A GUIDE TO SOME GEOLOGICALLY SIGNIFICANT AREAS OF THE ALPS

BY

ARIEL A. ROTH

TEXT AND GRAPHICS EDITOR: KATHERINE CHING

1998 EUROPEAN FIELD CONFERENCE
FOR SDA EDUCATORS

GEOSCIENCE RESEARCH INSTITUTE
LOMA LINDA UNIVERSITY
LOMA LINDA CA 92346 USA
TELEPHONE (909) 824-4548; FAX (909) 824-4314

http://www.tagnet.org/gri

EDUCATIONAL MATERIALS

(ADAPTED FROM THE ORIGINAL PRINTED VERSION)

“The Alps conceal many mysteries.”

CONTENTS

INTRODUCTION TO THE ALPS

A knowledge of the main events in Alpine history will be helpful in understanding the meaning of specific areas of study. The reader is warned that many concepts of Alpine geology are tentative and subject to changes in the future. The newer concepts of plate tectonics have provided both answers and questions to some Alpine geological concepts. Further evaluation is warranted.

The reader unfamiliar with geological terminology will find it useful to consult the last sections of this guide which include a stratigraphic column, a description of the basic kinds of rocks, and a glossary. While the author disagrees with the time scale proposed in the stratigraphic column, the time units are often useful on a relative basis.

BASIC CONCEPTS

As one deals with the geologic history of Europe, the complexities demand that one distinguish between different realms of thought. Important concepts include:

1. *Geographic Location* — the present location of a geologic feature.
2. *Paleogeographic Domain* — the “original” location of a geologic feature which, in the case of the Alps, may have been a considerable distance from its present geographic location.
3. *Tectonic Unit* — the unit that moved, i.e., a nappe or sheet. These units are usually many km in size.
4. *Stratigraphic Position* — the position of a unit in the stratigraphic column. This may either be a very specific position or involve minor to major portions of the column.
5. *Alternative Interpretations* — in Alpine geology, these abound.

As an example: above the valley of the Rhône in Switzerland (geographic location) there is the Diablerets Nappe (tectonic unit) which originated from the Helvetic region (paleogeographic domain) further south. This nappe consists of Mesozoic and Tertiary sediments (stratigraphic position). Some have suggested that this nappe was emplaced as a result of a simple push from the south (embryonic cordillera model), while others have proposed that a complex, volcanic island arc system in the ocean (Tethys) south of Europe was involved in this process (alternative interpretation). Most unfortunately, the same proper noun is sometimes used to represent different categories (e.g., Helvetic nappes and Helvetic paleogeographic domain), and only the context enables one to determine which one is being referred to. The beginner must make a special effort to distinguish between the various concepts as they are introduced.

As one considers the geology of the Alps, it is convenient to divide the various paleogeographic units (regions of origin) into two parts: a *basement* and a *cover*. The basement is usually pre-Permian and usually consists of noncalcareous deposits, especially granites and various metamorphic rocks. The cover usually consists of Permian, Mesozoic or later sedimentary deposits of which marine limestones and shales form a major part. The tectonic map of the Alps (Fig. 1) accompanying this introduction distinguishes between these two convenient divisions. A few moments spent studying this map will be rewarding.

MAJOR DIVISIONS OF THE GEOLOGY OF EUROPE

In a general way Europe is divided into regions that have significance for the sequence of geologic events. The *tectonic* history of Europe proceeds from early to late as one goes from north to south. In other words, the northern parts belong more to the lower part of the geologic column, while the southern part belongs to the upper part and is thus considered more recent. The following outline gives details:

1. ***Early Paleozoic***

   Caledonian Europe — this is northwestern Europe and includes NW Scandinavia and NW British Isles and Ireland. The mountains of these regions were formed earlier than the other groups listed below. These mountains continue to the west on the east side of the North American continent.

2. ***Late Paleozoic***

   Variscan (Hercynian) Europe — this is mid-Europe. The massifs forming the central European cordillera extending from southern England, through France, Germany and Czechoslovakia belong to this period. Much of the coal of Europe is found in this region.

3. ***Permian to Recent***

   Alpine (Mediterranean) Europe — this is the southern part of Europe. Included are the Betides and Pyrenees in the west, the Carpathians and Dinarides in the east, and between are the Alps where we will concentrate our attention.

While there is an earlier history to the Alps than the Permian, it does not appear as significant, nor is it as clear as the more recent (Permian to Recent). The comparable early history of the Caledonian part of Europe to the north is better understood.

GEOGRAPHIC DIVISIONS OF THE ALPS

The Alps form a range about 1000 km long and 250 km wide. Consult the upper left-hand corner of the accompanying tectonic map (Fig. 1) for the main geographic divisions: western, central, eastern, and southern Alps. The Jura can be considered as an extension of the western Alps. The southern Alps are geologically distinctive from the other three divisions and separated by the Periadriatic line, a major fault (dark line on both parts of Fig. 1) running E-W. The western and central Alps have much in common; the eastern Alps are more distinctive.

PLATE TECTONICS AND THE ALPS

It has long been known that the structural pattern of the Alps represents considerable lateral compression, especially in a N-S direction. When the idea of moving continents and its associated plate-tectonics concept became generally accepted a few years ago, Alpine geology was quite readily accommodated by many geologists into the plate-tectonics paradigm.

It has been postulated that the African and Eurasian plates collided, resulting in the African plate overriding part of the Eurasian plate in the region of the Alps. Further to the east it has been proposed that the Eurasian plate overrode the African plate.

The collision of continents which formed the Alps took place mainly in the Cretaceous and Tertiary. Prior to this, large quantities of marine deposits accumulated in the Alpine "geosyncline," a part of the ancient Tethys sea. This is assumed to have been an ocean, between and partly over the Eurasian and African plates, which reached its maximum in the Jurassic.

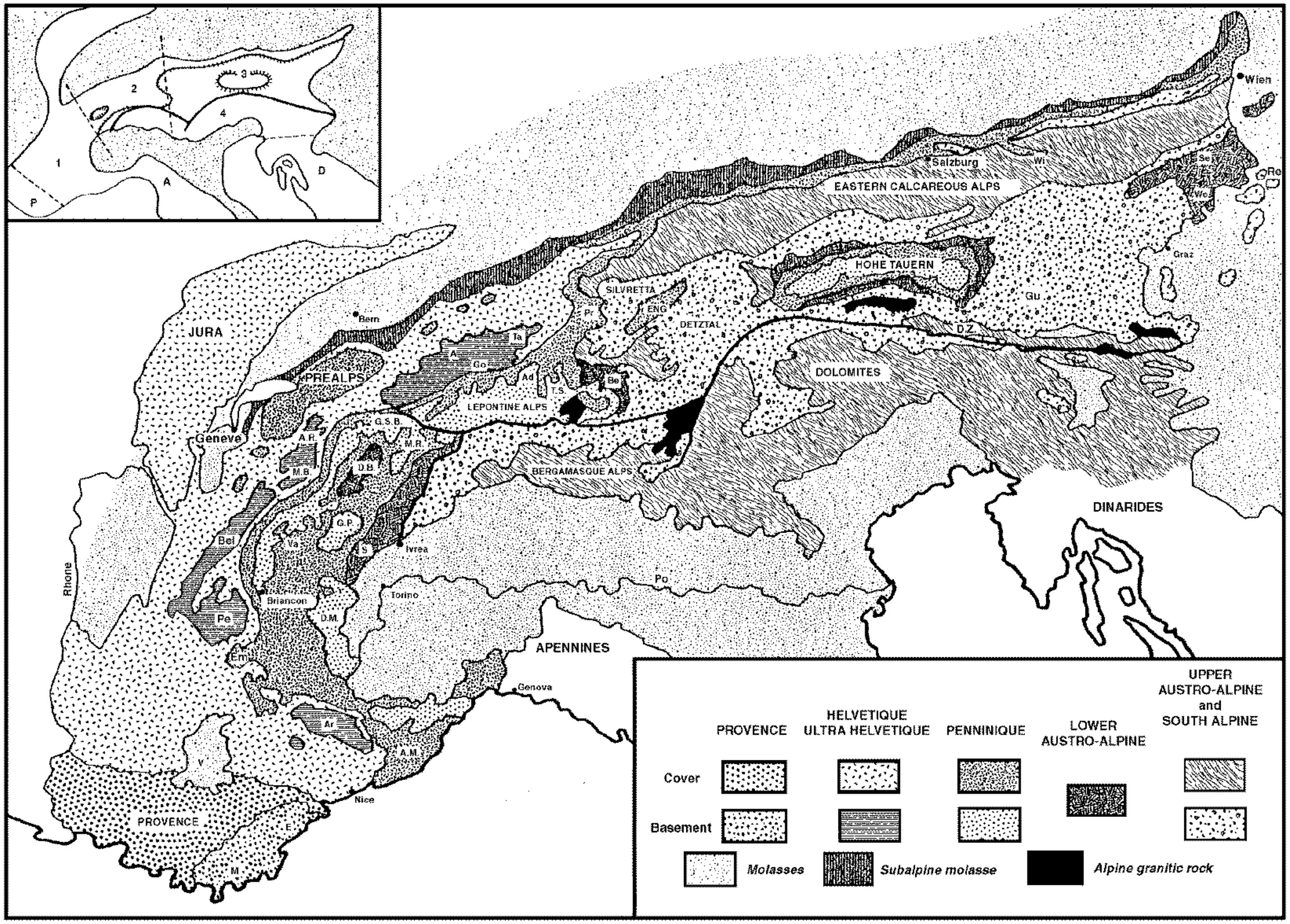


FIGURE 1. Tectonic map of the Alps (modified from Carraro et al. 1974, Figure 1). A = Aar; Ad = Adula; A.M. = Maritime Alps; A.R. = Aiguilles rouges; Ar = Argentera; Be = Bernina; Bel = Belledonne; D.B. = Dent-Blanche; D.M. = Dora-Maira; DZ = Drauzug; E = Esterel; Em = Embrunais; ENG = Lower Engadine; Go = Gotthard; G.P. = Gran Paradiso; G.S.B. = Grand-Saint-Bernard; GU = Gurktal; M = Maures; M.B. = Monte rosa; Pe = Pelvoux; Pr = Prätigau; Re = Rechnitz; S = Sesia zone; Se = Semmering; Ta = Tavetsch; TS = Tambo-Suretta; V= Valensole; Va = Vanoise; We = Wechsel; Wi = Windischgarsten. Inset, upper-left: 1 = Western Alps; 2 = Central Alps; 3 = Eastern Alps; 4 = Southern Alps; A = Apennines; D = Dinarides; P = Provence.

