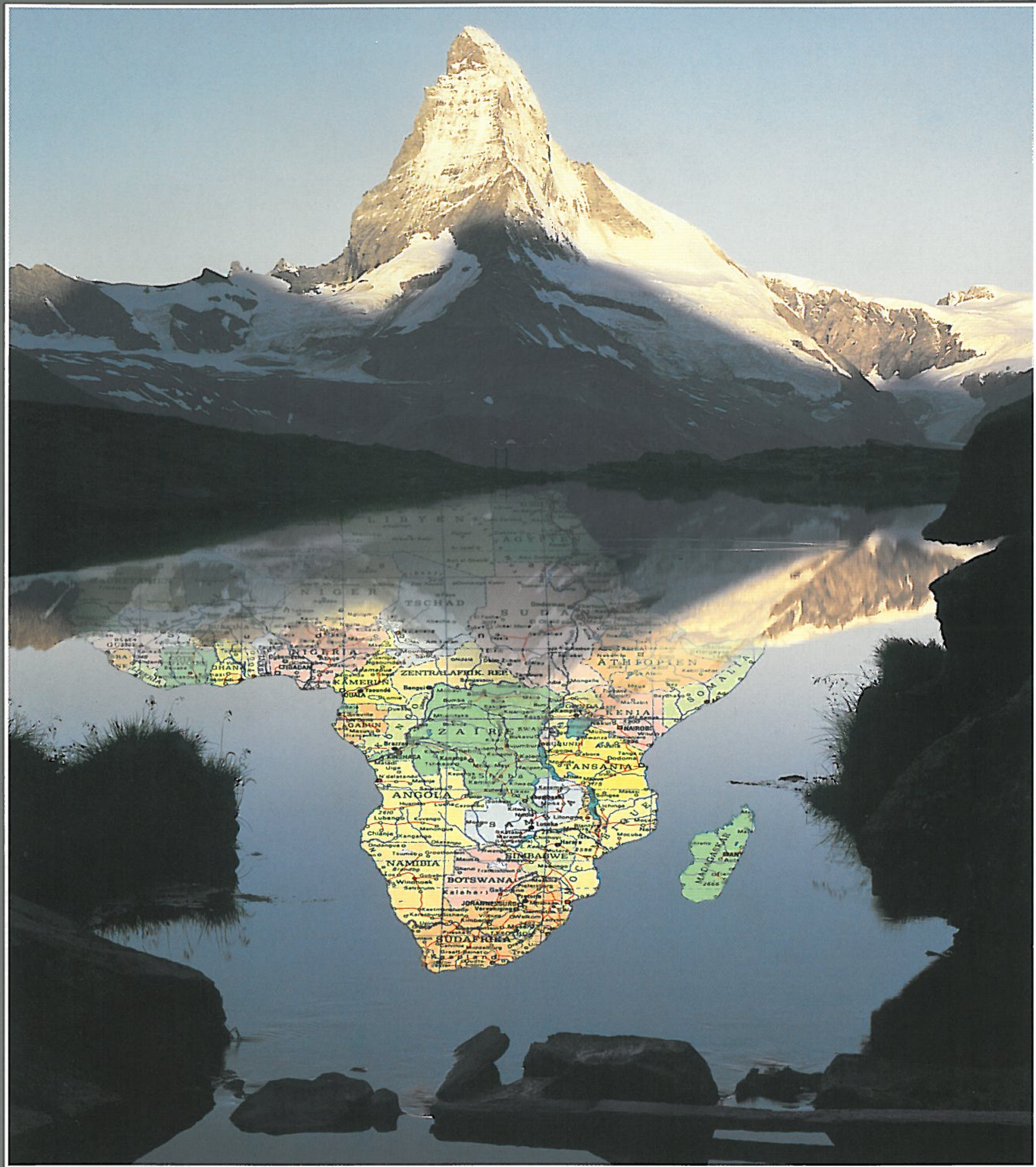


Echo from the Swiss Underground

National Research Programme
Deep Geological Structure

NFP 20
NRP 20

Echo from the Underground

Results from the Research Program 20 (NFP/NRP 20) of the Swiss National Science Foundation on the Deep Geological Structure of Switzerland.

Franz Auf der Maur
Peter Heitzmann
Peter Lehner
Beat Schenk

Sixty Kilometers Below Sea Level

Owing to many years of intense research, the surface geology of Switzerland is very well known. The underground continuation of surface structures, however, and the deep structure of the Swiss Alps, are still a mystery. Until recently we knew less about the foundations of the awesome four thousand meter peaks than about the surface of the moon. The National Research Program (NFP/NRP 20) "Deep Geological Structure of Switzerland" is redressing this imbalance: on behalf of the Swiss government and of the Swiss National Science Foundation, geologists and geophysicists have been studying the deep underground of Switzerland.

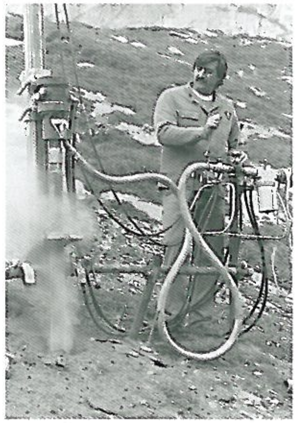
Three large seismic reflection profiling campaigns cut through the east, the west and the south of Switzerland with acoustic waves penetrating the underground to depths of up to 50 kilometers. The evaluation of this extensive amount of data yielded surprising facts: the echoes from the underground revealed forgotten valleys and lakes, hitherto unknown rock nappes, as well as a more solid idea of how Africa and Europe interlock..

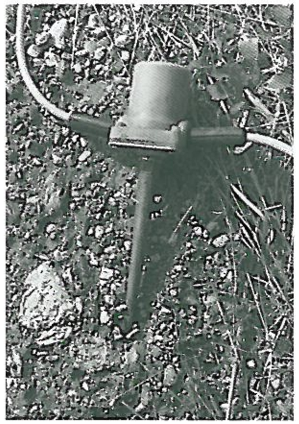
The National Research Program "Deep Geological Structure of Switzerland" on which the Swiss National Science Foundation spent 14.5 million Swiss Francs, is also part of an international research program initiated by the European Science Foundation to study the European continent from the North Cape to the coast of Tunisia. The results from this study will be of great practical value for the accessing of raw materials and geothermal energy, for earthquake prediction, or for the planning and construction of underground transport corridors.

Mysterious Rawil

The landscape at the Rawil Pass between Berne and the Valais looks the same as in the beginning of creation: "In the beginning ... the earth was waste and void." But those who look more closely will see several groups of people in the scree slope laying kilometers of cable, and a military convoy carrying supplies. Then a helicopter comes circling around the peaks, landing briefly at the summit of the pass at 2400 m.a.s.l.: On take-off it scares up a flock of Alpine choughs. The brief silence which ensues is soon interrupted by the screeching noise from a drilling rig which echoes from the rock faces. No doubt, there's something afoot here ...

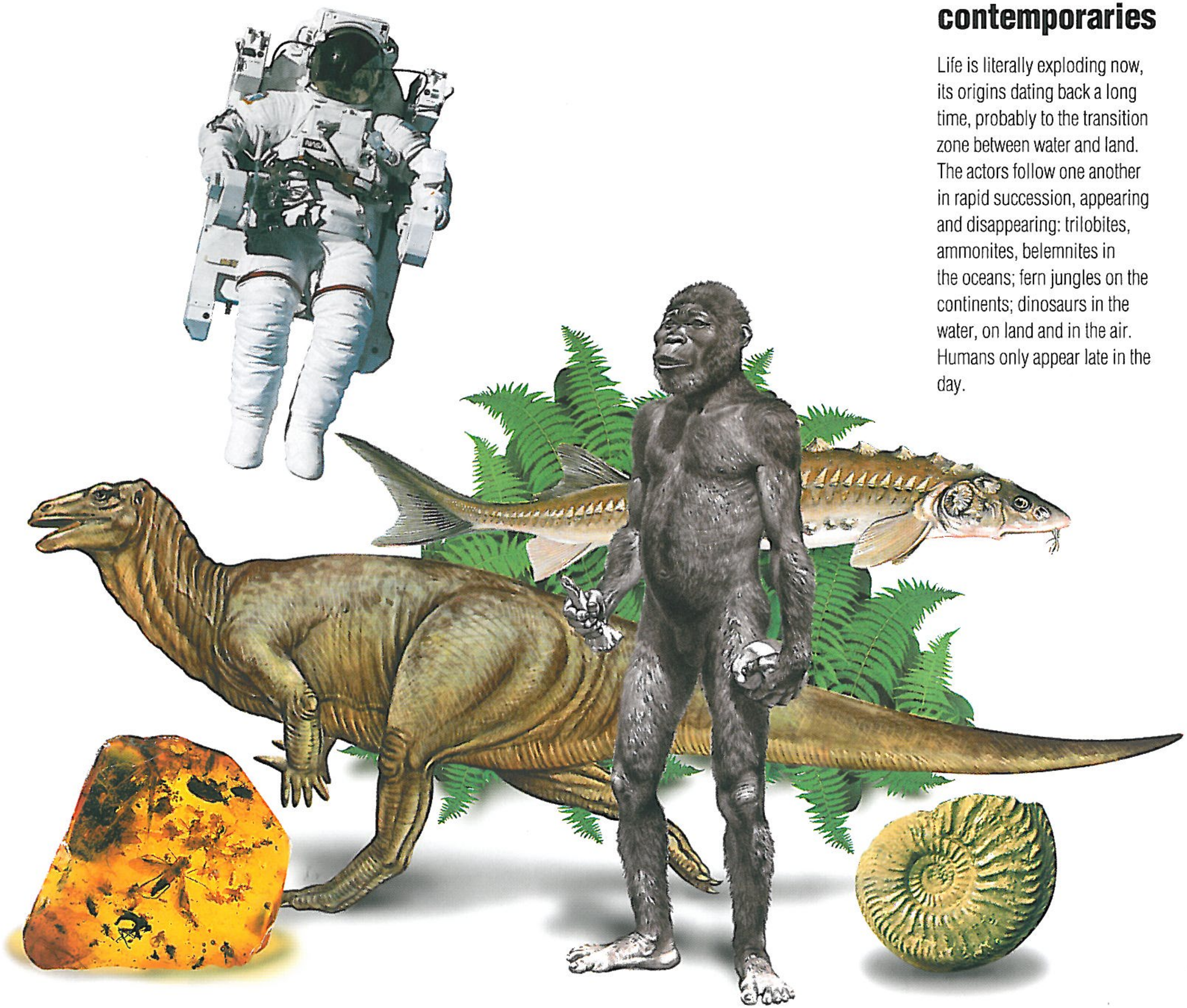
Boom! Dust spews up and is carried off by the wind before the echo from the explosion has died. Acoustic waves penetrate the ground; the boundaries between the rock strata reflect them back to the surface. Captured by geophones, they inform geologists about the internal structure of our mountains. Two hundred years after Horace-Bénédict de Saussure initiated scientific Alpine research (his portrait is on every Swiss 20 franc note), a new chapter of the natural sciences is being opened here: what does Switzerland look like deep down? To answer this question, we must begin by going back 18 billion years ...





The Big Bang

Eighteen billion years ago (or perhaps twelve or even twenty, the astrophysicists are not quite agreed on this) – an unimaginably long time ago, all matter of our universe was concentrated in one single point. A bang ... the Big Bang! Dust went whirling through space, forming galaxies. Much later – some five billion years ago, the astrophysicist are quite agreed on this – our solar system was being formed in one of these milky ways, with our sun as a fixed star in its center and the nine planets orbiting around it. But we are now going to focus on the Earth, which is planet number three. The earliest traces were obliterated by more recent upheavals. A clearer picture only begins to emerge from the time around 500 million years ago ...



Non-contemporaries

Life is literally exploding now, its origins dating back a long time, probably to the transition zone between water and land. The actors follow one another in rapid succession, appearing and disappearing: trilobites, ammonites, belemnites in the oceans; fern jungles on the continents; dinosaurs in the water, on land and in the air. Humans only appear late in the day.

