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Young tectonics and karst formation in the Albanian Alps

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Ст.Шанов — Молодая тектоника и карстообразование в Албанских Альпах. Анализирована структурно-тектоническая информация исследования карстового массива в Албанских Альпах, находящегося к северозападу от посёлка Боге. Массив сложен юрскими известняками, деформированными главным образом в конце эоцена. Водоносная система, развитая в нём, трещинно-карстового типа. Реконструированы направления главных осей тектонических напряжений s_1, s_2 и s_3, действовавших на массив с ранней юры до наших дней, полученные в результате анализа рассеивания пар трещин скалывания, тектонических штрих и механизма в очаге одного близкорасположенного к району исследования землетрясения. Деформации Пиринейской фазы, благоприятствовавшие открытию систем трещин направления СВ — ЮЗ, определяют главные черты развития карста в районе. В качестве второстепенных проявляются наложенные во время неотектонического этапа открытые системы трещин направления СЗ — ЮВ. Разрывные нарушения играют контролирующую роль для дренирования атмосферных вод и механического выноса раздробленного материала и вокруг них открываются глубокие до сотен метров пропасти, главным образом в сильно брекчированных зонах. Во время четвертичного периода скорость эрозии доминирует над процессом воздыгания массива и большинство поверхностных карстовых форм заполняется делувиальным материалом.

Abstract: Structural and tectonic information concerning the karstic massif in Albanian Alps situated NE from the Bogë settlement has been analyzed. The massif is built up of Jurassic limestones, deformed at the end of the Eocene. The type of water-bearing system is jointed-karstic. The direction of the principal tectonic stress axes σ_1, σ_2 and σ_3, having acted on the massif from Early Jurassic time up to present days have been determined by analyzing the dispersion of the pairs conjugate shear joints as well as tectonic striations and one fault-plane solution from an earthquake near the region of investigations. The Pyrenees tectonic phase deformations have favoured opening of the joint systems striking a NE-SW. Faults play a control role about atmospheric waters drainage as well as about mechanical transportation of debris and deep up to several hundred meter precipices open around them mainly in brecciated zones. The erosion velocity is dominating on the process of massif uplift during the Quaternary, and many of superficial karstic forms are filled up by deluvial material.

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Key words: karst process, young tectonics, Albanian Alps, tectonic stress fields

Introduction

The present investigation is a result of the analysis of the structural-tectonic information collected during a speleological expedition in the summer of 1994 in one region of difficult access in North Albania. The expedition was organized by Bulgarian Federation of Speleology. The main goal of the study is to show a strong influence of young tectonic processes on the formation of specific conditions of karst formation. The study has been performed on a scale 1:100 000, and the only available geological information was geological and hydrogeological maps of the Republic of Albania in scale 1:200 000. The geological map is worked out on a chronostratigraphic principle. Some corrections and specifications, concerning mainly the fault structures on the limited area of the investigations, were necessary during the field observations. The faults are conventionally named after settlements and geographical area names through which they pass.

Short geological and tectonic characteristics

The structural complex characterizing the exceptionally complex geological structure of the not so large Albanian territory is named by Albanian geologists as Albanides (Бичоку и др., 1978). The both basic megastructural units of the Albanides — North Albanides and South Albanides (related with the Helenides) are separated by the Shkodra — Pejio transversal zone representing an old paleogeographic province.