Subsequent to this, it was obliterated as the Eurasian and African plates collided, forming the Alps. At the same time the Atlantic Ocean to the west opened up as the North American plate moved west of the Eurasian and African plates. The present Mediterranean Sea is considered by some to be a latecomer (Pliocene and later) which developed further south, although many questions are being raised about the eastern Mediterranean. A variety of models of the detailed relation of Africa to Europe have been considered (e.g., Coward and Dietrich 1989), but there is no sign of consensus. Recently the suggestion has been made (Hsü 1993, p 224-228) that Africa did not override Europe, and that the division between the African and European continents is, as it was in the past, under the "Mediterranean" (Tethys). The picture is further complicated by the suggestion of some 20 microcontinents between Europe and Africa in a complex island arc system. In recent years the addition of microplates has been a noted trend in plate-tectonics theory.

THE EASTERN ALPS

These mountains, which are so well-developed in Austria, are characterized by a significant overthrust of tectonic units from the south (Austro-Alpine paleogeographic domain) on top of more local units (especially the Penninic paleogeographic domain). Figure 2 gives a proposed arrangement of the paleogeographic domains before the events that formed the eastern Alps.

In the collision that formed the Alps, the lower Austro-Alpine domain was pushed north over onto the Penninic domain, and the upper Austro-Alpine domain was pushed further north over both of these to form the Northern Calcareous Alps which include the mountains just south of Salzburg. Where all three paleogeographic domains are still superimposed, the Penninic is lowest, the lower Austro-Alpine is next, and the upper Austro-Alpine is highest. Note that the N and S movements described herein are relative terms depending on one's point of reference.

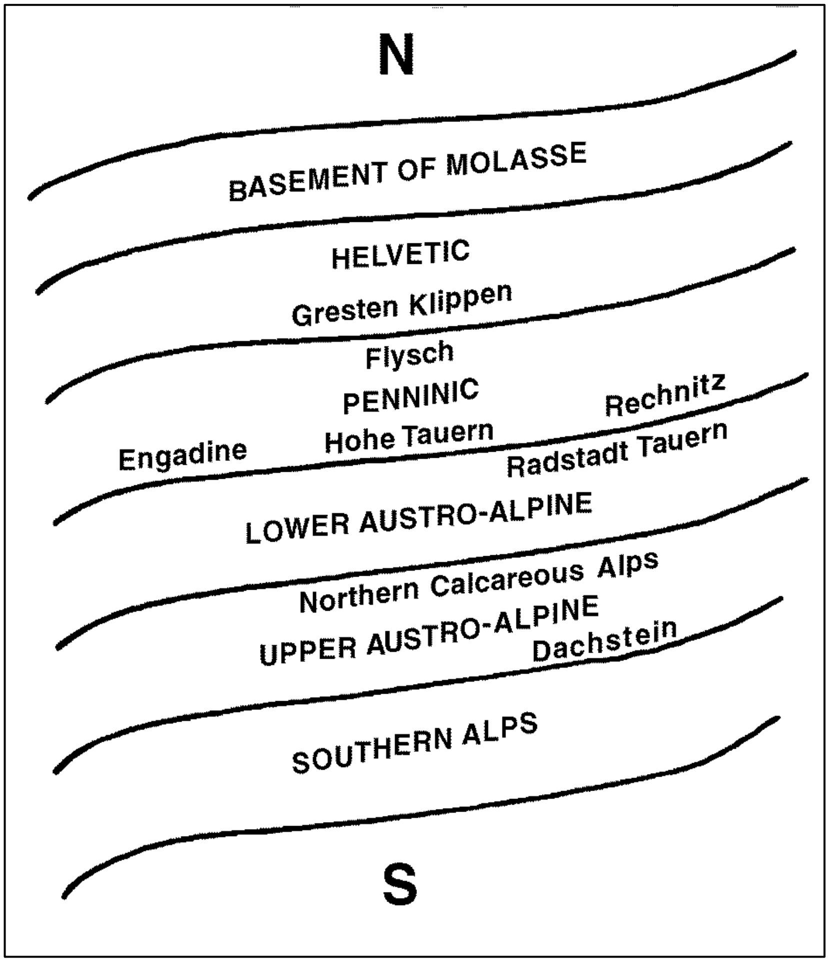


Figure 2. Eastern Alps; paleogeographic domains of the Mesozoic before Alpine orogenies.

CENTRAL AND WESTERN ALPS

The central and western Alps have much in common. The same general pattern of N-S compression found in the eastern Alps applies to them, except here the direction is generally NW-SE (central Alps) and E-W (western Alps). There is not as much overriding of the Austro-Alpine domain on more northerly domains, but the compression has resulted in a very complicated set of changes. The proposed arrangement of the original paleogeographic domains are illustrated in Figure 3. Note that the Valais, Briançonnais, and Piedmont domains are subdivisions of the Penninic which is also found in the eastern Alps.

By consulting Figure 1, you will see that some Austro-Alpine units such as the Dent-Blanche Nappe ("D.B.") are over the Penninic. Some nappes from the Penninic domain, like those now found in the Prealps, have moved north over the Helvetique domain. In some cases the basement of some nappes has been separated from the cover which has traveled north, and a new cover from further south has replaced the original cover over the basement by a process known as *cover substitution*. As an example, the Median Prealps nappes (now in the Prealps) are the original cover of the Penninic Grand Saint Bernard Nappe (G.S.B.) which remains further south and has a new cover (Fig. 31). Also of note is the move of the Ultrahelvetic domain from south of the Helvetic domain to the north of it. The changes which produced the central Alps have taken place mainly in the Cretaceous and Tertiary stratigraphic time periods of the geologic column (consult the stratigraphic column in the reference section of this guide if these terms are unfamiliar to you).

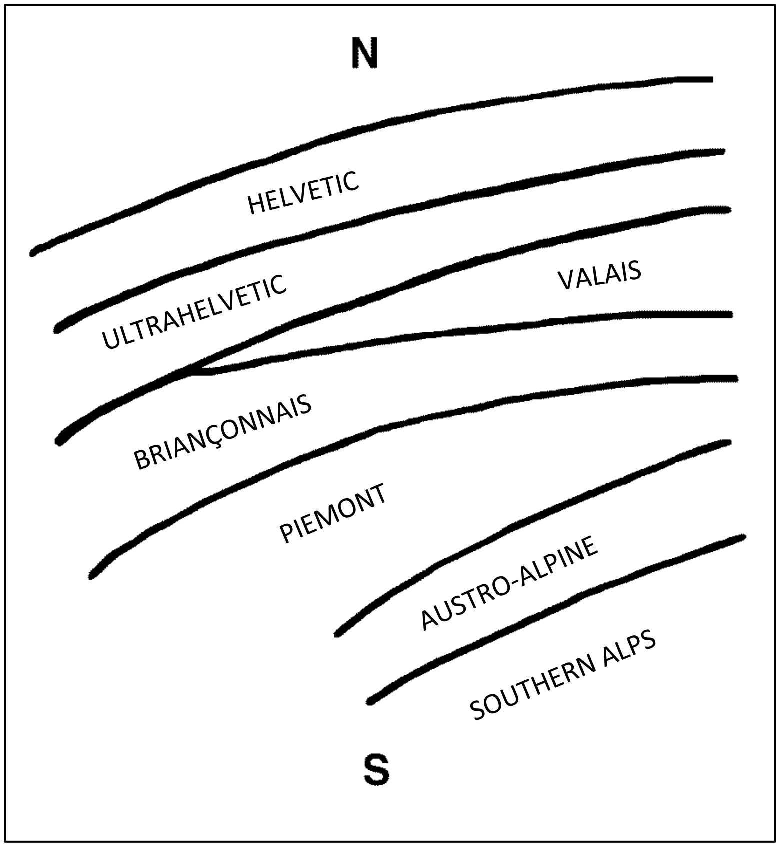


FIGURE 3. Central Alps; paleogeographic arrangement of the central Alps before the Alpine orogenies. The Valais, Briançonnais, and Piedmont domains are subdivisions of the Penninic paleogeographic domain.

MOLASSE BASIN

The basin north of the Alps from Geneva to Vienna (Fig. 1) is filled mainly with sandstones, conglomerates and other sediments from the Alps. These deposits, called molasse, are thickest near the Alps and thin out to the north. They may reach depths as great as 5000 m. The molasse closest to the Alps (S) is somewhat folded and thrusted and is called subalpine molasse, while further north one finds the more extensive planar non-folded molasse. Below the molasse is a Mesozoic cover over a crystalline basement. The molassic deposits are interpreted as alternating freshwater and marine deposits formed during the Oligocene and especially the Neogene.

JURA MOUNTAINS

While the Jura (Fig. 1) is not simple, it does not appear to be as complicated as the rest of the Alps. It seems to be mainly a case of NW-SE cover compression causing an epidermis type of thrusting and folding, the folds running in a NE-SW direction perpendicular to the direction of compression. The detachment level is in Triassic evaporites which are not exposed in the Jura but have been noted in oil- and gas well-drilling operations. Compression of this cover has caused an estimated 30% shortening. The Jura is divided into two main regions: the internal or folded Jura on the SE side which consists of many tight folds, and the external or tabular Jura which consists of larger flatter “folds” on the NW side. Further details will be discussed in the section dealing with the Jura field localities. The events forming the Jura are thought to have taken place from Oligocene into the Neogene.