The Earth Is Alive ...

While life is evolving, the face of the Earth is changing as well: continents drift apart and together; oceans form and disappear; mountain ranges rise up and are eroded; ice ages cover parts of the planet with a shroud until the glaciers give way to palm trees ...
Since primeval time, the Earth has been a living planet.

Black Smoker, East Pacific Rise, at a depth of 2815 m

The hot interior of our home planet contains the motor which keeps the thin crust of the Earth in constant motion. Viscous currents of rising and sinking magma in the mantle transfer their forces to the outer crust, which is made up of numerous drifting plates.

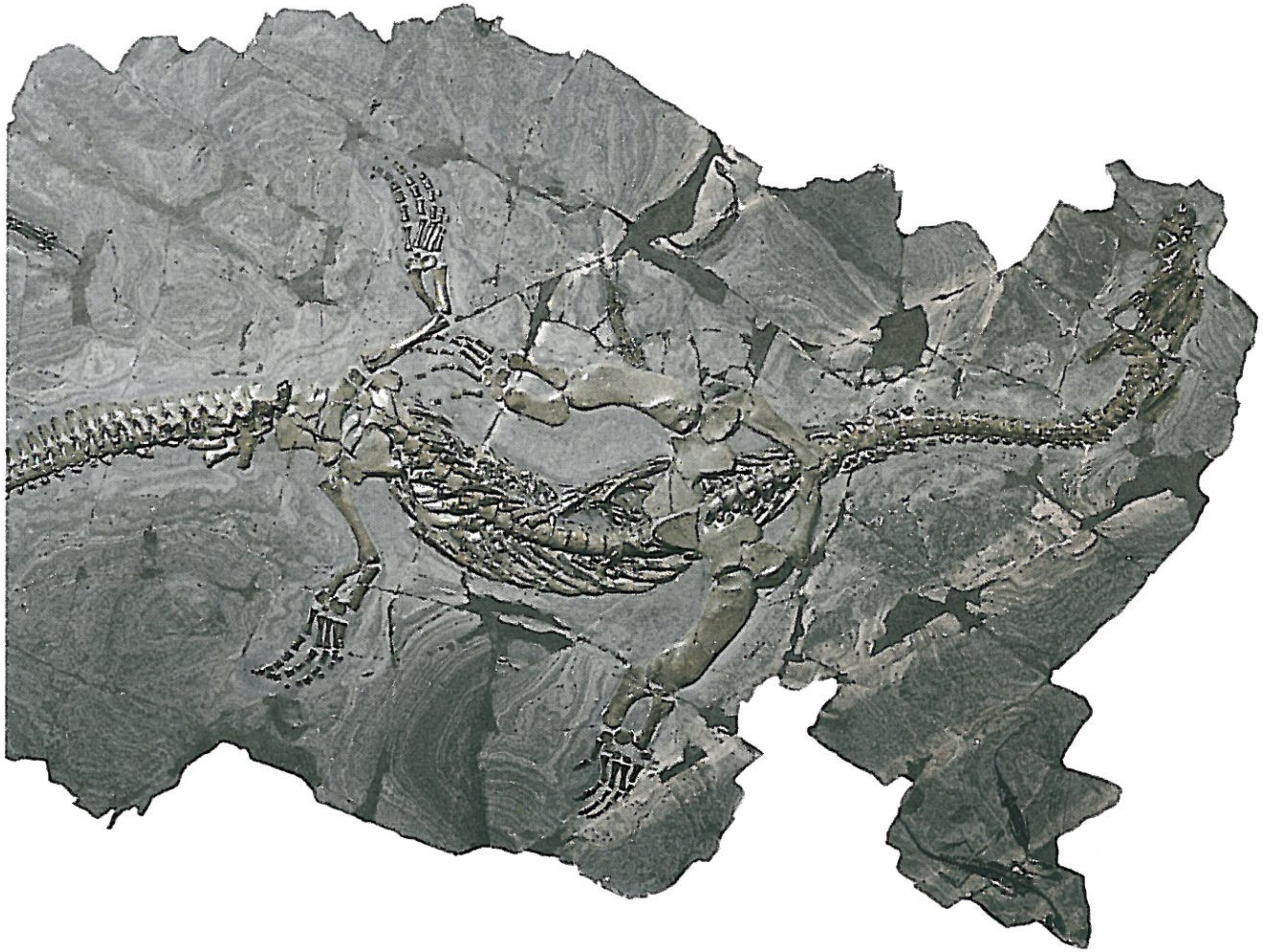
... And Rocking.

The effects of plate tectonics become evident unimaginably slowly by human standards, but surprisingly rapidly on a geological time scale (tectonics is the study of the Earth's "architecture"). In the oceans, submarine volcanoes at the boundaries between plates spreading apart from one another spew forth molten rock, forming a new seafloor. But where two plates collide, one of them is forced down into the Earth's mantle, and chains of islands or mountain ranges are created – a process always accompanied by earthquakes and erupting volcanoes. These plates may move several centimeters each year, totalling up to several meters within a human lifetime, and to hundreds of kilometers over millions of years. It is therefore conceivable that land and water, mountains and plains were distributed quite differently in previous geological epochs ... also in the region that is now Switzerland!

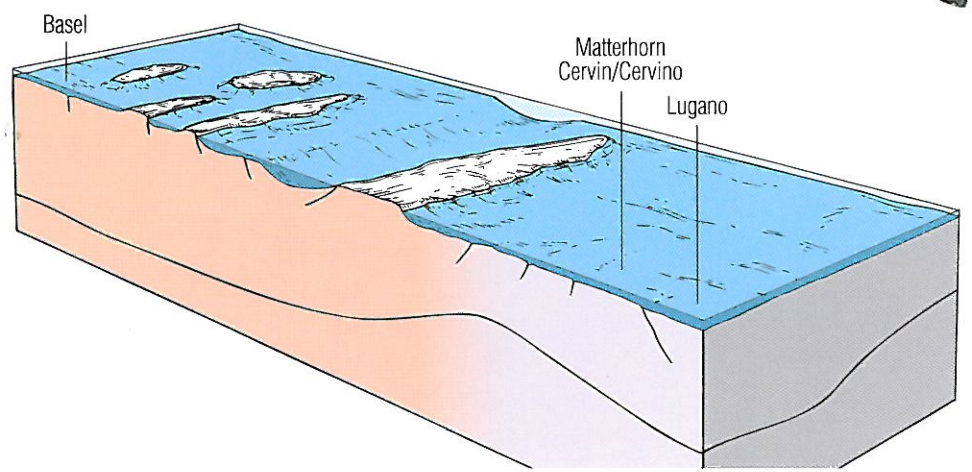
Bay Bridge (San Francisco, CA), after the Loma Prieta earthquake of 17 October 1989 (magnitude of 7.1)

200 Million Years Ago

Ticino, 200 million years ago. In the Triassic Period it is covered by a shallow sea with numerous islands. Strange dinosaurs cavort in the warm water or on the beaches: fish-like Mixosaurus, agile Ceresiosaurus, rapacious Ticinosuchus, and Tanystropheus with its long neck measuring three meters. Scientists found the fossilized remains of these animals in the slate quarries on Mount San Giorgio near Serpiano. The shallow Triassic Sea covered almost all of present-day Switzerland, a fact documented by dinosaur finds in the Argovian Frick Valley, near Emosson in the Lower Valais, as well as in the Swiss National Park in Lower Engadine. Towards the end of the Triassic Period and in the early Jurassic, the time ran out for this shallow sea: as the plates drifted apart, a deep ocean formed between the African and European continents: the Tethys Sea.



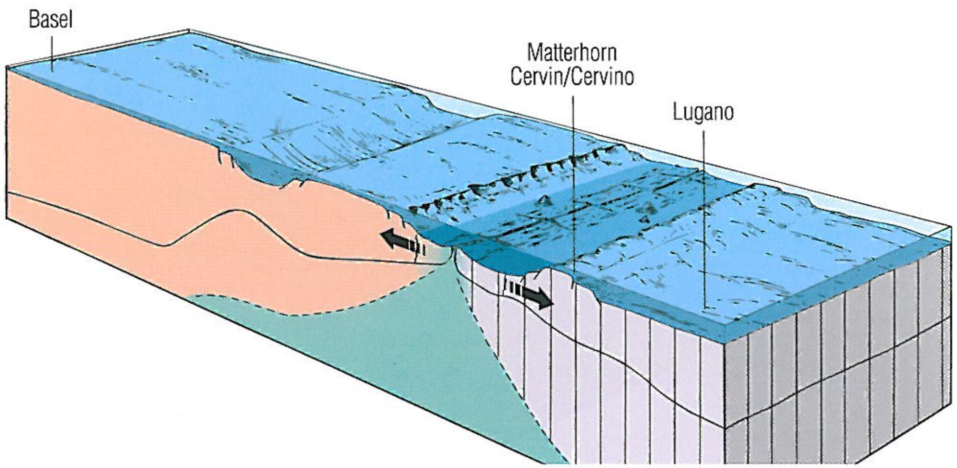
Ceresiosaurus, Mount San Giorgio



150 Million Years Ago

150 million years ago, in the Valais: there are volcanoes on the sea floor rather than the snow-capped three to four-thousand-meter peaks in what is now the high mountain region between Saas Fee and Zermatt. This is where, during the Jurassic Period, the Tethys deep-sea basin formed, creating a trough in which the sediments were deposited that later turned up in the rock faces of the Alps: sediments such as limestones and sandstones, but also the so-called pillow lavas of the submarine "fire-mountains". On contact with the cold sea water the upwelling lava congeals in pillow shapes. To the geologist, such rocks always indicate submarine formation.

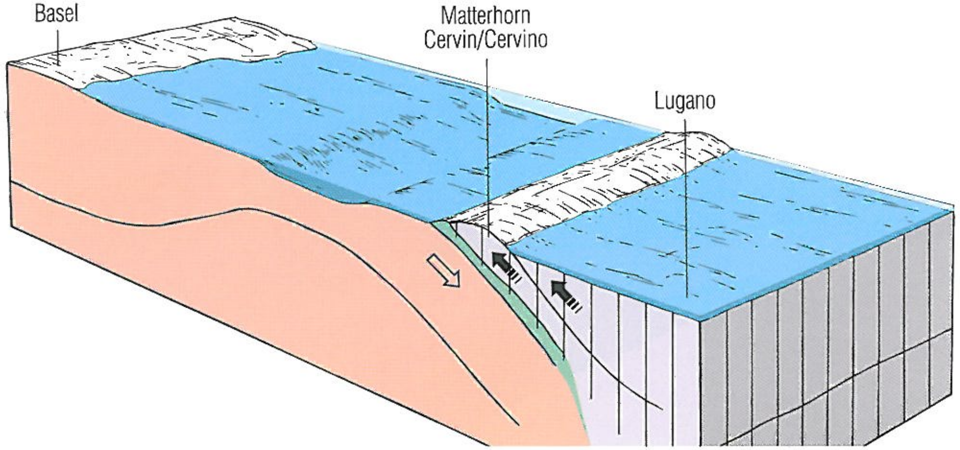
Pillow lava



90 Million Years Ago

Ninety million years ago, again in the Valais. Now, in the Cretaceous, Africa begins to drift towards Europe – the plates collide. A part of Africa thrusts over Europe. Masses of rock of a depth of several kilometers, called nappes, collide, thrusting into and over one another. This is the beginning of the formation of the Alps. In this process, some nappes were pushed down to considerable depths (40 to 60 km), where they were transformed by high pressure and heat. This transformation is called metamorphism. In this way, pillow lava, for example, was modified to form eclogites, dark green rocks such as those which can be found in the higher regions of the Visp valleys.