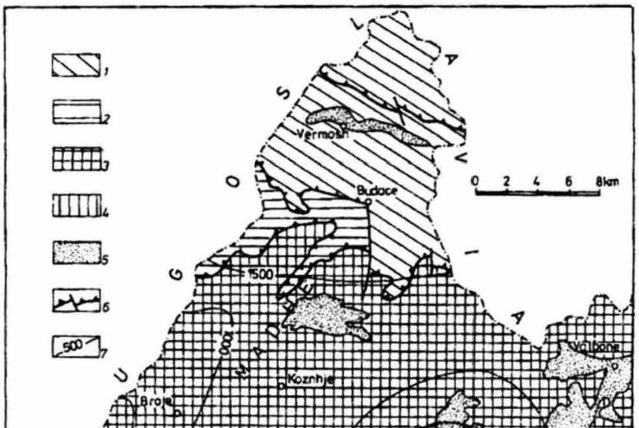

Fig. 1 Regional tectonic scheme of North Albania (after Biçoku, Aliaj, 1973 and Geological Map of Albania in scale 1: 200 000)
1 — zone Gashi — uplifted after Early Palaeogene; *2* — zone of the High Karst — uplifted after the end of Early Palaeogene; *3* — Albanian Alps zone — uplifted during the first half of the Palaeogene; *4* — Zone Krast-Cukali — uplifted during the second half of the Palaeogene; *5* — Neotectonic superimposed depressions; *6* — thrust fronts lines; *7* — isolines of the maximum upliftings during neotectonic stage (after Buçoku, Aliaj, 1973)

Albanian Alps zone (Fig. 1) is considered as a continuation of the High Karst of the Dinarides. The lower part of the geological section is represented by terrigenous sediments of Permian up to Lower Triassic age. They are covered by carbonate sediments. Their accumulation have begun during Middle Triassic. There are boxites formed in the same time. A continuos sedimentation of neritic limestones follows up to Maastrichtian time. Jurassic pelagic limestones with silicitics layers occur in the Eastern part of the Albanian Alps. This part (called also subzone Valbone) is considered as an independent transitional element of uplifted neritic Albanian Alps (Vermosh flysh) which covers a period from Maastrichtian up to Eocene.

At the end of Eocene time, the Albanian Alps zone have been deformed and thrusted to the South over the zone Krasta-Cukali. From structural point of view the Albanian Alps are a monocline dipping north-west. The big Valbone anticline is located to the north-east in its back, and the big syncline Malesia-Madhe is situated to the north-west.

The region in which the expeditions of the Bulgarian Speleological Federation worked during the four consecutial years (beginning from 1990) is a part of the North Albanides. According to the age of the more intense folding, the region belongs to the areas deformed at the end of Eocene time. More detailed structural and tectonic investigations in 1994 have been carried out on the territory belonging to the SE limb of the syncline Malesia-Madhe, and especially near its axial part. The geology of this territory is represented mainly by carbonate complexes of Lower Jurassic up to Lower Cretaceous (Baremian-Aptian) age.

Different-order faults determine the formation of the tectonic block structure of the limestone massif. Those are long-term acting faults with quite explicitly manifested neotectonic activity affecting the relief and the karstic processes in the region. The recent activity of some of the faults is manifested by concentration of earthquake foci along them (Fig. 2). The fault Rapsh-Boçani is quite active during the recent tectonic stage (No. 4 on the Fig. 2 and Fig.3). It is clear, that energy accumulation occurs along this fault, periodically being released by earthquakes in the zones of its crossings with other regional faults (e. g. with fault No. 1 — Pjetroshan-Veliçikut-Kozhnje, or with fault No. 3 — Bogë-Budace). Following the most general considerations reflected on the geological map of the region, it could be assumed that in the contemporary tectonic stage there is an uplift of Northern fault wall and subsidence of the Southern one. This is a continuation of the tendency of

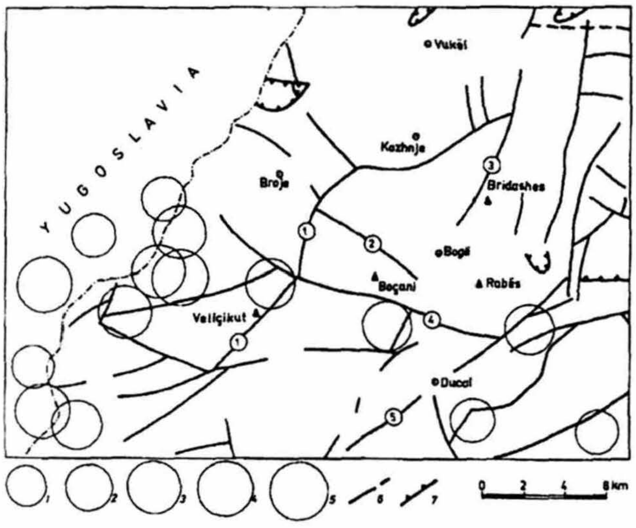

Fig. 2. Main fault structures in the investigated region and epicentres of recorded earthquakes for the period 1961 — 1988. Earthquake magnitudes: *1* — M < 2.0; *2* — M = 2.1 — 3.0; *3* — M = 3.1 — 4.0; *4* — M = 4.1 — 5.0; *5* — M = 5.1 — 6.0; Faults: *6* — normal faults; *7* — thrusts. More important regional faults: 1 — Pjetroshan-Veliçikut-Kozhnje; 2 — Dobromiri; 3 — Bogë — Budaci; 4 — Rapsh — Boçani; 5 — Ducal

neotectonic development of the region which predestines the contemporary relief. The neotectonic stage of the Albanian Alps development is marked by intense uplift whose total amplitude in some parts is more than 200 m.