A CREATION-FLOOD PERSPECTIVE

The biblical account of beginnings describes a recent creation by God in six days. Following this creation the wickedness of man became so great that God destroyed the earth with a worldwide flood, thus bringing about new beginnings. Within this context the flood would be the event that would bring about the formation of the Alps. Many of the processes accepted for the formation of the Alps can be included in a flood model. One major difference is the amount of time involved. Standard geologic interpretation suggests some 200,000,000 years, while the Bible suggests one year; however, many changes would be expected after that horrendous catastrophe. A suggested model is that the sedimentary layers which form the Alps were deposited before and during the early to the later stages of the flood, while the extensive compressive folding and erosional processes evident took place during the latter stages of the flood; and some changes continued for a significant time thereafter. It is of interest that there is no consensus in the geological community about how rapidly the Alpine changes occurred. Some propose catastrophic rates with long periods of quiescence between, some feel that the rates were quite variable, while others suggest only extremely slow continuous changes.

FIELD STOPS IN THE EASTERN ALPS SOUTH OF SALZBURG

PASS LUEG

LOCATION

Take the autobahn south from Salzburg for about 30 km to Golling exit. Go east toward Golling, and as you reach the town, turn south on the old highway going to Bischofschofen, etc.

FIGURE 4. View of three Lofer cyclothems just north of the tunnel at Pass Lueg.

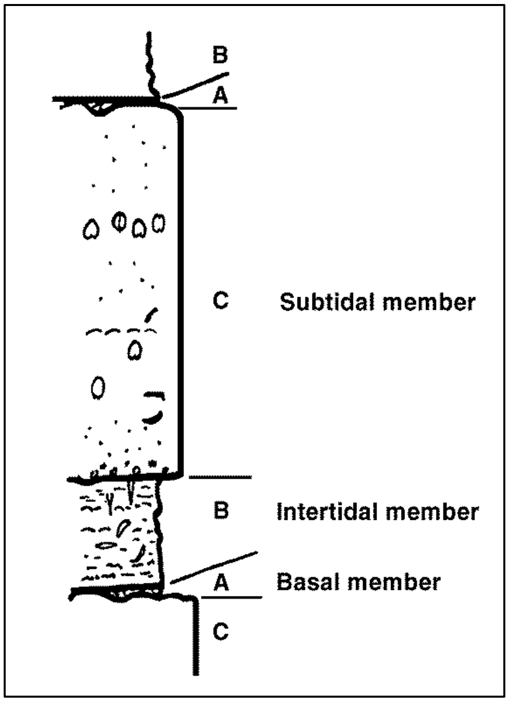


FIGURE 5. Dachstein limestone. Lofer cyclothem. Structures interpreted as follows: A — basal member of conglomerate with red or green matrix sometimes only in cavities. B — intertidal member consisting of fine laminated sediments, few fossils, algal mats, and desiccation features. C — subtidal member consisting of a more fossiliferous limestone including the large bivalve *Conchodus infraliasicus*, algae, other molluscs, and solution features. A complete cyclothem may vary in size up to several m.

About 3 km south of Golling is the Pass Lueg area. Across from the road to the large industrial plant north of the tunnel is a good exposure of the Dachstein limestone. Also north of the tunnel on the southwest side of the road are some fossils and glacial grooves on a sloped limestone surface near road level. The best fossils will be found by taking a trek down the "Klamm." The path starts above the tunnel. Look along the sides of the rocks near the lower parts of the gorge.

DESCRIPTION

The exposures of Lofer cyclothems (Fig. 4) are of the upper Austro-Alpine paleogeographic realm. More specifically these are interpreted as Triassic marine limestones of the Dachstein Formation. The layers which alternate between massive limestone and limy shale represent the Lofer facies. These sequences are said to represent cyclothems with the typical sequence illustrated in Figure 5.

As you examine the outcrops, you should note the following: massive limestone layers, shaley lime layers, relation of thickness of units, dipping of the bed, cracks, load casts on the underside of massive limestone layers (Fig. 6), fossils of a variety of molluscs, orientation and closure of the molluscs' shells. The fossils can be best studied in the areas exposing glacial polish (Fig. 7) and in the "Klamm" (Fig. 8).

FIGURE 6. View looking up at the underside of a C unit in a Lofer cyclothem. The numerous bulbous forms which project downwards are called load casts. Load casts are often associated with turbidites. One bulb would be around 10-20 cm in diameter.

A brief summary of the present interpretation by geologists is given in the following quotation from Matura and Summesberger (in Geological Survey of Austria 1980, p 149):

> *After Fischer the Dachstein formation comprises about 300 cycles, each representing a timespan of 20,000 to 100,000 years. For the whole formation of 1,000 to 1,500 m thickness a timespan of 15 million years is calculated. To explain the mechanism of the Lofer cycles Fischer assumed a periodical fluctuation of the sea level superimposing the general subsidence. After Zankl (1971) it is necessary to assume a third criterion to give a full explanation: current*

FIGURE 7. Exposed layers of the Dachstein Formation just north of the tunnel at Pass Lueg. In the lower left part of the figure, note the parallel grooves from glacial activity. Several good fossils can be found in this exposure.

FIGURE 8. Fossils of the bivalve *Conchodus infraliasicus* in the Dachstein Formation as seen in the "Klamm." The larger shells are about 10 cm long. Note that many of the shells are closed, indicating rapid burial while alive.

> *activity should be an additional factor for mass distribution and regular bedding, additional to general subsidence and low amplitude eustatic sea level changing.*

Satterley (1996) proposes a more local autocyclic process based on Ginsburg's (1971) model of accumulation (progradation) of sediments cyclically covering up their sources.

A CREATION-FLOOD PERSPECTIVE

It would seem that the mass distribution suggestion above is warranted. This could reflect catastrophic activity. Good preservation of large fossils (10 or more cm) would require fairly rapid burial. The fact that many of the bivalve fossils are closed (Fig. 8) suggests rapid burial before the animals had died. The load casts (Fig. 6) and some of the bedding sequences (Fig. 4) suggest a rapid turbidite type of deposition. The formation of Lofer cyclothems at a rate of 20,000 to 100,000 years each for a period of 15 million years would seem to require an unusual set of fortuitous circumstances. It would require that subsidence for 1000 to 1500 m proceed at such a uniform rate that the area of deposition be kept at the tidal-subtidal level for 15 million years. It would seem that other models should be considered.

VIEW OF THE TAUERN WINDOW

LOCATION

One can get a general view of a small portion of the Tauern Window by approaching it from the northeast on the road between Pass Lueg and Zell am See. Proceed southeast from Bischofshofen for about 16 km just to the east of the town of Schwarzach. If you want to examine closely the main kinds of rocks in the window, you can go west to Lend, south to Bad Hofgastein (schist layers), then to Badgastein (gneiss).

DESCRIPTION

The Tauern Window (See "Hohe Tauern" in Fig. 1) gives a good introduction to some of the dramatic changes that have taken place in the eastern Alps, and is a magnificent example of Alpine tectonics. As N-S compression has taken place, various units have slid over others.

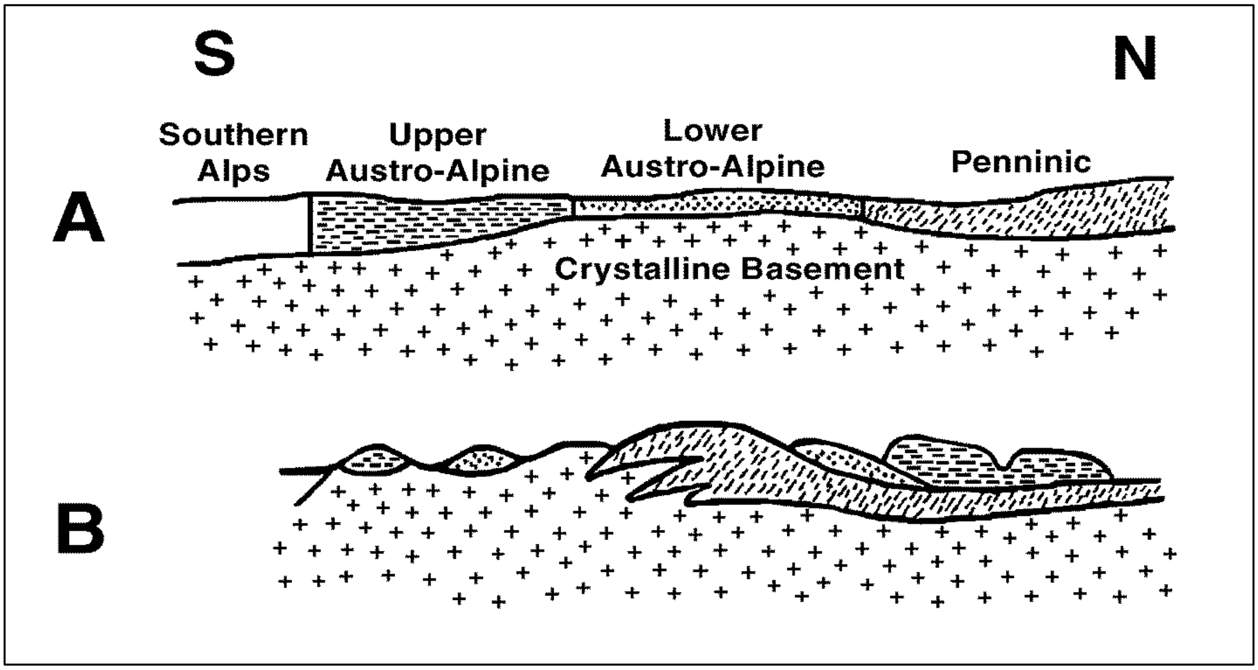


Figure 9. Generalized tectonic model for the formation of the eastern Alps. A, Mesozoic arrangement; B, present arrangement after the layers have been pushed to the north of A.

Occasionally orogeny and/or erosion has exposed some of the lower covered-up units in what are called “windows.” These exposures have provided strong support for lateral compression concepts of the Alps. The Tauern Window is the largest example of a tectonic window in the eastern Alps.