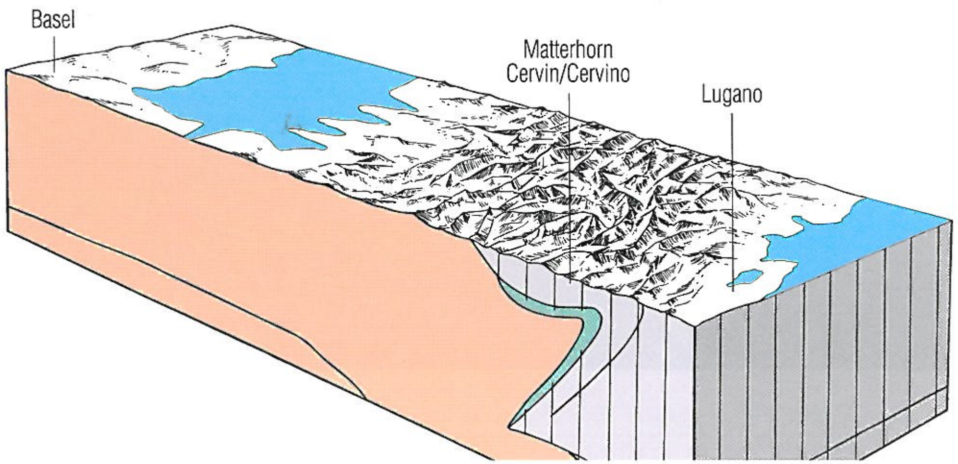
Eclogite (high pressure rock)



20 Million Years Ago

Twenty million years ago, in the Glarus region. After the transition from the Cretaceous to the Tertiary Period, the formation of the Alps reached its climax. The two continents interlocked. For the Earth sciences it is a difficult – but extremely fascinating – task to reconstruct past events based on present geology. Erosion has meanwhile worn away much of the nappes, which impedes scientific study, but this also exposed the core of the massif, and thereby key zones. Such a zone is the Glarus Overthrust at the Tschingelhörner, near Segnes Pass. At this location, dark Verrucano rocks over 200 million years old were thrusted over the lighter-colored and significantly younger flysch rocks. The boundary is razor-sharp and caught the attention of 19th century geologists, giving rise to theories on the genesis of the Alps.

Tschingelhörner (Hans Conrad Escher von der Linth, 22 July 1812)

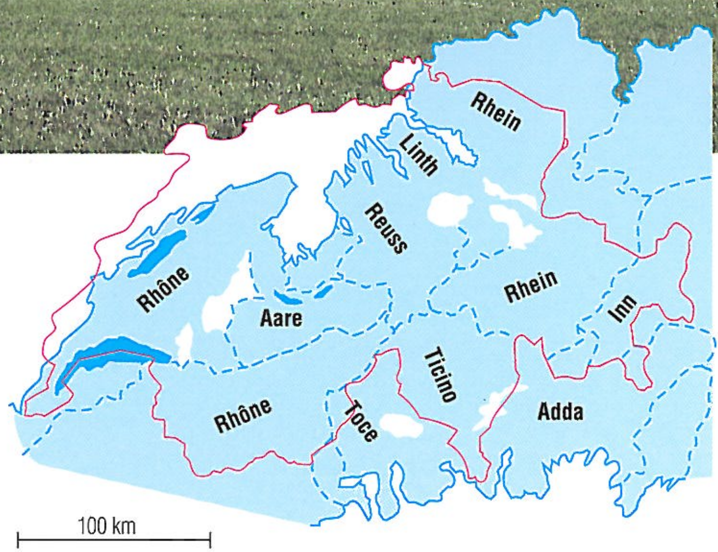


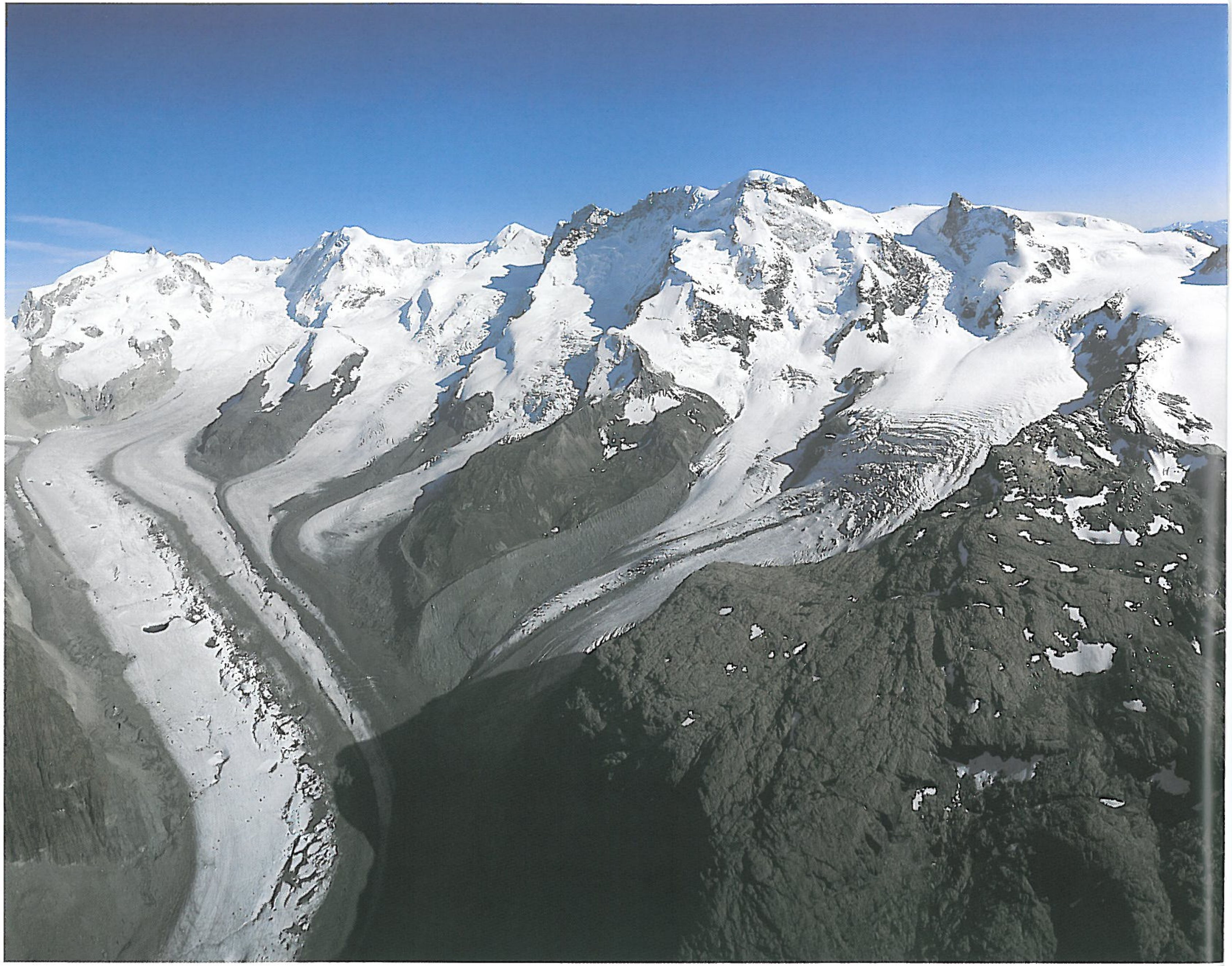
20 Thousand Years Ago

Twenty thousand years ago, near Berne. It was dark and cold – there were no doubt more pleasant places than the base of a glacier at the height of an ice age. Three hundred meters of ice towered over the spot where the Swiss capital would later be situated. At that time, the Aare and Rhone Glaciers, and the debris they carried from the Alps, were united here. Much later, scientists were to examine the moraines and to attribute this glacial advance to the most recent ice age.

The surface relief of Switzerland has largely been sculpted by the cycles of ice ages and inter-glacial periods during the past million years. We owe the beauty of our landscape, the creation of valleys and lakes, and the fertility of our moraine soils, supported by mineral fertilizer supplied by the finely ground debris transported by glaciers, to these glacial cycles.

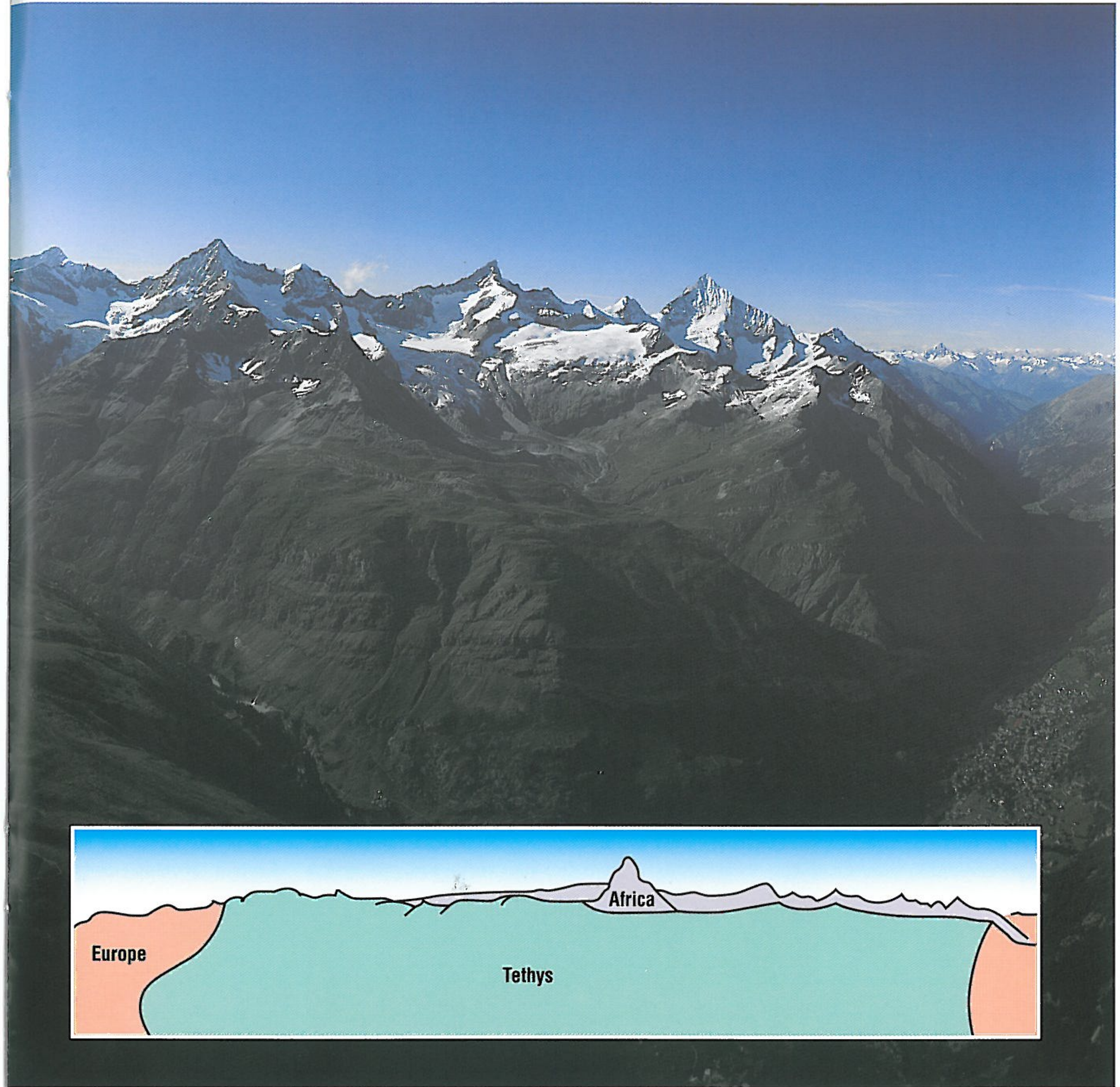
Erratic block,
Steinhof, Canton of Solothurn