Geological and hydrogeological conditions of karst formation

During the whole Mesozoic after Early Triassic time, the sedimentation conditions existing almost continuously up to the beginning of Maastrichtian have resulted in the formation of a thick limestone complex. The following tectonic development during the Alpine tectonogenetic phases and especially the expressed overthrusting of a part of the limestones complex to the South, have increased the complex thickness. The neotectonic uplift and denudation have led to the contemporary complex relief, with altitudes exceeding 2000 m. It could be supposed that the thickness of the carbonate rocks, now subjected to karstification, is more than 1500 m. This supposition is argumented by the concentration of big karstic springs at altitude of some tens meters over the sea level and running out of impressive quantities of fresh water in Shkodra Lake and Adriatic Sea. The tectonic factor should be also taken into account. It comprises fault sets that facilitate the drainage of superficial water outflow occurs by channels which do not allow always the formation of karstic cavities.

According to the Hydrogeological map of Albania, the fault marked by line Pjetroshan-Veliçikut-Kozhnje plays a role of main distributor of underground water outflow in the region localized West — Northwest from the Bogë settlement. There are concentrations of karstic springs at the Northwestern fault wall. Probably, an enormous underground water flow is drained by the same fault, coming out on the surface near the village of Pjetroshan by a well-developed karst spring system. One of the springs has a debit up to 4 m^3/sec.

In the same time, the Southeastern fault wall constituted by faulted blocks supplies all conditions needed for draining of huge superficial water quantities (most of all atmospheric) and their running towards the drainage zone. According to the Hydrogeological map of Albania in scale 1:200 000, the investigated region is localized in joints-karstic type of water-bearing system having an effective infiltration ratio about 0.6 — 0,7. In these conditions the atmospheric waters penetrate fast in the water-bearing system and flow towards their natural drainage level. In this way, no conditions stimulating horizontal karst system developing could practically exist. The conditions for vertical channels-precipices are much better. Several expeditions of the Bulgarian Speleological Federation just prove the mass development of precipices reaching depths from tens up to 500 m.

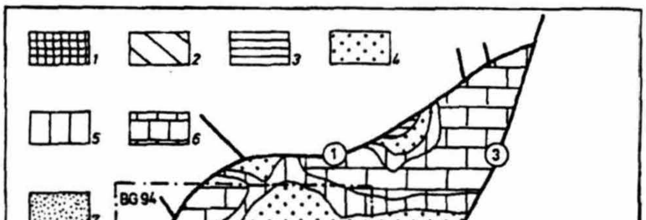

Fig. 3 Geological scheme of the investigated territory NW of the Bogë settlement (North Albania), carried out on the base of Geological Map of Albania in scale 1:200 000. The rhomb sighed BG94 is the region of investigations of the Bulgarian expedition during 1994
1 — Upper Triassic limestones and dolomites; *2* — Lower Jurassic limestones and dolomites; *3* — Middle — Upper Jurassic undivided limestones and dolomites; *4* — Upper Jurassic limestones and clay sands; *5* — Tithonian limestones; *6* — Lower Cretaceous limestones, carbonate limestones, clay sands; *7* — Quaternary sediments in superimposed depressions; *8* — faults: 1 — Pjetroshan-Veliçikut-Kozhnje; 2 — Dobromiri; 3 — Bogë — Budace; 4 — Rapsh — Boçani; 5 — Ducal