To understand the changes, you should study Figure 2 which illustrates the proposed arrangements of the regions (paleogeographic domains) before Alpine formation (Early Cretaceous). During the formation of the eastern Alps the lower Austro-Alpine domains ended over the Penninic (Pennine) zone, the upper Austro-Alpine zone ended even further to the north. The cross-sections in Figure 9 illustrate in a general way the changes envisioned. The window is illustrated by the Penninic exposed in the middle of Figure 9B. Figure 10 shows the view from Schwarzach.

As you look to the southwest from Schwarzach, the highest hill (in the far distance) to the right of the apparently higher hills in the foreground, is part of the Penninic paleogeographic domain, while the hills in the foreground are the Austro-Alpine “frame” of the window (Fig. 10). The layers forming the Austro-Alpine frame once covered the Penninic, but have been eroded, exposing the Pennine layers seen in the distance at the right ¼ in Figure 10. In other words, the oldest and normally lower Penninic layers pop up through the horizontal-lying Austro-Alpine frame of the window.

The geology of the Penninic Tauern Window is complex. In general there is an outer schist-like portion over a gneissic core. You can see these main kinds of rocks in road cuts near Bad Hofgastein (schist) and Badgastein (gneiss).

FIGURE 10. View to the east from the town of Schwarzach into the Tauern Window. The lower Penninic paleogeographic domain is now exposed in the peaks to the right of the picture. The hills in the left ¾ of the picture are of the Australo-Alpine paleogeographic domain. These Australo-Alpine layers, which were pushed over from the south (left), once covered the Penninic layers now seen in the peaks at the right. Their subsequent erosion exposed the lower Penninic layers, resulting in what is called a tectonic window.

VORDERER GOSAU LAKE AREA

LOCATION

Go to the town of Gosau, then south to the northwest end of Vorderer Gosau Lake.

DESCRIPTION

Gosau Lake is a glacial lake; the valley in which it lies has been carved out largely by glacial action. The northwest edge of the lake is a terminal glacial moraine. The surrounding hills are interpreted as a reef complex in the Triassic of the northern Austro-Alpine paleogeographic domain. Figure 11 gives the basic pattern of a reef.

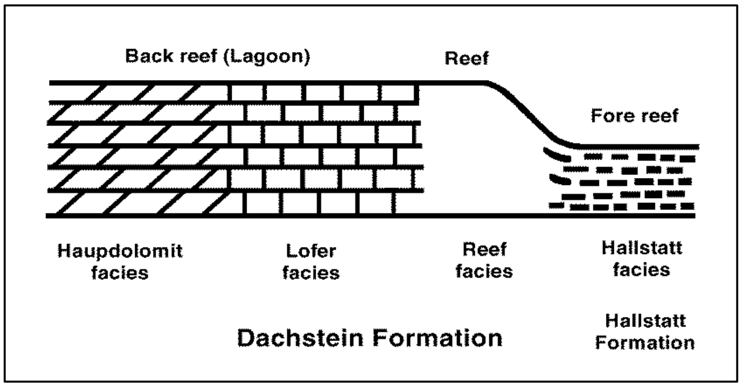


FIGURE 11. General structure of a reef and proposed original facies arrangement of a reef in the upper (northern) Austro-Alpine of the eastern Alps.

FIGURE 12. View of the massive reef (right) on the east side of Gosau Lake.

In this location you can get a view of what is considered one of the largest reef complexes of the Calcareous Alps of Austria. As you stand at the northwest end of the lake, on a clear day you can look south (toward the lake) at the high peaks of the Dachstein group. These layered carbonates represent the Lofer cyclothems of the backreef (lagoon). To the southwest (right) is the reef facies (Fig. 12) which nearly comes down to lake level. To the west (right and behind you as you face the lake) is the Hallstatt forereef facies.

On the southwest (right) side of the lake is a tallus slope which has some typical fossils from the reef facies. Fossils include mainly sponges (Fig. 13), coral, algae, and molluscs.

The tectonic relation of the Hallstatt facies to the Dachstein facies has been the subject of extended controversies. Some suggest major overthrusting, while others suggest minor changes from the present relationship. These models could greatly affect the degree of lateral (N-S) compression involved in the transport of the Northern Calcareous Alps which are estimated to be 1.5 – 5 times smaller, in a N-S direction, compared to the original paleogeographic domain. Regardless, it is agreed that the reef has been transported from a long distance from the south during the formation of the Alps.

FIGURE 13. A fossil sponge from the reef region at the north end of Gosau Lake. The sponge is the darker round object (near the middle of the picture) having a small light center and a darker filled-in crack cutting across it.

A CREATION-FLOOD PERSPECTIVE

Growing a reef this size would take many thousands of years, and this would preclude placing such a structure within the year of the Genesis flood. This Triassic reef lies in the middle of the geologic column with many layers of fossils below and many above. If this is a true reef which grew in its present location, it is a challenge to the biblical account of a recent, all-inclusive creation and the destruction of life during a one-year flood.

One could suggest that this reef grew between creation and the flood and was moved to its present location during the flood. Probably all geologists agree that the Dachstein Limestone, which contains this reef, was transported at least many dozens of kilometers from an ocean to the south.

A more likely creationistic explanation is that this is not a true reef. A true reef is formed by organisms producing a wave-resistant structure. As can be seen by examining the fossil-bearing rocks, there is an abundance of detritus (sediment) between the fossils. Detritus is not wave-resistant when laid down. If this was a true reef, it should be a solid mass of fossils including more reef-frame building and binding organisms such as coral (Fig. 43) and algae.

HALLSTATT SALT DEPOSIT

LOCATION

A good view of the region can be found at the south end of Hallstätter See. Several beach facilities provide convenient observation points.

DESCRIPTION

The Hallstätter lake is in a steep-walled, fjord-like valley. Looking to the northwest, one sees the town of Hallstatt. The salt deposits are above this town (see Figs. 14 and 15).

FIGURE 14. View to the west of Plassen Mountain showing the location of the salt deposits behind the town of Hallstatt. See Figures 15 and 18 for explanation.

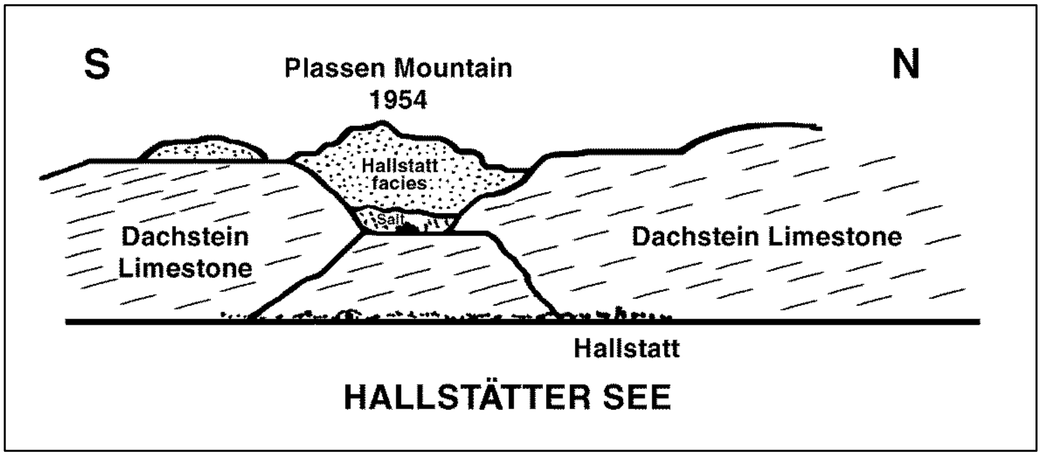


FIGURE 15. Diagram interpreting the region around Plassen Mountain.

The salt comes from the Upper Permian "Haselgebirge" beds at the base(?) of the Triassic Hallstatt deposits. This layer is a combination of salt, gypsum, anhydrite, clay, dolomite, some volcanic rocks, etc. It is an important sliding horizon in the Northern Calcareous Alps and is considered to be part of the famous Zechstein salt deposits which are widespread in northwestern Europe. Usually the salt is layered and mixed with clay (Figs. 16 and 17).

FIGURE 16. Close-up view of light-colored salt and darker surrounding clay and other minerals. The photo from the Bad Ischl salt mine is about ½ m across.

FIGURE 17. Close-up view of lighter salt and darker clay layers from the purer salt deposits. Note the offset of layers due to movement of the deposit. Photo from the Bad Ischl salt mine is about ½ m across.

The origin of the salt is assumed to be by evaporation of seawater. Under normal conditions this process would take considerable time. Origin by transport from another "original" salt locality would not take so long. Obviously some transport is implied in the local deposits as the salt includes huge blocks of entrained limestone and schists (Fig. 18). How it has come to its present location, i.e., from above or below, is a disputed point. All agree that there has been some transport.

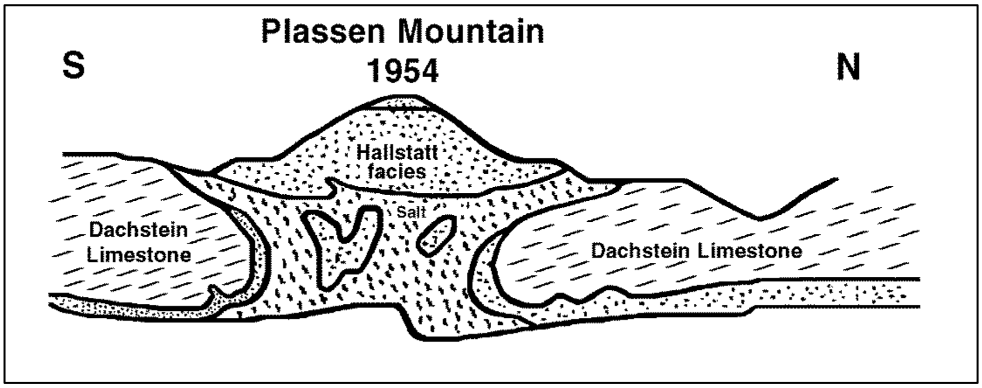


FIGURE 18. Section in the region of Plassen Mountain showing the Hallstatt Salt Deposit. The top of the peak has been interpreted as a Jurassic reef. Note the large inclusions in the salt mass.