Monte Rosa
Liskamm
Castor
Breithorn

Theodulpass Matterhorn Dent-Blanche

Weisshorn



And Now: Greetings From Africa

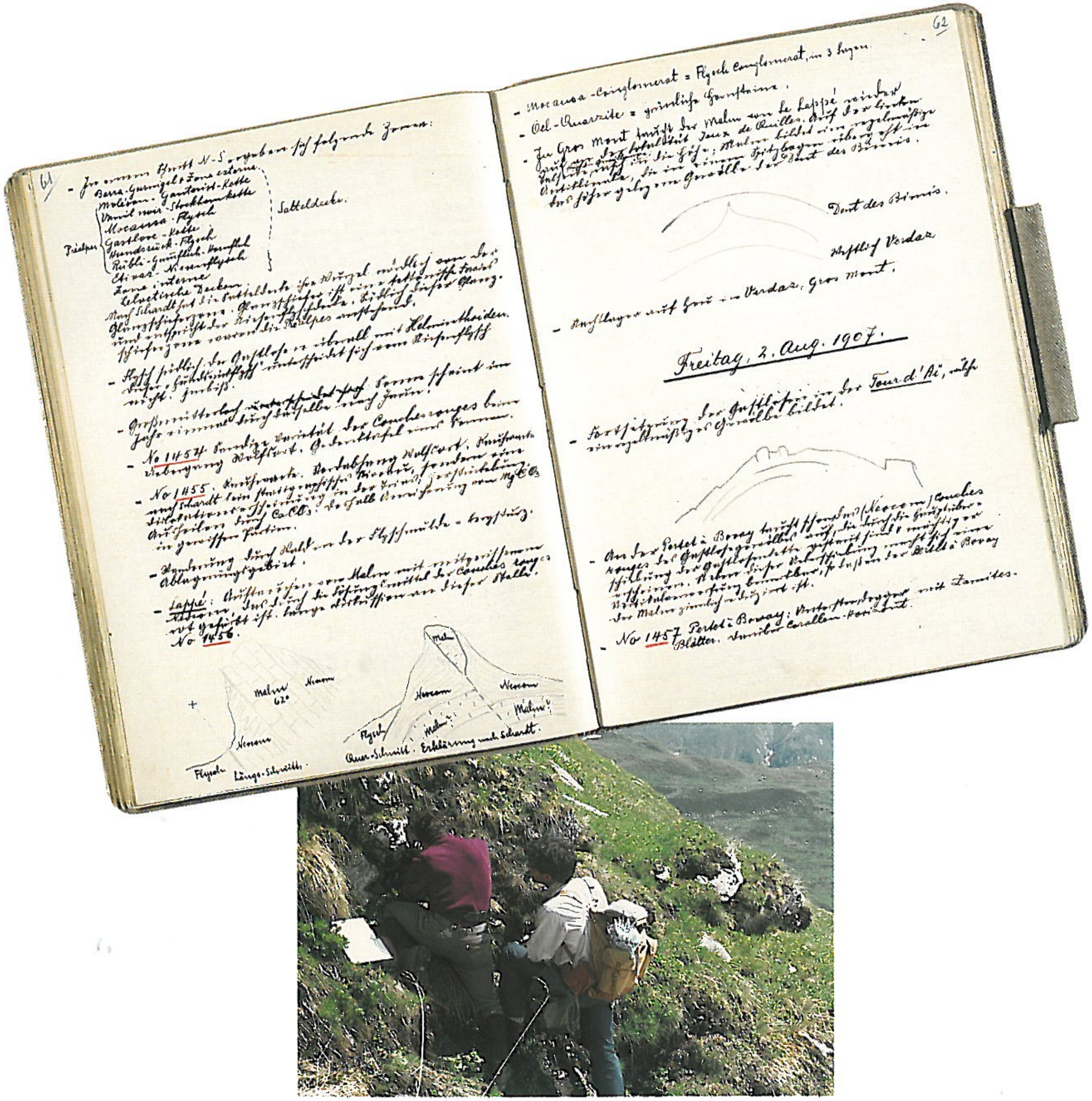
Once again in southern Valais – today. Majestic ruins rise to the sky. Where tourists see beautifully formed, snow-capped mountains like the Matterhorn and its neighbours, the geologists perceive nothing more than the ruins of a mostly eroded mountain range. If you followed the geological evolution over the past 200 million years (pages 10 to 14), you will have no problems recognizing that the Matterhorn, for example, was once part of Africa. The way in which the African continent thrusted over the European plate becomes particularly evident near Zermatt. Here the collision suture is in the high mountains. It took two hundred years of geological research until these processes were understood. Decisive insights about the deeper underground have only been gained in the most recent past ...

Yesterday

His head protected by a weatherproof felt hat, a hammer in his hand, a backpack with some sausage and bread plus kilograms of rocks, sleeping in the hay in a dairy hut or under the stars – this is the image of an Alpine geologist between 1800 and 1950. "Mente et malleo", with wit and hammer, was the motto of these sons of nature. Despite limited means, they amassed important knowledge recorded in their notebooks – so-called field books:

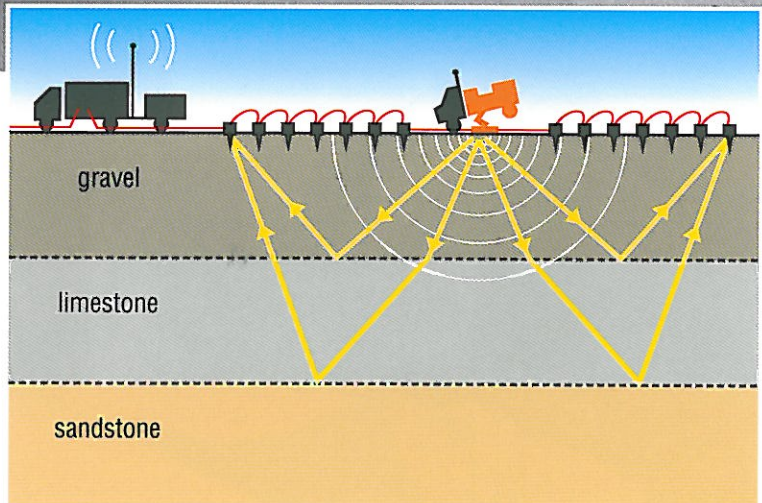
- information on the distribution, age and genesis of the various types of rock;
- the insight that tectonic forces (overthrusting nappes), rather than the energy of volcanic activity, raised the Alps to their towering heights;
- that the interior structure of the Alps is extraordinarily complex;
- that Switzerland is not particularly rich in mineral resources.

And, as is the nature of science, each new insight raised many new questions ...



Eduard Gerber's field book (1876 to 1956)

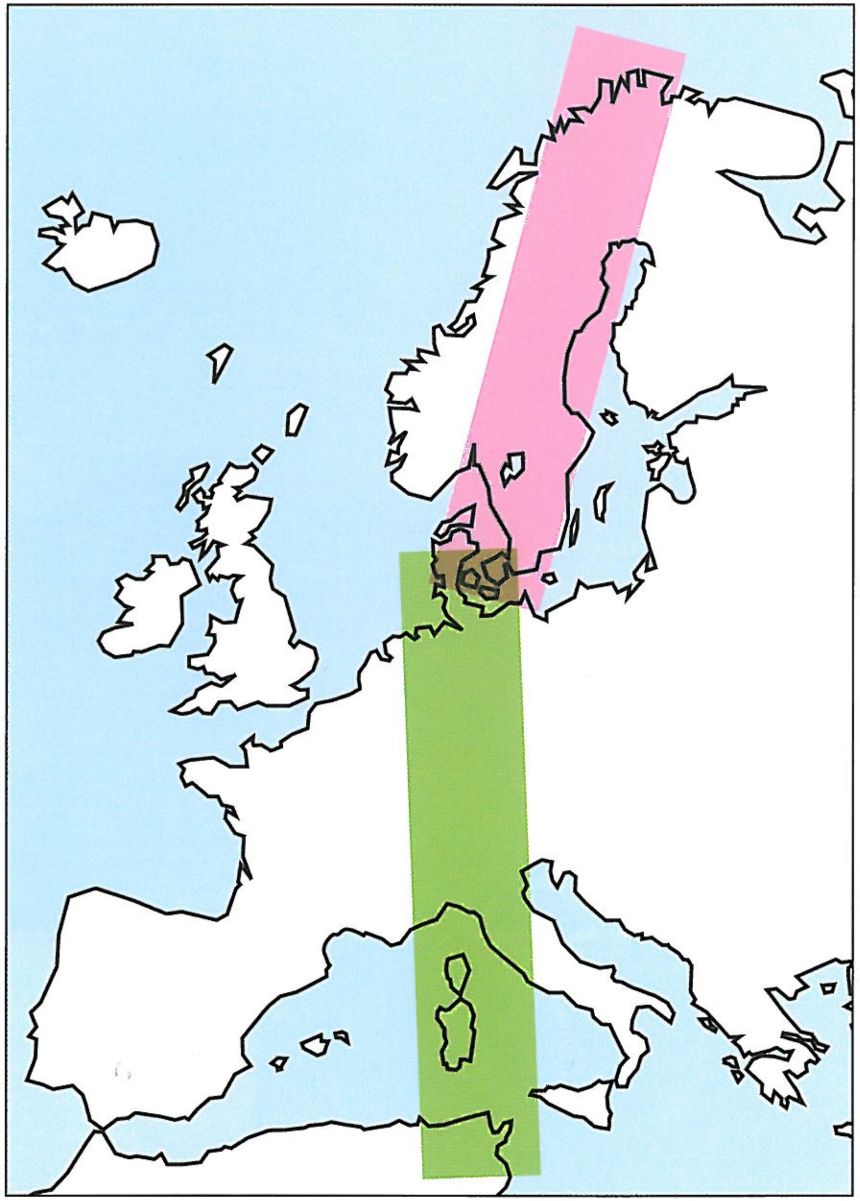
Today

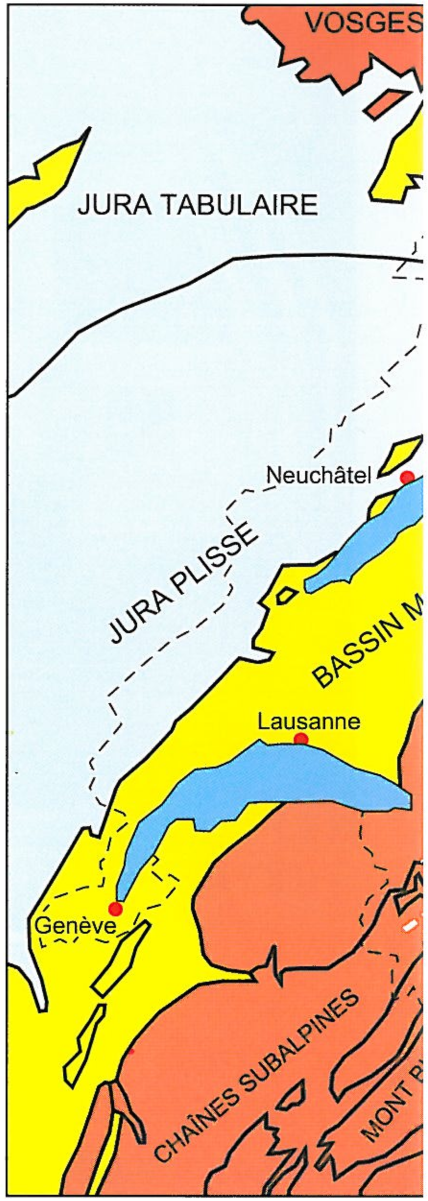


The few mines on Swiss soil only managed to scratch the surface of the massif, and while the record-length railroad tunnels did lead through the Alps, they did not reach their foundations – for a long time the roots of the mountains remained hidden from observation, leaving important questions on their structure unanswered. Until, about fourty years ago, geophysics came to the rescue. Since their arrival on the scene, detonations and vibrators have become particularly important complements to the geologist's hammer: acoustic waves penetrate the underground and are reflected by the boundaries between rock strata; seconds later, their echo is recorded at the Earth's surface. Thus, millions of data help to create a conceptual image of those areas which are hidden to the human eye. And so, as high-tech is replacing the son-of-nature image of Alpine research, geology is changing from an empirical to an exact science.