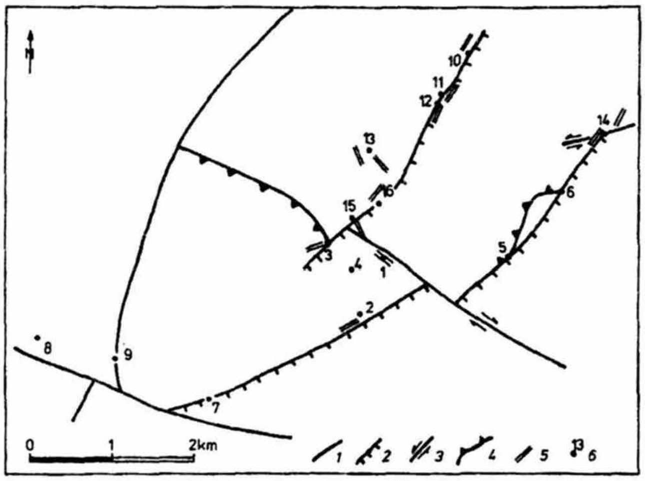

Fig. 4. Scheme of fault ruptures in the region investigated in 1994, points of structural measurements and base karst forms orientations on plan. *1* — fault with undetermined type of displacements; *2* — normal fault; *3* — strike-slip fault; *4* — thrust; *5* — points of structural measurements. Faults: 1 — Pjetroshan-Veliçikut-Kozhnje; 2 — Dobromiri; 3 — Rapsh — Boçani

The speleological as well as the structural-geological investigations in the karstic massif to the North-West of Bogë settlement (Fig. 3) clarified additionally some problems and showed a strong significance of the fault tectonics as a factor for precipices and caverns formation in the most fragmented zones by young displacements.

The measurements of the space elements of joint systems and 'tectonic striations on different surfaces of outcrops have been carried out only at 16 points (Fig. 4) because of relief complexity, its difficult passibility and the limited time for field observations. The information turned to be sufficient for reconstruction of the main tectonic deformation phases after Early Jurassic times up to present days which determine the main relief characteristics as well as the superficial and underground karst features.

Investigation methods

Three basic methods are used for the reconstruction of the tectonic stress field principal axes reconstruction in the region studied. Detailed analysis of the final results from each observation point allowed to distinguish the different deformation phases expressed in the structure of the joint systems of the karstic massif and controlling the basic characteristics of the karstic processes and to determine their age.

1. Fault-plane solutions from earthquakes

This is the most precise method for determination of the principal axes of the youngest tectonic stress field. It is easy to determine P (compression) and T (tension) axes of the recent tectonic stress field in the Earth's crust by this method. Only one mechanism was available for the purposes of the present investigation, i. e. an earthquake with magnitude M=5.1 (03 November 1968) and epicentre localized to the South-West of the studied region ($\lambda^{\circ} = 42.10^{\circ}$, $\varphi^{\circ} = 19.35^{\circ}$). These data are taken from the paper of Muço (1994).

2. Tectonic stress field reconstruction from striations on slickensides

These investigations take the most significant place in the collected information because in 11 points of structural investigations indicators of displacements on the joint and fault surfaces have been found out — exceptionally well-preserved tectonic striations covering in some cases surfaces of several square meters. This type of reconstructions correspond to a mesoscopic level of rupture structures and the kinematic characteristics of the rock block displacements are used. The methodology (Caputo, 1990) requires strict determination of the elements of the displacements on the friction surface.The computer program for data processing and analysis was kindly given by R. Caputo (University of Florence, Italy) to the Geological Institute of the Bulgarian Academy of Sciences.

3. Reconstruction of the tectonic stress fields from tectonic jointing

This study has been carried out following method of Nikolaev (Николаев П. Н., 1977), which has been commented and adopted for computer based use (Шанов, Стоянов, 1986) and successfully applied in a number of karst regions in Bulgaria, France and Cuba. The method is built up on a basic principle, i. e. the pair of systems of conjugate shear joints appearing simultaneously at a certain tectonic stress field shows some dispersion towards the minimum main principle stress axis σ_3. In statistical estimations of mass measurements of joint elements of a certain outcrop this is expressed by well-observed in the distribution of maxima, thus allowing for an undoubted identification of the principal stress axes. One of the handicaps of this method is that it is difficult to differentiate in a given rock massif more than 3 or 4 tectonic influences. In the region studied mass measurements of joints have been carried out in 4 points.