This is a convenient place to point out the distinction between geography, paleogeography, tectonics, and stratigraphy. Geographically you are near Hallstatt; paleogeographically this is the original upper Austro-Alpine domain that was originally much further south (see Fig. 2); tectonically according to the classic model the Dachstein facies is the Upper Juvavicum tectonic unit or sheet, while the Hallstatt facies is the Lower Juvavicum; stratigraphically the Dachstein Limestone is Triassic, while Plassen Mountain represents a sequence from Permian (salt) to Upper Jurassic (Malm) at the top. The upper part of Plassen Mountain has been interpreted as a reef limestone.

Salt has been mined here for 3000 years. The local deposit is about 50-60% salt. Salt has been leached out from the sediments at the mountain surface. The mine shafts go down about 700 m to 12 horizons. There are 32 km of tunnels and shafts in the mine. Solution mining, where water is used to dissolve the salt, is employed at present. The saturated brine is piped 40 km to Ebensee where it is evaporated to extract the salt.

A CREATION-FLOOD PERSPECTIVE

The serious question between creation and non-creation interpretations is the amount of time involved in the evaporation of seawater to produce all the salt. Alternatives would include methods of depositing the salt rapidly such as transport from an original primordial salt source during the Genesis flood, or formation of salt from hot brines as has been reported from the deep ocean. These possibilities need further investigation.

STEINPLATTE REEF

LOCATION

On a clear day the reef can be viewed at a distance from all the region around the town of Waindring. A convenient place is to look to the northeast along Highway 312, 3 km west of the west connector road to Waindring.

DESCRIPTION

The Steinplatte Reef is a famous classic example of a Triassic reef of the Upper Austro-Alpine paleogeographic realm. It forms a dramatic limestone cap in the High Calcareous Alps of western Austria. As viewed from the west, the main cliff of exposed limestone at the top of the hill (Fig. 19) represents the forereef (Fig. 11), the reef core lying behind and on top of this cliff. The reef has been studied for over a century. Fossils are not scarce, but do not present a convincing picture of a defined reef structure. There have been at least 3 major studies giving different identifications for the various parts of the reef (Piller 1981).

A CREATION-FLOOD PERSPECTIVE

As mentioned for the reef at Gosau Lake, the presence of a reef such as this in the middle of the geologic column presents a major challenge to the biblical creation-flood model. However, the lack of a well-defined reef structure can suggest that this is not a real reef, but represents sedimentary deposition during the flood. A non-creationist geologist (Stanton 1988) recently studied the reef and pointed out the lack of a skeletal frame of organisms necessary to build a wave-resistant true reef. He characterized the so-called Steinplatte Reef as a "sandpile" and commented further that "The Steinplatte is not an ecological reef nor is it easily considered a reef by any other definition." Satterley (1994) agrees. A "sandpile" could be deposited rapidly during a flood. This reflects some of the problems of identifying ancient reefs.

FIGURE 19. The Steinplatte Reef as viewed from the west. The pale limestone cliff at the top (partially covered with clouds) represents what is considered to be the forereef.

FIELD STOPS IN CENTRAL SWITZERLAND

VARVES IN THE WALENSEE

LOCATION

The Walensee can be seen anywhere along the Swiss Route N3 which runs south of the Walensee. The varves are not that easily found, because they lie on the bottom of the lake.

FIGURE 20. View of the Walensee. The high hills in the distance are part of the Cretaceous Säntis-Drusberg Nappe.

A CREATION-FLOOD PERSPECTIVE

One of the challenges to creation is the presence in lake deposits of many thousands of thin layers less than one mm in thickness called varves. A single varve is thought to have been deposited in one year, as determined by seasonal factors. Hence, when one finds 13,000 varves in some European lakes, this suggests a timeframe beyond the few thousands of years with which many creationists are comfortable. In addition, the Green River Formation in the northwest United States has some 5 million layers which have been interpreted as varves, but this is most likely a precipitation process and not the kind of transport feature found in the Walensee (Fig. 20). A recent study (Lambert and Hsü 1979) of the rate of formation of "varves" in the Walensee indicates that the average rate of formation is greater than 2 per year; sometimes as many as 5 per year were produced. It appears that each major storm may produce a layer that can be interpreted as a varve. The same report suggests that the varves in Lake Zurich are annual, but this is questioned (Giovanoli 1979). The question of the annuality of varves is complex. Associated scientific literature dealing with this topic is extensive.

THE GLARUS OVERTHRUST

LOCATION

Take the road south from Glarus to Schwanden. Just north of Schwanden, take the road going southeast to Elm for almost 2 km. After you leave the last group of houses on the west side, you will find a small parking area on the right where you should stop. Walk back about 100 m to steps and a path up the hill to the east. The Glarus overthrust view is in the forest east of the path.

DESCRIPTION

This is probably Switzerland's most famous geologic feature which gave birth to the "outrageous" concept of large-scale movement in the Alps. The relationship is better exposed elsewhere but not as accessible.

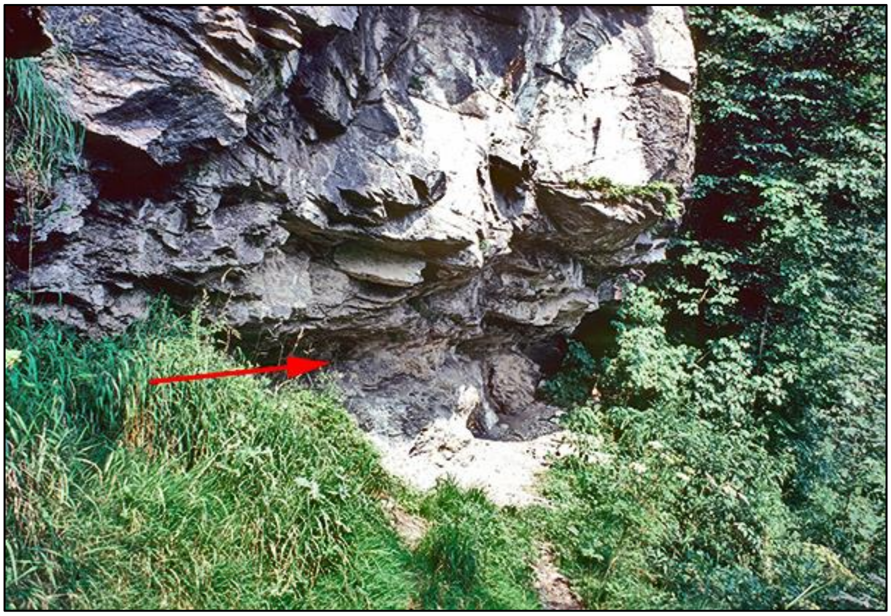


FIGURE 21. Thrust fault contact between the Eocene flysch (below) and the Permian Verrucano (above) near Schwanden. The arrow points to the fine contact line.

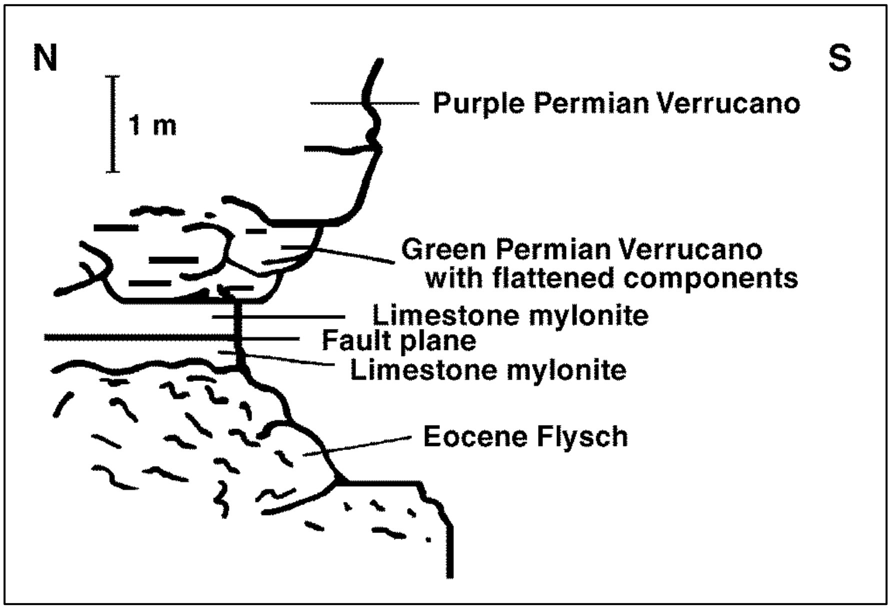


FIGURE 22. Interpretation of the units seen in the vicinity of Figure 21.

Here are layers in a different sequence than is normally found elsewhere. The difference is explained on the basis of widespread (25 x 50 km area) overthrusting of older layers over younger ones. Arnold Escher, who discovered this in 1840 but did not publish his find, once told his student Albert Heim, "No one would believe me; they would put me into an asylum." The concept was eventually accepted and was applied to much of the Alps.

The arrangement at this location is given in Figures 21 and 22.

Here the Permian Verrucano is *above* the Eocene flysch with a thin, fine-grained limestone mylonite (formed by grinding) between. According to the stratigraphic column and also according to the arrangement in other localities such as east of the Wallensee, this is reversed and is explained on the basis of a widespread thrust of the Permian Verrucano over the Eocene flysch. The limestone mylonite (Lochseiten Limestone) is usually only a few centimeters to meters thick. Across the valley note the disturbed Eocene flysch in the stream bed.

A CREATION-FLOOD PERSPECTIVE

This is one of the examples used by some creationists to point out the invalidity of the fossil sequence and the geologic column, because the Permian is over the Eocene. However, because of the obvious evidence for movement here, this is not a good argument. Perhaps this locality illustrates the abundance of movement that would be expected during the Genesis flood. There are other creationistic explanations for the normal order of fossil sequence.