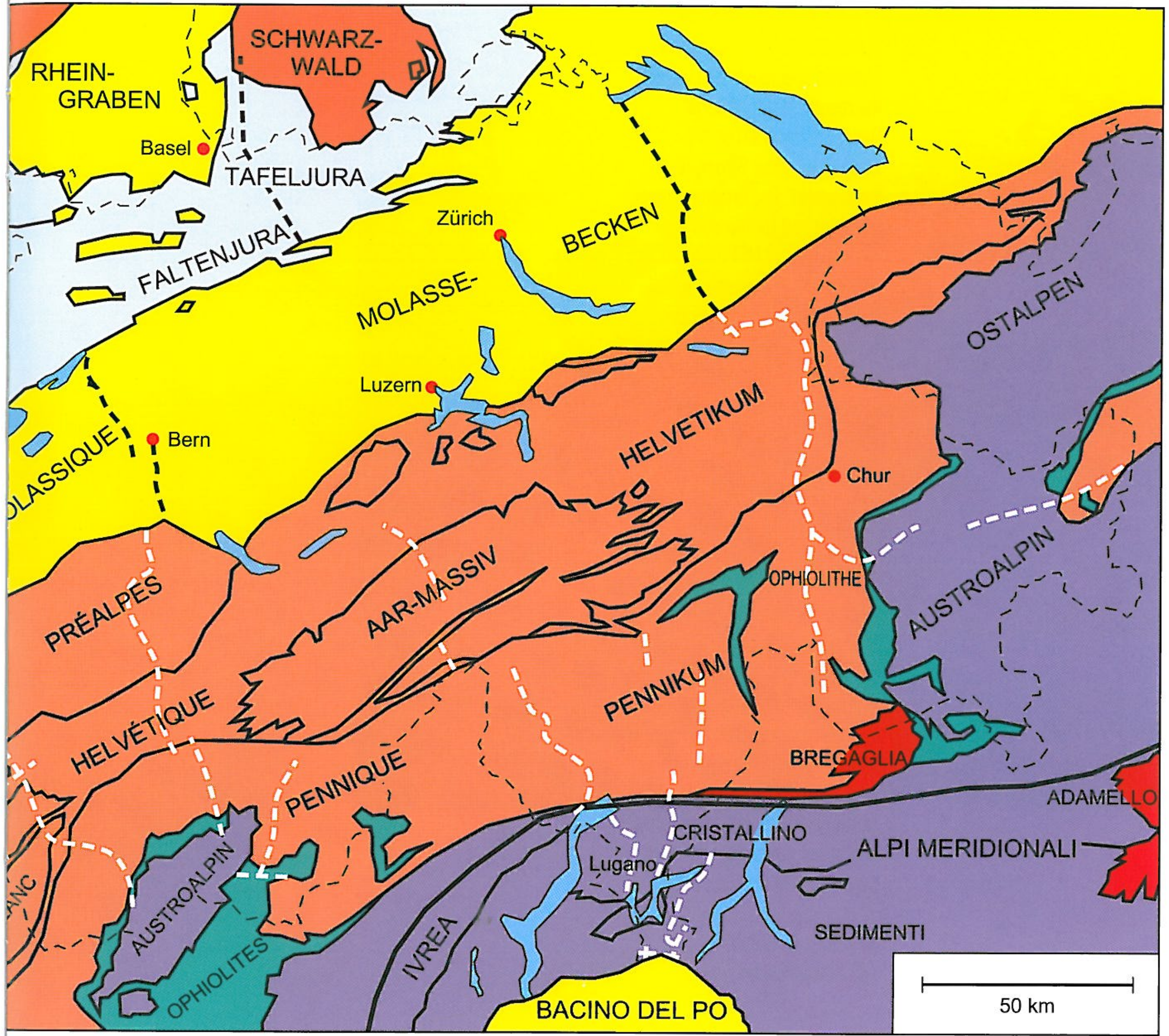
NFP/NRP 20 ...

In the recent past geophysical research methods – predominantly the seismic approach which has just been outlined – have significantly improved our knowledge of the structure of Europe. Along a 4000 kilometer transect from the North Cape to Tunisia, the European Geotraverse, a thorough study of the whole continent has been made within the framework of an international collaborative project. Naturally, the Alps are a key zone, and the segment on Swiss soil is of special importance: our contribution is "The Deep Geological Structure of Switzerland", a National Research Program (NFP/NRP 20) of the Swiss National Science Foundation.





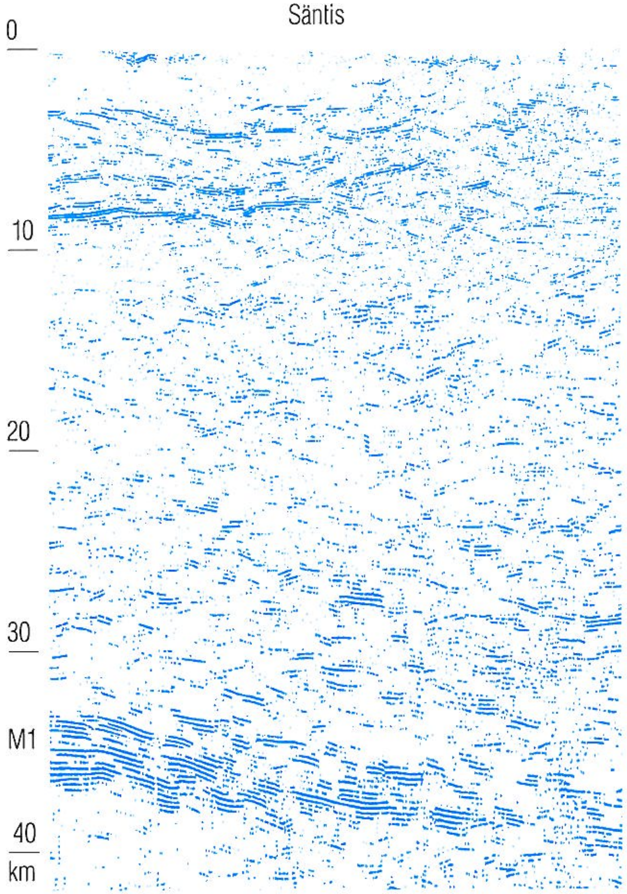
... forward ...



In order to study the entire surface of the Swiss Confederation, geologists and geophysicists selected various transects rather than restricting their work to one single traverse. The map on this page shows their paths. Thanks to a well-informed population, the field work for this basic research proceeded without a hitch. The NFP/NRP 20 is one of the more complex National Research Programs, with several hundred participants; the collected data were processed in Zürich and Lausanne at special computer centers. The following are the most important figures concerning this program:

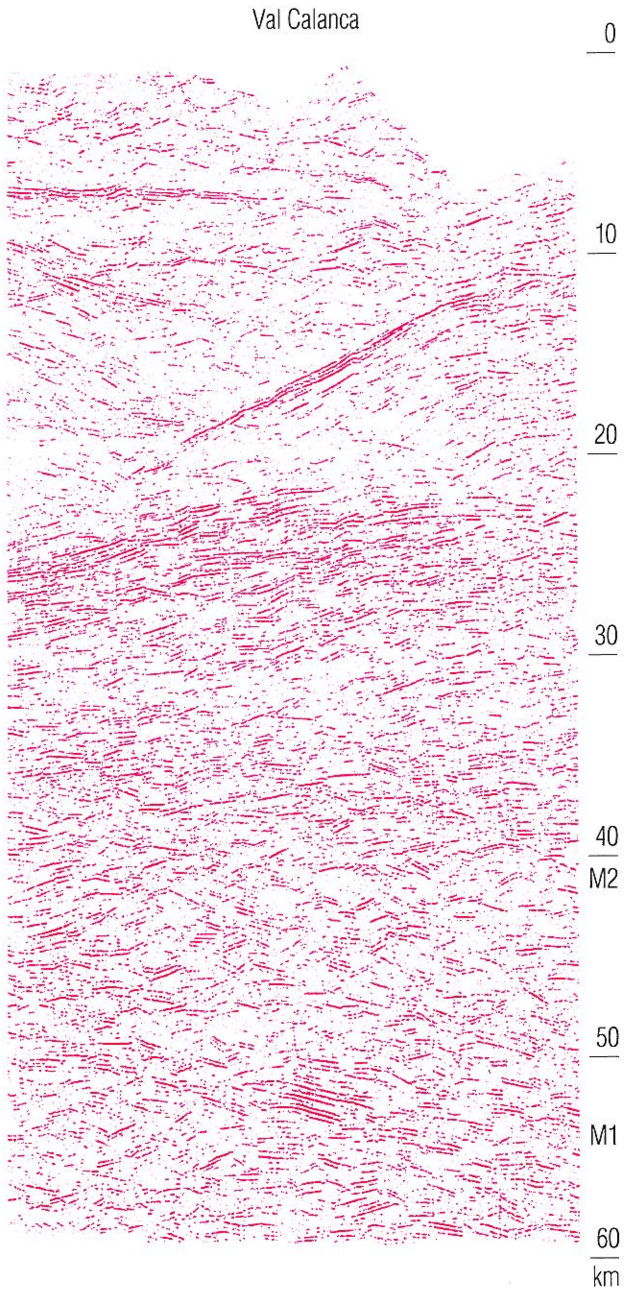
Duration: 1985 – 1993
Costs: 14.5 million Swiss francs
Number of individual projects: 34
Total length of traverses: approx. 700 kilometers