Investigation results

Structural investigations applied for rock formations of different age (but within the Jurassic Period) allow to differentiate by time reconstructed tectonic stresses. Figure 5 shows diagrams of the reconstructed tectonic stress fields in the measurement stations, which are related to a certain tectonic phase of a global scale. This turned out to be the most logical scheme when interpreting and comparing reconstructions in Jurassic limestones of different age.

The youngest (Quaternary and recent) tectonic stress field is defined by the mechanism solution of the only available earthquake focus near the territory studied. Its features (NW-SE compression and NE-SW tension) could be found out in reconstructions in points 13 and 14. This field is characterized by exchanged stress axes compared with those of Neotectonic (post-Miocene) stage, where minimum tectonic stress σ_3 of NW-SE to E-W trend has determined formation of neotectonic superimposed depressions generally elongeted towards NE-SW (see Fig.1). The compression was subvertical (uplifting) and it is well-expressed by the striation on the tectonic slickenside of point 13.

The most considerable deformations can be referred to the Pyrenean phase (end Eocene). Then, under the conditions of strong pressure of almost North-South direction (see points 5, 10, 12, 13, 15, 4 and 9) a Southward trusting of the Albanian Alps zone onto the Krasta-Cukali zone occurred. After the Middle Jurassic times, young Cimmerian, and after that, Laramian tectonic deformations affected the massif of limestones and dolomites. Clear reconstructions in points 13, 14, 16, 4, 2, 7, and 8, are an evidence of this. The Laramian phase is characterized by a strong sub-horizontal (except p.7) North-West — South-East trending minimum principle stress σ_3. The young Cimmerian phase has features which are very similar to the contemporary tectonic stress field. Taking into consideration that during the Pyrenean phase the whole massif has been displaced to the South, presumably with some rotation, both most ancient phases possess an element of relativity in reconstructed directions of tectonic principle stress axes.

Relations between karst formation and concrete tectonic conditions

The first step for determination of tectonic factors influencing karst formation is the analysis of the principal stresses, that have led to the now observed structural ruptures in the investigated massif, described above. The karst formation has started most likely after Eocene-Oligocene times. By this time, the displacements of