ZUG 1887 CATASTROPHE

LOCATION

The site of the catastrophe is at the northeast end of the Zuger See in the town of Zug along the lake at Vorstadt street.

DESCRIPTION

This celebrated flow of 1887 has been carefully studied and is significant both as an example of catastrophism and of a turbidity type of flow.

FIGURE 23. Town of Zug after the 1887 catastrophe.

The city of Zug is built in part on the unconsolidated sands of an old delta. The shoreline along this old delta was being extended and a retaining wall was built. Cracks appeared in the new landfill, but work was continued until 5 July 1887, when two underwater slides terminated the project. At 15:35 two houses and a section of sea wall sank suddenly into the lake. Seven lives were lost. At 18:50 a great commotion was noted in the lake — later interpreted to be the foundering of older lake sediment under the load of new sediments. At 18:55 strip after strip of land on the shore subsided so that an area extending 150 m along the shore and 80 m inland had sunk 7-8 m, destroying more houses (Figs. 23 and 24). About half of the sunken area was old land.

A subsequent study including 3200 soundings in the lake showed two extensive mudslides originating from the shore. They were estimated to have traveled several meters per second. The first flow was broader, extending about 0.5 km into the lake; a second one was 200-250 m broad, extended more than 1 km, and up 4 m thick. This second flow eroded a trench in the first flow. The average slope was 4.4%. The volume of material displaced was estimated at 150,000 m3. While this example illustrates how sediments can be distributed underwater quite rapidly, much larger and more rapid underwater mudflows have been recorded.

FIGURE 24. Town of Zug about a century after the 1887 catastrophe. Note some of the same church steeples on the far side of the lake.

MYTHEN KLIPPEN

LOCATION

These impressive steep mountains are located northeast of the town of Schwyz and can readily be observed from many places around the towns of Seewen, Schwyz, or Ibach.

DESCRIPTION

The Mythen (Mithen) are the best publicized example of outliers in the Alps. Their jagged topography is in sharp contrast to the soft hills of Ultrahelvetic flysch on which they lie. The stratigraphic sequence is out of order with the Mesozoic Klippen lying on top of Tertiary Eocene flysch which in turn covers other Mesozoic formations. The out-of-order sequence is explained on the basis of transport of a Mesozoic nappe fold(s) over the Tertiary flysch. The position of Grosser mythen over part of Kleiner Mythen (Fig. 26) indicates some transport.

The origin of the Mythen has been a matter of conjecture. Some older interpretations include: 1) the suggestion that the younger, lower layers are only plastered around the base and not below; 2) the possibility that the Mythen rose like a plug from below, with steep faults around the base; and 3) the interpretation of the old age for the Mythen layers based on fossils is incorrect.

FIGURE 25. Looking east into the Mythen Klippen near Schwyz.

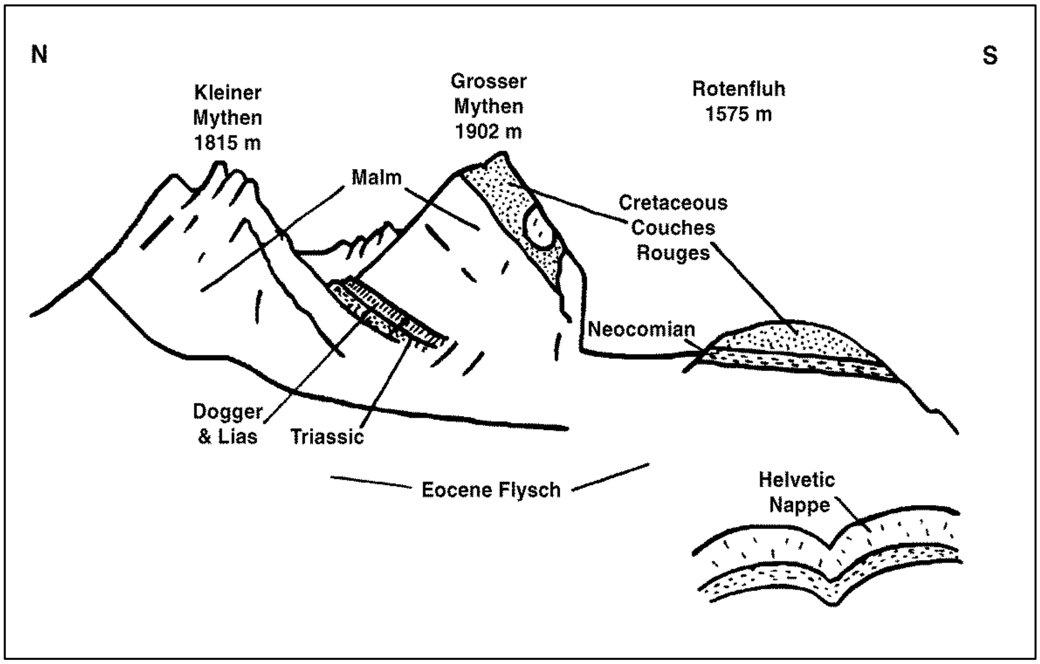


FIGURE 26. Identification of the geologic layers in the Mythen.

It is now accepted that they represent transported sedimentary layers, but their origin (i.e., previous location) is puzzling. The facies of the layers do not match at all that of the Helvetide folds (Wildhorn or Säntis-Drusberg Nappe) found below and to the south (Fig. 26) and could not have the same source. Some have postulated that they might have come from the higher Austrides (Africa?) but this is often doubted. There are facies affinities between the Mythen and the Sulzfluh Nappe of the Graubünden of east Switzerland and also the Median Prealps nappes to the west. They probably came from the south from a similar source.

The Mythen are interpreted as erosional remnants of a widespread nappe. Why they should have been spared from erosional factors while most of the rest of the nappe in this region has been removed is no doubt related to the question of their origin. It does not appear that ordinary weathering would remove most of a nappe and leave a few conspicuous isolated remnants. A slow process of rock weathering would not be expected to spare the Mythen. Weather fronts over long ages would not always skip over where the Mythen were to remain. Glaciation and river runoff would produce more localized erosion, but to leave such extremely isolated blocks seems odd for any normal process. One also wonders if the Mythen could not have been transported as isolated blocks to their present position.

A CREATION-FLOOD PERSPECTIVE

The whitish, round block of Malm in the Cretaceous Couches Rouges near the top of the Grosser Mythen (Figs. 25 and 26, right peak) can raise the question of the competence of the Malm limestone for recycling during the flood. Why should it already be hard enough to be transported as a mass? For some suggested answers, see the discussion below for the wildflysch of Chantemerle.

MOUNT PILATUS

LOCATION

Mount Pilatus is located south of the town of Lucerne. A good view of the fold structure can be obtained by going to the town of Alpanach-Stad and taking the cog railroad to the Esel. Hike up to the peak of the Esel above the station.

DESCRIPTION

Mount Pilatus gets its name from its fractured appearance and its reputation as a locale for angry storms. One of the legends purports that Pontius Pilate, after delivering Christ to the Jews, was cast into prison by the Roman Emperor Tiberius. There he took his life. His body produced storms wherever it was taken — including Mount Pilatus, where it caused terrific devastation.

FIGURE 27. View to the east (right) as one ascends Pilatus. Note the near-vertical layers of rock in the left side of the picture.

Local laws prohibiting access are reported for 1469, 1564, and 1578 A.D., indicating the fear and respect for the mountain.

On the way up the cog railroad, note the finer flysch sediments at the base, blocky limestone up higher. On the east (right as you face the direction of travel) note some very steep layers (Fig. 27). Higher up, take a good look to the west to the high peak called Matthorn (Fig. 28) and note the contorted layers. These were originally deposited in a horizontal or near-horizontal position.

FIGURE 28. View to the west (left) near the top of Pilatus. Note the very contorted layers. sliding was from the south (left of picture).

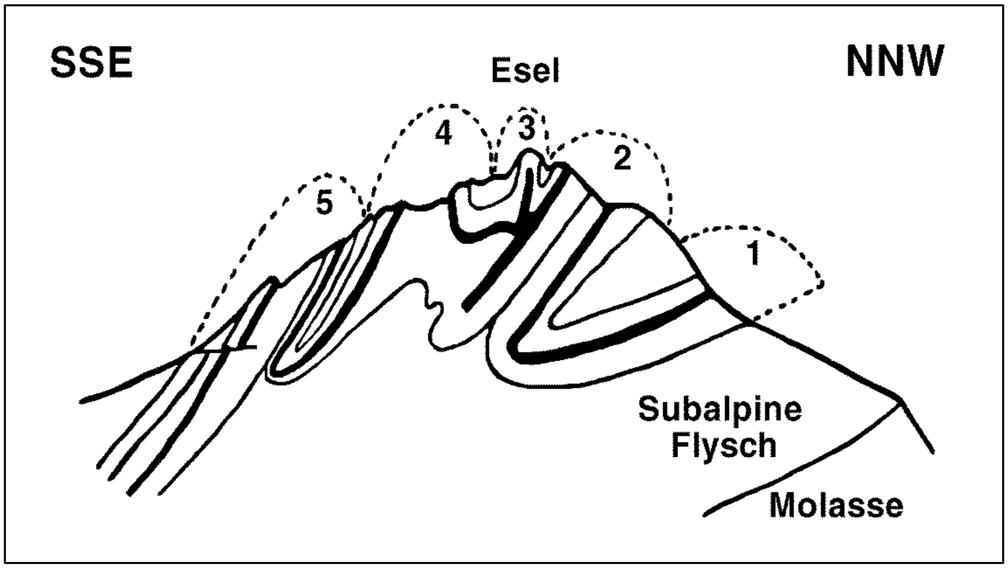


FIGURE 29. Section through Pilatus in the region of the Esel showing five folds forming the "breakers" at the nappe front. The nappe (probably the Wildhorn Nappe) came from the south (left).