... downwards

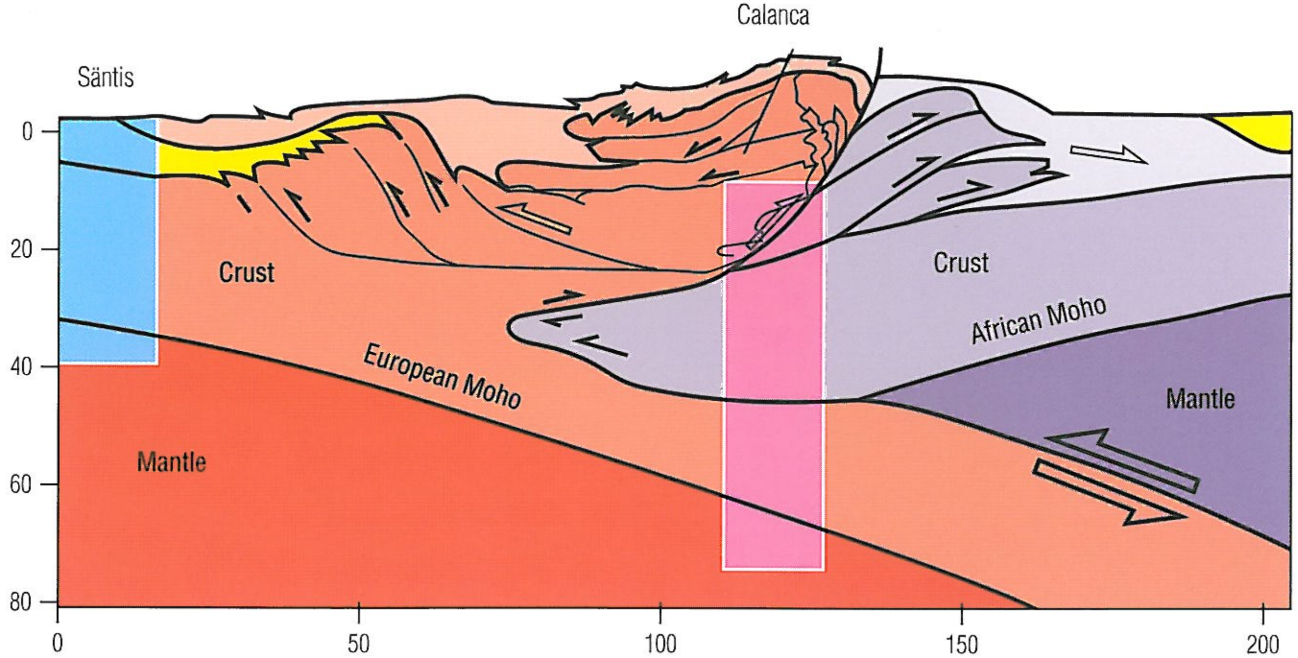


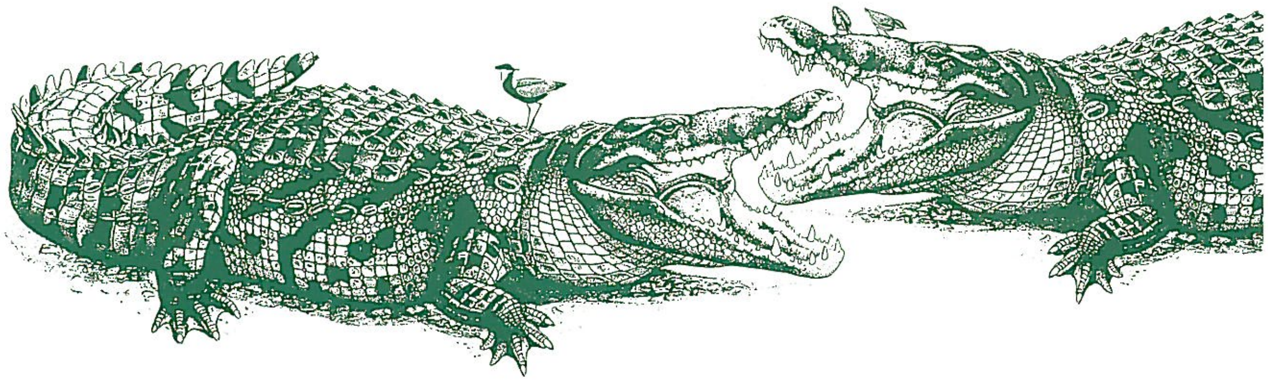
At a symposium in Interlaken in November 1992, some one hundred specialists discussed the results of the National Research Program on the Deep Geological Structure of Switzerland. The program management had formulated the general goal of NFP/NRP 20 as follows: "One important initial task is to establish a link between the visible, surface zone and the deeper underground." The seismic profiles indeed showed that the nappe structure, which was known from earlier field studies, also continues at depth. In Ticino, for example, the nappe structure of the deepest hitherto known geological unit, the Leventina Nappe, has now been established. And below it, two hitherto unknown nappes were even discovered. The Aar Massif, previously regarded as the epitome of geological stability, proved not to be firmly anchored, but to have thrusted far north over the foreland.

M1 European Moho
M2 African Moho



Continents, Collisions, Crocodiles.



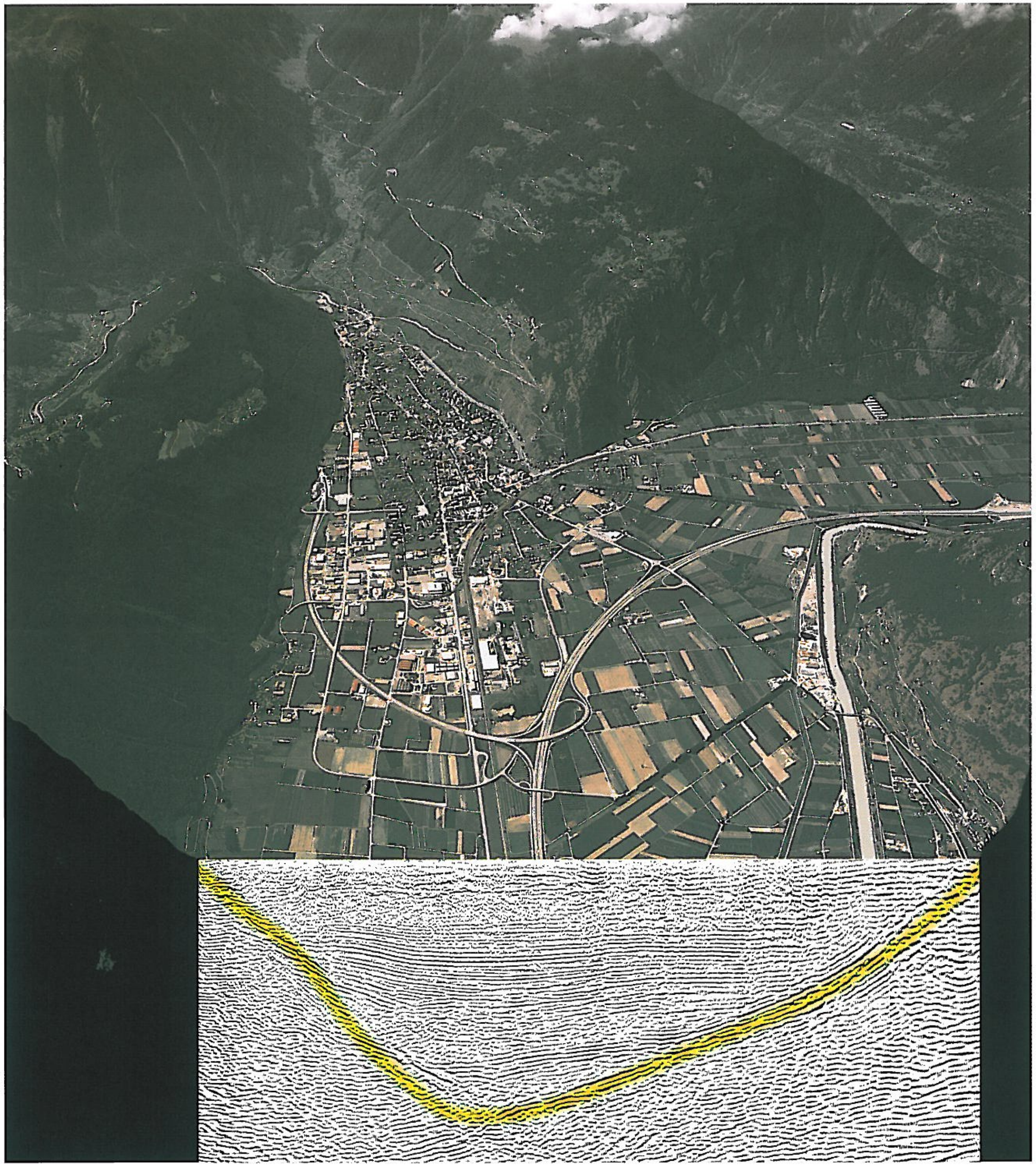


In Southern Switzerland, interest focused on the Insubric Line: How does this boundary between the Central and Southern Alps continue at great depths? Seismic profiles to a depth of 60 kilometers – that from Calanca Valley, for example – show its course. As our cross section shows, the Insubric Line plunges below the Central Alps – thus, like an underground wedge, the "African" Southern Alps protrude far to the north. The structure resembles the jaws of two crocodiles which have locked onto each other. After the African nappe complex had been thrust over the European crust, the Central Alps apparently moved to the south in a second phase of movement against the prevailing direction of motion.

Cross section through the Eastern Swiss Alps

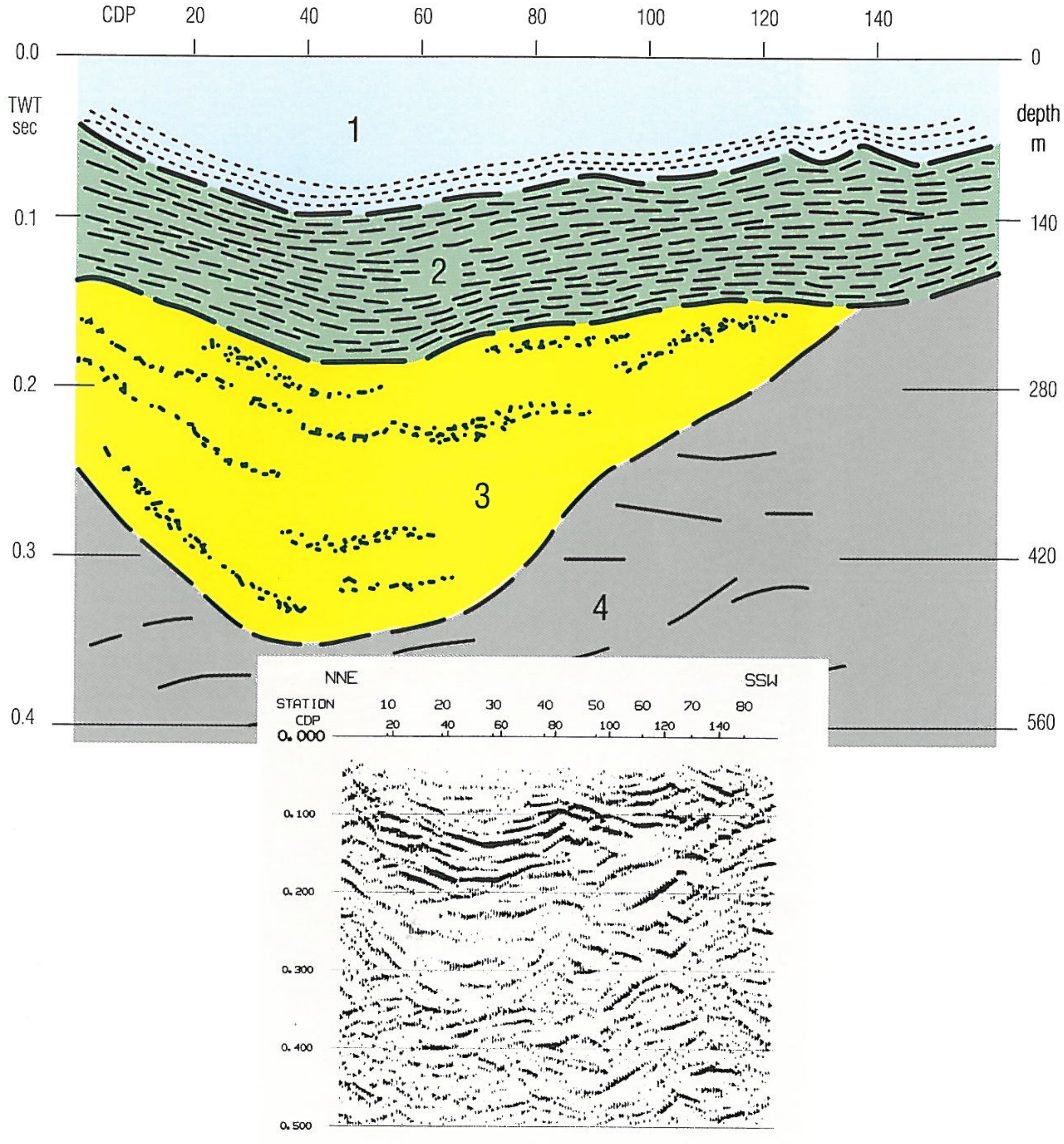
Looking At - And Looking Into the Ground

In addition to new insights into the deep structure and the geology of Switzerland, research within the NFP/NRP 20 also yielded interesting regional data. Take, for example, the Rhone Valley between Sion and Martigny. In central Valais, at the end of the last glacial period several thousand years ago, there was a deep, elongated lake. Its sediment deposits could be detected in the course of seismic profiling carried out in an NFP/NRP 20 study. Surprising is the depth at which the bedrock lies buried beneath the present surface.
Near Martigny the bottom of that former lake is some 1000 meters below today's valley floor, or some 550 meters below sea level. In this way, modern geophysical methods can discover traces of lakes which have long disappeared and can prove the spectacular overdeepening of our Alpine valleys. These are primarily scientific insights; but they are also of economic interest – for example, with respect to tapping geothermal resources or tunnel construction.



