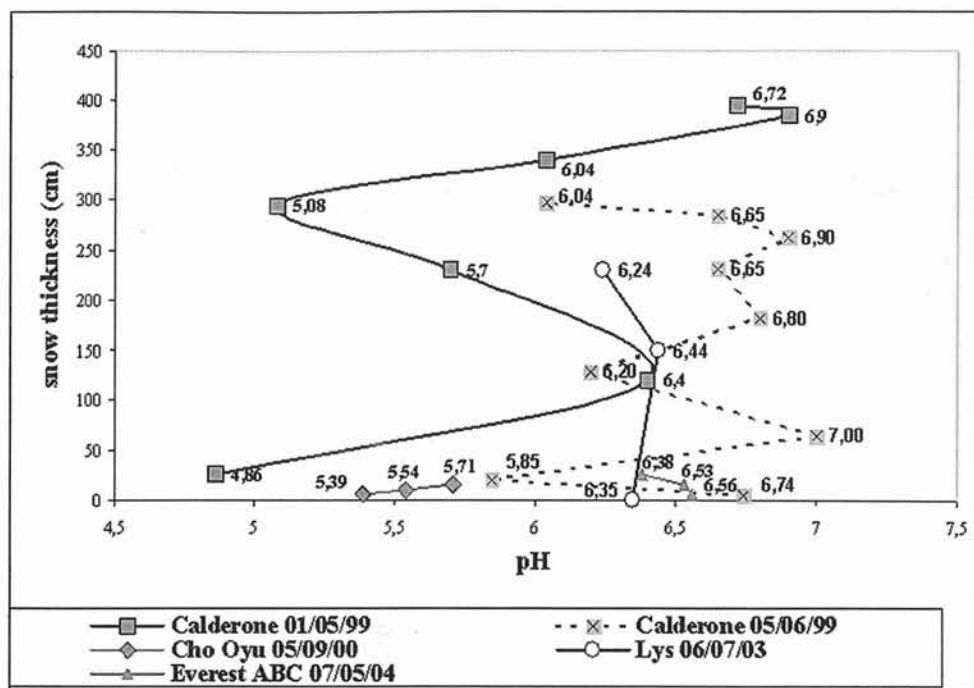
- all the profiles show air temperatures equal or higher than 0°C, subsequently the snow cover is in isothermal condition in Himalayan profiles, or close to this condition in Italian profiles, due, in this case, namely to the higher snow cover, even if the snow pack is in isothermal condition, the snow layers still show crystals produced by both high and low temperature gradient;
- the profiles of the Italian sites include several ice layers and superficial and buried melt-freeze crusts;
- different geographical locations in high mountain seem to be highlighted by different snow pack profile types;







FIG. 8 - *In situ* pH values measured within the snow pits dug in high mountain remote sites of Alps, Apennines and Himalaya during the years 1999-2004; x axis: pH values; y axis: height of the snow in cm.



ferent geographical location; the same variation also represents for the ghiacciaio del Calderone a monthly evolution of the chemical conditions of the snow towards the neutrality, confirming, at the same time, the promotion of a significant «ionic impulse» on the melting water from the snow cover (Pecci & alii, 2004); this is well evidenced by the drainage threshold represented by the cohesive and high-resistive snow layer, surveyed around 150 cm;

- as presented and discussed in the literature for the Himalayan area (Jenkins & alii, 1987; Marinoni & alii, 2001a; Marinoni & alii, 2001b; Balerna & alii, 2003), the pH values, measured in the snow cover of Cho Oyu in 2000 and of Everest in 2004, seem to match the previous ones. On the northern slope of Himalaya and in the Everest area, pre-Monsoon pH values (ranging between 5.5 and 7.0) are probably due to the resulting neutralisation process of acidity from the atmosphere by calcium carbonate dust; at the same time the values are an indicator of the presence of calcium carbonate from dust transported either from the arid regions of Central Asia or from more local glacial deposits or local carbonatic rock sources (Jenkins & alii, 1987). On the other hand, during the post-Monsoon season, the values of the Na/Cl ratio reveal a strong marine contribution on the Himalayan southern slope; the non-alkalinity of the pH (Marinoni & alii, 2001a) can be attributed to the presence of the total organic acid (natural and released by the sampler). In this way the Himalaya freshsnow data seem to show an alternation between a monsoon season, with values not substantially influenced by anthropogenic inputs, and an extra-monsoon (post-Monsoon,

winter and pre-Monsoon) season characterised by the influence of dust from Central Asia (Balerna & alii, 2003), also according to Wake & alii (1990, 1993).

- On the surveyed snow layers of the Gyabrag Glacier at Cho-Oyu Advanced Base Camp (Pecci, 2000) and of the Rongbuk Glacier at Everest Advanced Base Camp in 2004, taking into account the low possibilities of ionic release and reactions, due to the short time passing between the precipitation and the measure, it is possible to extrapolate a «typical trend» in the pH distribution pattern in the snow pack, to be deeply investigated in further analyses. In fact on the northern slope of Himalaya (see the diagram of fig. 8) the snow deposition from basal layers (older precipitations) to the superficial (recent precipitation) shows an increase of acidity trend during the pre-Monsoon season (Mt. Everest) and, vice versa, a decrease during the post-Monsoon season (Mt. Cho Oyu);
- the pH values measured in the Colle del Lys (Monte Rosa) snow pit draw a stable trend, maybe showing a «ionic impulse» already realized, with a weak acid pattern, probably related to a local source (contribution from industrial activity of Po Plain).

## RESEARCH PERSPECTIVES

The *in situ* surveys on the snow pit and trenches in the high mountain areas represent a unique occasion to study the remote environment and to collect data, highly useful for understanding the atmospheric circulation mechanism and related environmental global change.

A good practice to be proposed during the field campaign of snow sampling for chemical purposes is the realisation of snow pack profiles, according to the international standards, both for the knowledge of the avalanche safety conditions (always important and vital for a surveyor in high altitude) and for the perspective of the realisation of an «international inventory of high altitude snow pack profiles».

A prior issue could be represented by the identification of «high altitude snow pack profile types» (typical and easy detectable snow pack features), corresponding to «snow pack classes» and related stability conditions.

At the same time the use of portable little instruments, such as a pHmeter, is strongly to be encouraged during the scientific expeditions, in order to collect *in situ* data, for example, concerning the study of radioactivity or organic and inorganic toxic/hazardous compounds. The distribution of *in situ* surveyed pH within the snow pack can also preliminarily reveal the large scale atmospheric circulation pattern, enriching, at the same time the poverty of the existing data base on high altitude snow.

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