From the top of the Esel, view the contorted nature of the structure of Pilatus. The layers you see are almost all Cretaceous. This is a good example of the breakers at the foot of the nappes; in this case probably the Helvetide Wildhorn Nappe. The usual folded structure common at the foot of nappes is in contrast to the generally flat nature of nappes and is used to support the concept of gravity tectonics, instead of a push from behind which would tend to contort the entire nappe. This contorted nature can be contrasted to the much-flatter Permian Verrucano seen south of Glarus which is not at the front of the nappe.

The chaotic nature of the layers seen here has more order than is at first apparent. Figure 29 illustrates a set of five partially eroded folds (nappes) found in Pilatus. These folds are interpreted as the result of gravity sliding from the south. As the nappe slid down from the south, the frontal portion became folded (crumpled) into five folds as it met resistance in the region of Mount Pilatus.

The Esel is fold 3, Matthorn to the southwest is fold 5, while Tomlishorn beyond the hotel to the east is fold 2. To the east, projecting into Lake Lucerne, is Bürgenstock which is a continuation of the formations of Pilatus. To the southeast is Stanserhorn and beyond is Buochserhorn which, like the Mythen, are klippen (outliers) of the Median Prealps type. Rigi to the northeast across the lake is composed of uplifted molasse. The eastern Alps are to the east and the Bernese Alps to the southwest. On a very clear day you can see the Jura to the northwest.

A CREATION-FLOOD PERSPECTIVE

The concept that the Alps were formed by slow thrusting from the south would challenge any rapid flood event. The presence of breakers (folds) at the foot of the nappes favors gravity sliding tectonics which can occur rapidly. The breakers at the front of the nappes are a common feature of the Alpine nappes. That nappes should be moved around by gravity suggests conditions in the past quite different from the present. At present, gravity sliding of such dimensions has not been noted. The near-vertical layers on Pilatus seem stable. The breakers are evidence for catastrophism.

FIELD STOPS IN THE VALLEY OF THE RHÔNE

WILDFLYSCH OF CHANTEMERLE AND THE OVERLYING GURNIGEL NAPPE

LOCATION

From the Vevey autobahn exit (east end of Lake Geneva) go east through Blonay towards La Chanaz. When you reach high electric power lines, take the road to Chantemerle. The wildflysch is exposed in the roadcut to the left just before you reach the "Chemin du Poyet" sign. To reach the Fayaux Quarry in the Gurnigel Nappe, follow the road to Les Pléiades, turn right in Alliaz. The quarry will be on the left. Get permission to enter the quarry.

DESCRIPTION

You are in the north part of the Prealps (see Fig. 1). The Prealps have come from at least dozens of kilometers to the south. Study Figure 31 and note the Prealps to the north. On the lower part of the same figure, note the proposed domain of origin of the various Prealp units, some very much to the south. The Prealps are composed of at least 7 allochthonous units (not all indicated on the colored diagram) assumed to have traveled north during Eocene-Oligocene with subsequent deformation during the Neogene.

The wildflysch of Chantemerle is exposed at this field locality (Fig. 30). It lies at the base of the Gurnigel Flysch (Fig. 31) and rests on Ultra Helvetic nappes which in turn rest on molasse. It is assumed to have formed by gravity sliding of clasts ahead of the advancing allochthon. Wildflysch is characterized by having large inclusion (sometimes up to 2 km) that are often associated with catastrophic conditions. It is probably found between all the nappes of the Prealps and is interpreted as a subaqueous oceanic deposit. This is in contrast to the contact between the Helvetic nappes (see Wildhorn and Diablerets Nappes on Fig. 31), which is mylonitic (from grinding) and considered more dry.

FIGURE 30. Wildflysch of Chantemerle. Note the backpack in the lower right corner for scale. Many inclusions can be seen, including a large one which fills the center of the picture.

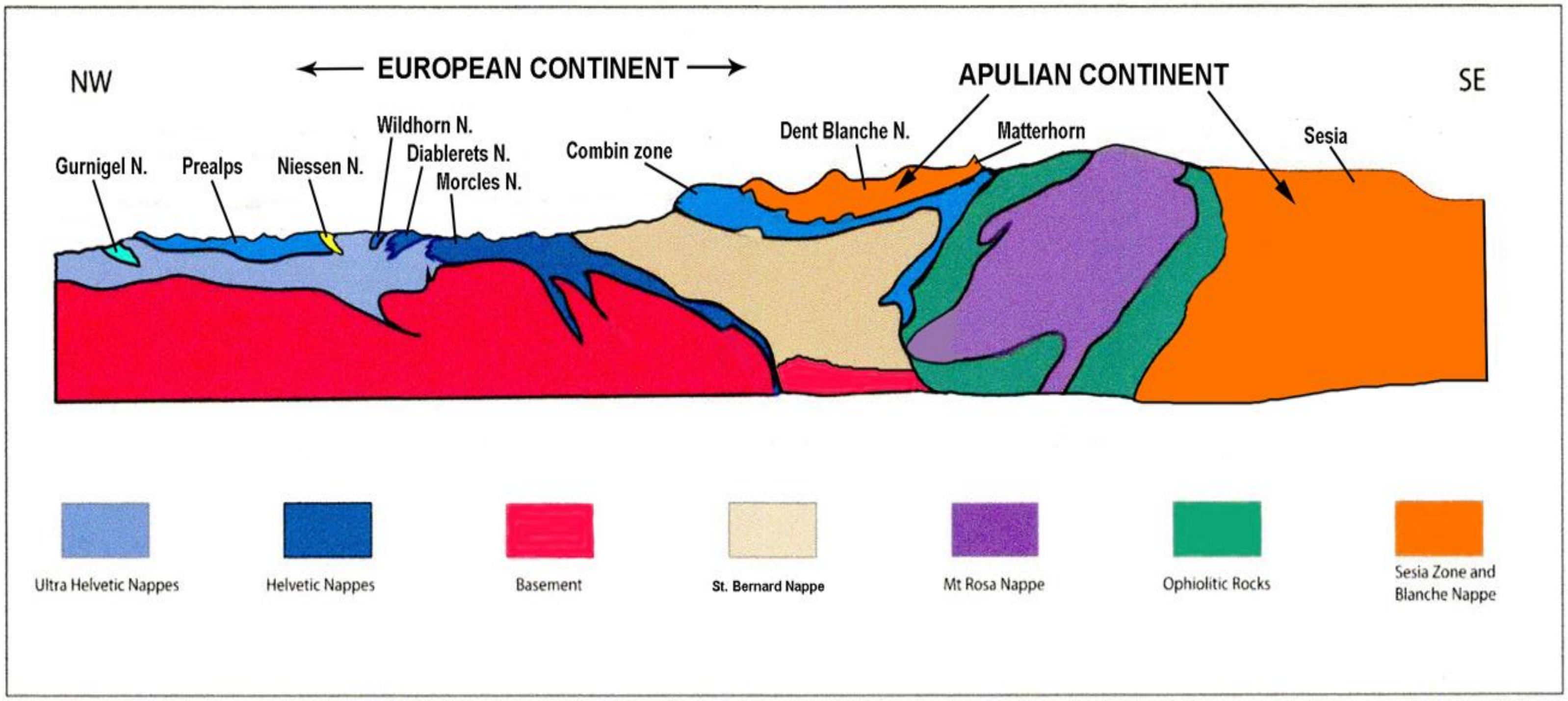


FIGURE 31. General cross section through the Central Alps. Not to scale.

Page intentionally left blank

Examine the wildflysch for inclusions. These originate from Helvetique, Ultrahelvetique, and Penninic paleogeographic domains and are of Jurassic to Eocene stratigraphic divisions. These are deformed (note direction of flattening) but must have had some competence at the time of accumulation. Look for joints in the deposit. The overthrust of the Gurnigel Nappe above would produce considerable deformation pressure.

The Gurnigel Nappe itself is a flysch with abundant turbidites (Fig. 32). It can be examined at the Fayaux Quarry above this locality. The nappe is an isoclinal slice with a thickness of 1600 m, assumed to have been originally deposited in a deep oceanic environment below the carbonate compensation depth in Late Cretaceous to Lower Paleocene time in the Penninic paleogeographic domain. It was transported north during Eocene-Oligocene epochs leaving some traces above the Median Prealps which in turn overthrust the Gurnigel Nappe during the Neogene.

FIGURE 32. The Fayaux Quarry exposes many turbidites of the Gurnigel Nappe. Each light-colored layer is part of a turbidite. Note people for scale.

A CREATION-FLOOD PERSPECTIVE

The competence of fossil-bearing clasts (inclusions) in the wildflysch of Chantemerle suggests induration of the original source from which they were derived, being recycled into the wildflysch. The presence of hard inclusions from other nappes has been suggested as a problem for a flood model, as time would be required to harden the sediments forming the inclusions which might not harden in a year. However, cementation can occur rapidly, especially under high pressure, and the inclusions may not have been completely indurated. Also, soft nappes could contain large, hard inclusions formed before the flood. Both soft and hard components could originate from the same general preflood source area of a nappe. Transport systems do not preclude moving both soft and indurated components. In transport a mixed source or selected breakdown during transport would be expected to produce mixed deposits unless factors favoring sorting dominated.

NIESEN NAPPE AT LE SÉPEY

LOCATION

From Aigle take the road to the northeast towards Les Mosses. Just beyond the town of Le Sépey stop at the junction of the road to Les Mosses and Col du Pillon. Good turbidites can be found at the beginning of the roadcut of the road to Les Mosses.

DESCRIPTION

You are at an overturned section of the Niesen Nappe (see Fig. 31). To the east from the junction (towards Col du Pillon) you will note some massive coarse Middle Jurassic limestone layers on the north side of the road. A few ammonites have been reported here. To the west from the junction (up the road towards Les Mosses) are Late Cretaceous turbidites and debris flows. They are well developed at the section of the roadcut, up from the junction (Fig. 33).