The Rhone Valley near Martigny

Hidden Valleys



A seismic profile near Novazzano in southern Ticino uncovered a hidden valley created some five to six million years ago and hidden by argillaceous-marlaceous marine sediments lying under a surface cover of glacial deposits. This valley, and similar ones in the Mendrisiotto region, were created at a time when the Mediterranean was almost dry and the low sea level caused the rivers to carve deep valleys into the bedrock. Later, when the water level rose again, this valley in the bay of Balerna-Novazzano was first filled with rough gravel, and then covered by fine marine sediments. These rough gravels may now contain groundwater.

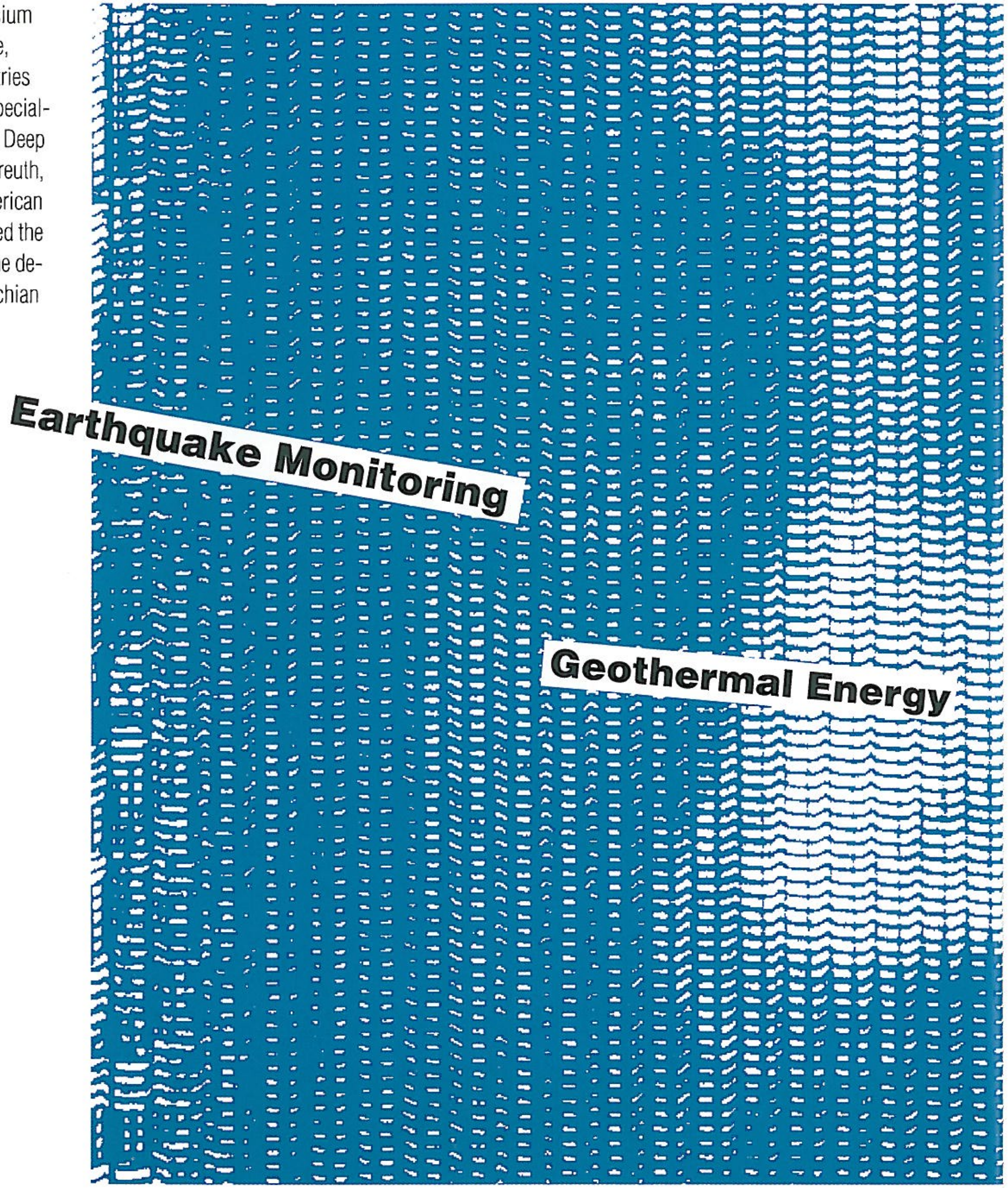
Seismic and geological profile of the hidden valley near Novazzano:
1 glacial sediments
2 fine marine sediments
3 rough gravel
4 bedrock into which the valley was carved

Insights ...

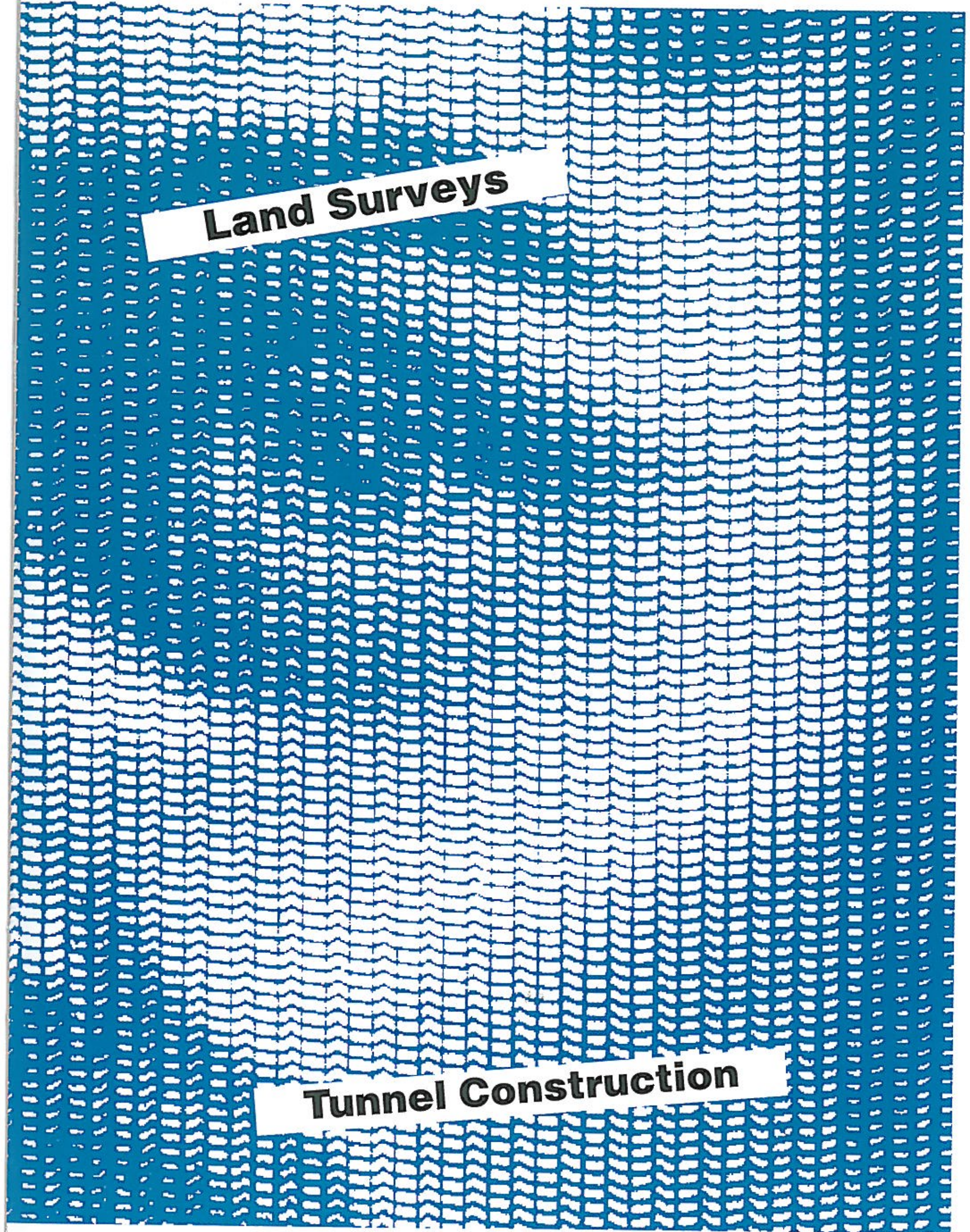
Few secrets remain hidden below the surface of Switzerland. Each and every square kilometer has been mapped in detail. This is not true for the subsurface – for a long time, the structure of the foundation of our country was a mystery and, until recently, gave rise to the wildest speculations. Thanks to the results of the National Research Program "Deep Geological Structure of Switzerland", important questions have been answered. We know where and how deeply the Alps are rooted. Like icebergs, these rocky and icy peaks only show their tips: Their height of four kilometers above sea level stands on an intricately structured crust of rocks over 60 kilometers thick. This knowledge is linked with a further result, that is, the insight that Europe and Africa interlock in the Swiss Alps in a structure much like the jaws of two fighting crocodiles.

Such basic research increases the geological knowledge of our country; it is, so to speak, vertical national history. Scientific progress not only benefits Switzerland, however, but also, via international contacts, the scientific community abroad.

At the NFP/NRP Symposium in Interlaken, for example, experts from many countries attended, among them specialists from the Continental Deep Drilling Project near Bayreuth, Germany, as well as American geologists, who compared the events in the Alps with the development of the Appalachian mountains.



... Gains



Fundamental research is not the only beneficiary. The NFP/NRP 20 has yielded abundant information of technical value:

Any exploitation of geothermal energy requires basic information on the geological deep structure. In the Valais, the NFP/NRP 20 cooperated closely with the regional geothermal project, which aims at future exploitation of this alternative source of energy.

Tunnel construction is applied geology. Only if the internal structure of mountains is known, can such huge projects be tackled. Part of the Eastern Transect ran above the then-planned Splügen tunnel and yielded relevant data.

The Alps, a mountain range with a turbulent past and present, are an earthquake zone which should not be underestimated. Monitoring of weak tremors and localizing their epicenters as part of the NFP/NRP 20 are of great value in risk assessment.

There is also a connection between the National Research Program and the exploitation of mineral resources: A fruitful, cooperative relationship evolved between the researchers on the NFP/NRP 20 and specialists from the mineral oil industry.

Alpine mountain formation is still in progress – our Alps continue to rise by about a millimeter every year. Continuing pressure, moreover, keeps squashing Switzerland: the distance between Lugano and Schaffhausen keeps getting shorter. This is of interest to land surveyors!

What Next?

The National Research Program NFP/NRP 20 "Deep Geological Structure of Switzerland" has answered many questions while leaving numerous other problems unresolved. The following is a selection of issues on which future research will focus:

Near the surface, Switzerland lacks mineral resources. At greater depths, however, valuable resources might be hidden. Where? What? (mineral oil? natural gas?)

When and where must the next greater earthquake be expected to occur?

When and how soon will another ice age be upon us?