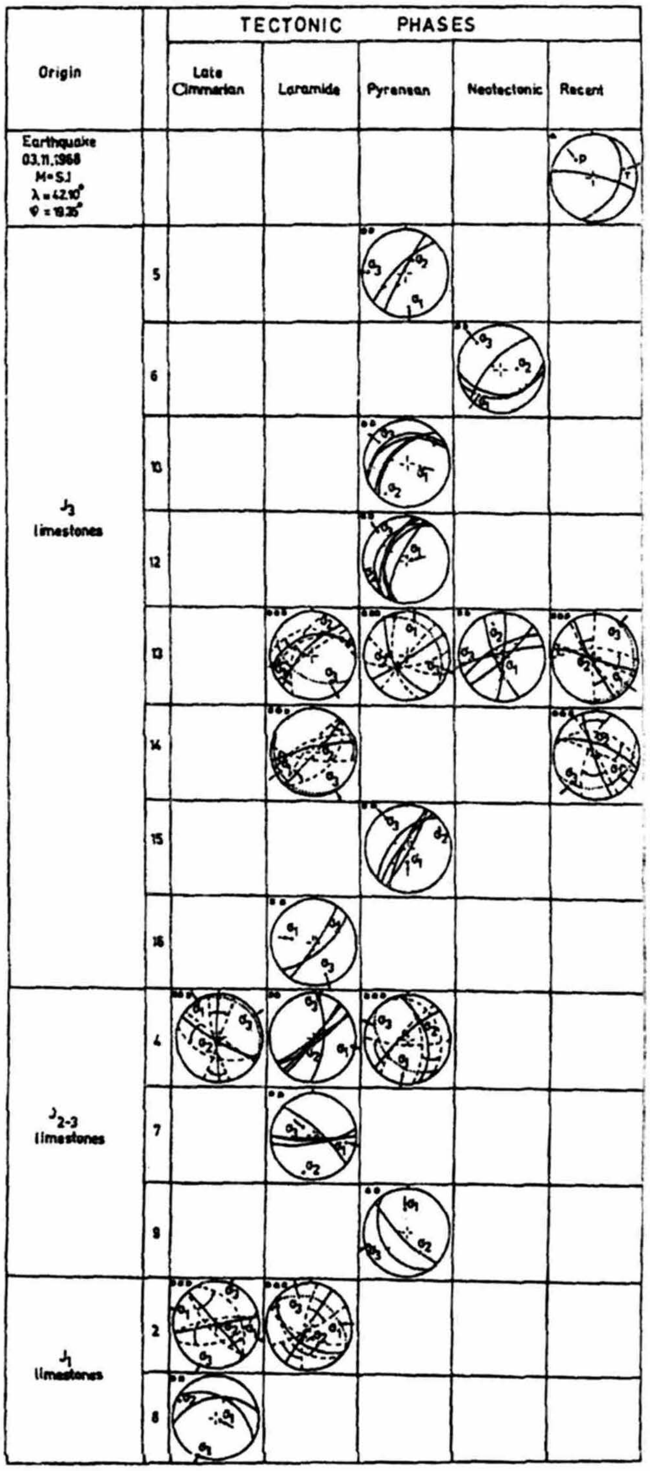

Fig. 5. Reconstructions of tectonic strength field principle axes during different tectonic phases in the investigated region of the Albanian Alps. All stereograms are given in upper hemisphere projection.
* — after earthquake fault-plane solution; ** — after tectonic striations; *** — after shear joints systems.
σ_1 — maximum principal stress axis; σ_2 — intermediate principal stress axis; σ_3 — minimum principal stress axis; P — axis of maximum compression in the earthquake focus; T — axis of the tension in the earthquake focus.

the limestone massif to the South had calmed down, and its intense uplifting started.

The detailed observations carried out in the points of reconstruction of the tectonic stress field have resulted in some changes of the ideas concerning the fault network of the area. On the one hand, the normal faults are complicated by strike-slip displacements, being of the youngest age, and they correspond to the youngest (contemporary) tectonic stress field (Fig. 4).

The well expressed thrust structures (points 3, 5 and 6) appear as relicts of the Laramian tectonic phase deformations. In the zones of shear and mylonitization there are conditions for formation (mainly because of mechanical export of particles by the water) of small horizontal cavities, which seldom reach more than several tens of meters (for example in points 5 and 6). Their orientation is along the slip surface.

During the Pyrenean phase, strong normal faulting on the ruptures of NE-SW direction and opening of joints systems into the same direction occurred. Most of investigated precipice caves developed on these joints. It is worth to underline that they all belong to zones with well-manifested faults.

Precipices around points 10, 11, 12, and 16 are located near a morphologically well-manifested fault still not shown on official maps. All these precipices are located in brecciated zones with clear tectonic slickensides and striations on them.

During the Pyrenean phase tensile stresses varied locally from NW-SE to NE-SW direction (point 9), and the compression was oriented N-S or subvertically (uplifting of the massif). Subvertical compression lasted also during neotectonic stage when minimum stress σ_3 orientation favoured both the existence of earlier formed open cracks of NW-SE direction (points 13 and 15 — open karren and precipices; in case of point 1 — widely open karren up to several meters). Some evidence of strike-slip displacements can be seen in point 14. The controlling role of the faults for the process of massif karstification is best observed in areas of Upper Jurassic clay sandstone where caves could not exist, without the tectonic factor influence. Strong faulting and crack opening favour mechanical export of debris and typical karstic precipices formation.

Contemporary displacements are not so active but in case of NW-SE orientation of σ_1 they have led to some clear strike-slip displacements along the Dobromiri fault. Besides that, obviously the erosion rate becomes dominating over the uplifting process, and this results in sealing of many of the superficial karstic forms with deluvial materials. Thus, in spite of the high permeability for atmospheric waters into the karstic massif, precipicial type open karstic systems are conserved only within faults zones, where, nevertheless, the young tectonic displacements do not allow their fast colmatation with rock weathering materials.

The sharp-shaped relief is a result not only of tectonic displacements, but also of chemical destruction of limestones and dolomites by rains and snow. The long lasting snow cover at this altitude (between 1000 and 1500 m) is a factor for chemical erosion durability through the year. Special analyses in the region for atmospheric waters aggression potential as well as of the snow covering melting waters have not been carried out. Such an investigation would deepen the analysis of reasons for the strong superficial and underground karstic processes in Albanian Alps.

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