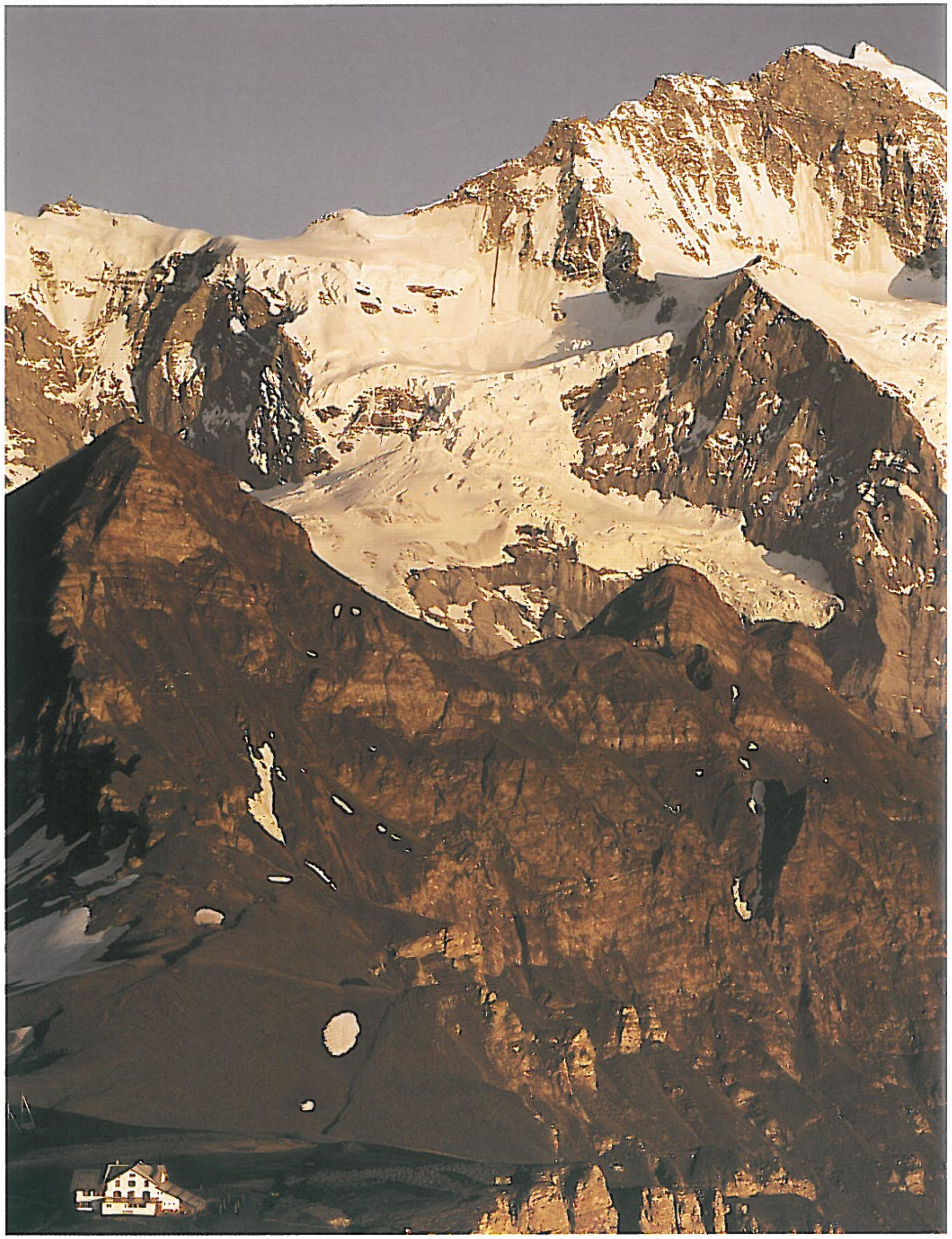
How long will proud Matterhorn, this African vanguard, resist erosion and serve to represent the natural attractions of our country all over the world?

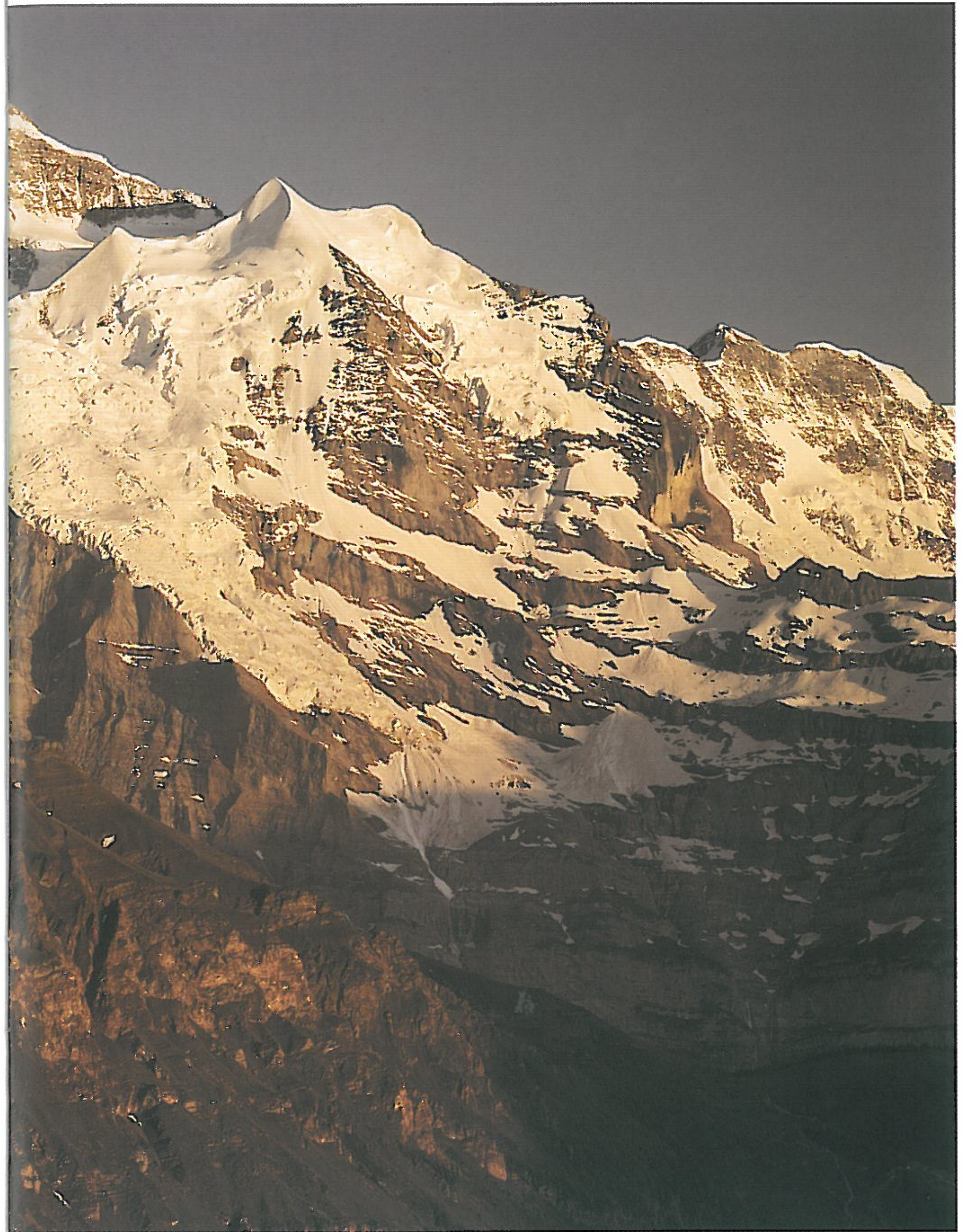
How long is the rising of the Alps going to continue? And what about the movement of the tectonic plates, which could reduce the aereal extent of Switzerland by some 30 kilometers over the next 10 million years?

How many million years will it take until another ocean covers the surface of the Swiss Confederation, obliterating both the beautiful and the ugly?

When, finally, will another high mountain range rise up here in Central Europe, succeeding our Alps?

Let's leave the final words to a writer. The German author, Friederike Brun (1765-1835), intuitively understood long ago what geologists have found out through hard work: that the seemingly eternal mountains are quite transitory and that their substance, too, is part of a returning cycle. Two hundred years ago, this writer visited the Bernese Oberland and noted in her diary:





"Dazzling face of the Jungfrau, you who receive the sun's first morning greeting and blush under his last ray, one day you will sink down into darkness and oblivion. Millennia admired you in your luminous attire, millennia will pass you by! But your time will come when your substance will dissolve into its parts and you will sink into the great crucible from which will rise up again creations of which we cannot conceive."

Experts:
Prof. E. Niggli, Berne, President
Prof. D. Bernoulli, Zürich
Prof. D. Betz, Hannover, Germany
Prof. Ch. Caron, Fribourg
Prof. M. Delaloye, Geneva
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Prof. P. Fricker, Strasbourg, France
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Prof. J.-P. Schaer, Neuchâtel
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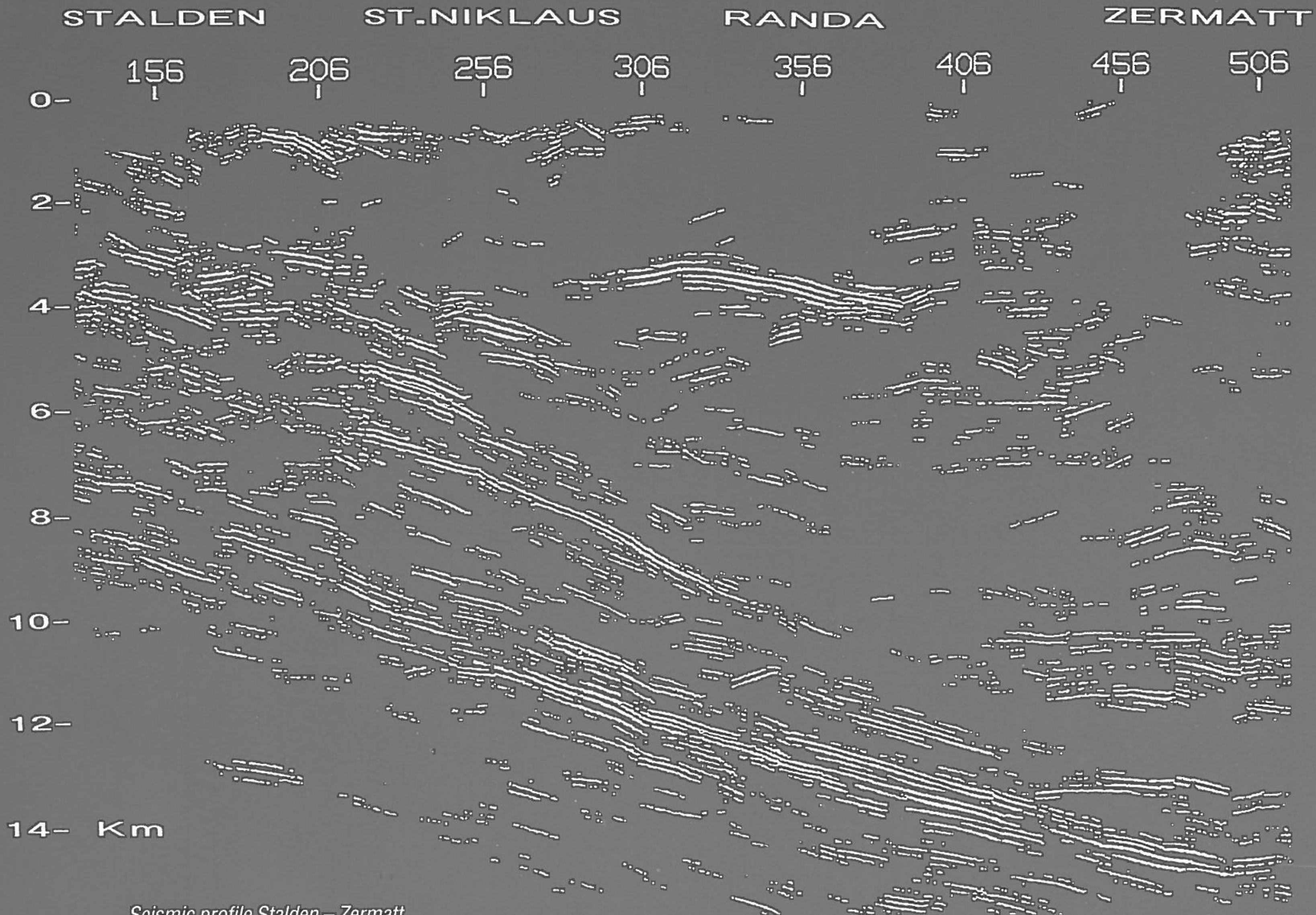

Seismic profile Stalden – Zermatt

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