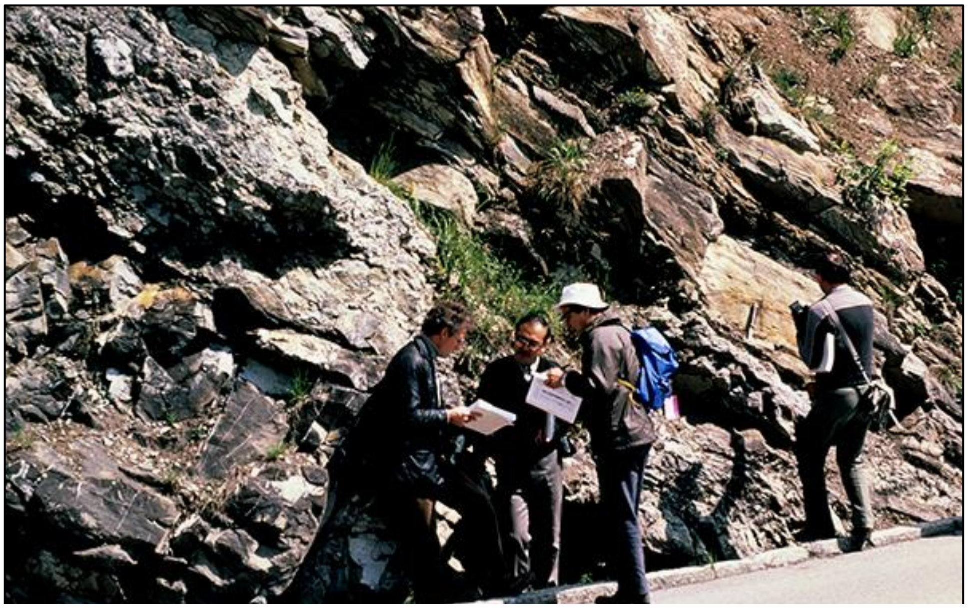


FIGURE 33. Turbidites and debris flows of the Niessen Nappe above the town of Le Sépey.

Examine this outcrop for turbidites (finer sediments) (Fig. 34) and debris flows (coarse clasts in a fine matrix). The turbidites have an exceptionally well-developed Bouma sequence. Study the sequence in Figure 35 and compare to the outcrop.

Since this is an overturned section, the sequence will be bottom-side up with the A unit on top instead of the bottom. Also examine the debris flow which probably formed quite rapidly. Blocks with a diameter of 14 m have been described in this nappe.

A CREATION-FLOOD PERSPECTIVE

The Niesen Nappe is interpreted as having been deposited at the base of a steep scarp in the ocean below the carbonate compensation level. It contains an abundance of coarse, terrigenous conglomerates and turbidites. An upper conglomerate in the nappe is believed to have been

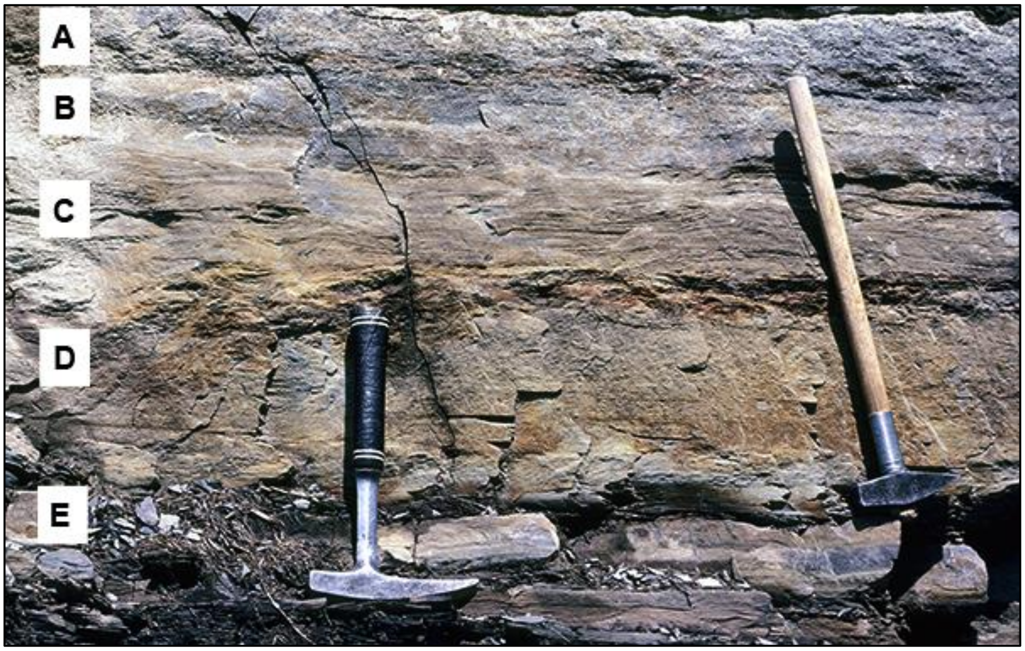
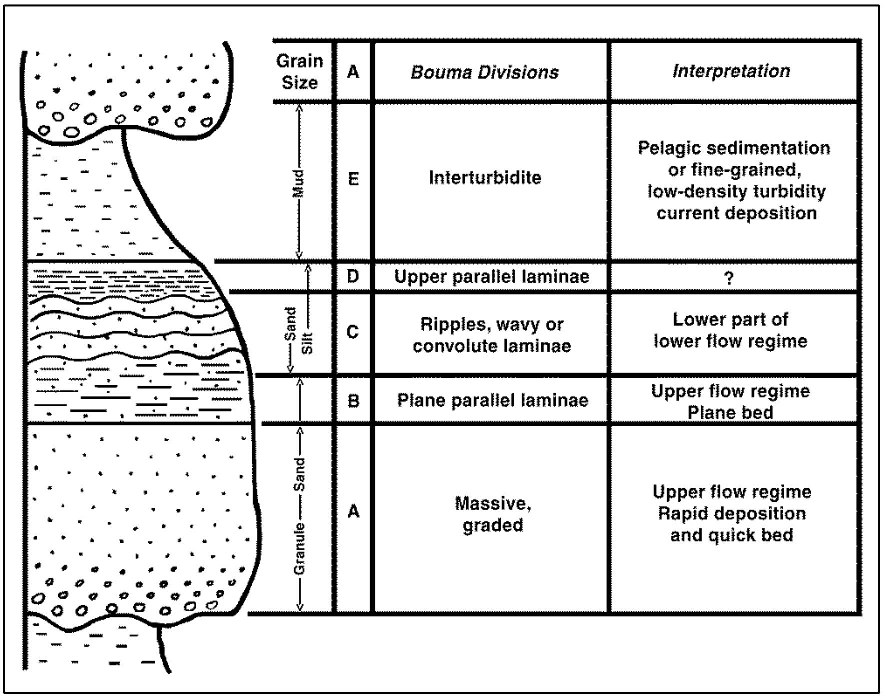


FIGURE 34. View of a single turbidite at Le Sépey. The letters identify the various units of the Bouma sequence (see Fig. 35). Note that the order of the units is reversed, because at this locality the Niesen Nappe is reversed.



Grain Size	A	*Bouma Divisions*	*Interpretation*
Mud	E	Interturbidite	Pelagic sedimentation or fine-grained, low-density turbidity current deposition
Sand Silt	D	Upper parallel laminae	?
	C	Ripples, wavy or convolute laminae	Lower part of lower flow regime
	B	Plane parallel laminae	Upper flow regime Plane bed
Granule —— Sand	A	Massive, graded	Upper flow regime Rapid deposition and quick bed

FIGURE 35. Bouma sequence of structures in a complete turdibite bed. (Modified from Middleton and Bouma 1973).

deposited by sheet flow. In other localities the nappe reaches thicknesses of more than 1000 m. The nappe gives evidences of an abundance of rapid, underwater deposition, and current interpretations fit well with a creation-flood model.

RELATIONSHIP OF NAPPES AT COL DE LA CROIX

LOCATION

Take the road towards Col du Pillon. At the town of Les Diablerets go south to the Col de la Croix. At the Col a small hill northwest of the parking area offers a good panorama to the northeast. Conspicuously eroded gypsum deposits are seen if you climb to the east of the parking lot.

DESCRIPTION

Figure 36 depicts the view to the east, and Figure 37 will help identify the major structural features. The extensive valley ahead of you is the Zone des Cols. It consists of marls, shales, and evaporites which are less competent than the rocks forming the hills to the sides. These marls, shales, and evaporites (gypsum) are easily eroded; hence, the valley. To the north is the Niesen Nappe; we are standing on the Ultrahelvetic Bex Nappe. To the east and southeast are the Diablerets and Wildhorn Nappes (Fig. 37). Note that the Wildhorn overrides the Diablerets. Also note the contorted frontal folds in these nappes. The third Helvetic nappe — the Morcles Nappe — is not exposed here. Some of the Triassic gypsum of the Bex Nappe is dramatically eroded to the east of the parking area. Rock salt is mined from the same evaporite source at the town of Bex to the southwest in the valley of the Rhône.

FIGURE 36. View to the east from Col de la Croix. See Fig. 37 for a geologic interpretation.

This is a good place to consider a general model for the formation of this part of the Alps. You should consult Figure 31 to understand the relationship. On the upper diagram note the line near the top delineating the present skyline. Compare the proposed original position in the legend below of the Helvetic nappes (Morcles, Diablerets, and Wildhorn), Ultrahelvetic nappes, and Niesen Nappe to their present position.

The following "classic" scenario is proposed but disputed:

1. Uplift of the Ultrahelvetic nappes and sliding of these to the northwest during Upper Eocene or Lower Oligocene. The process of gravity sliding caused what is called diverticulation of the Ultrahelvetic nappes where their order was reversed — the "originally" highest ones sliding down first and being covered later by originally lower ones as further sliding proceeded; thus, a reversal.

2. Uplift and folding of the Helvetic nappes forming the Morcles, Diablerets, and Wildhorn nappes. This is also thought to have occurred in Upper Eocene to Lower Oligocene.

3. Uplift of the Aiguilles Rouge and Mt. Blanc basement massifs (A.R. and M.B. on Figs. 1 and 31) during Upper Miocene and Pliocene causing further sliding of the Helvetic and Ultrahelvetic nappes to the north.

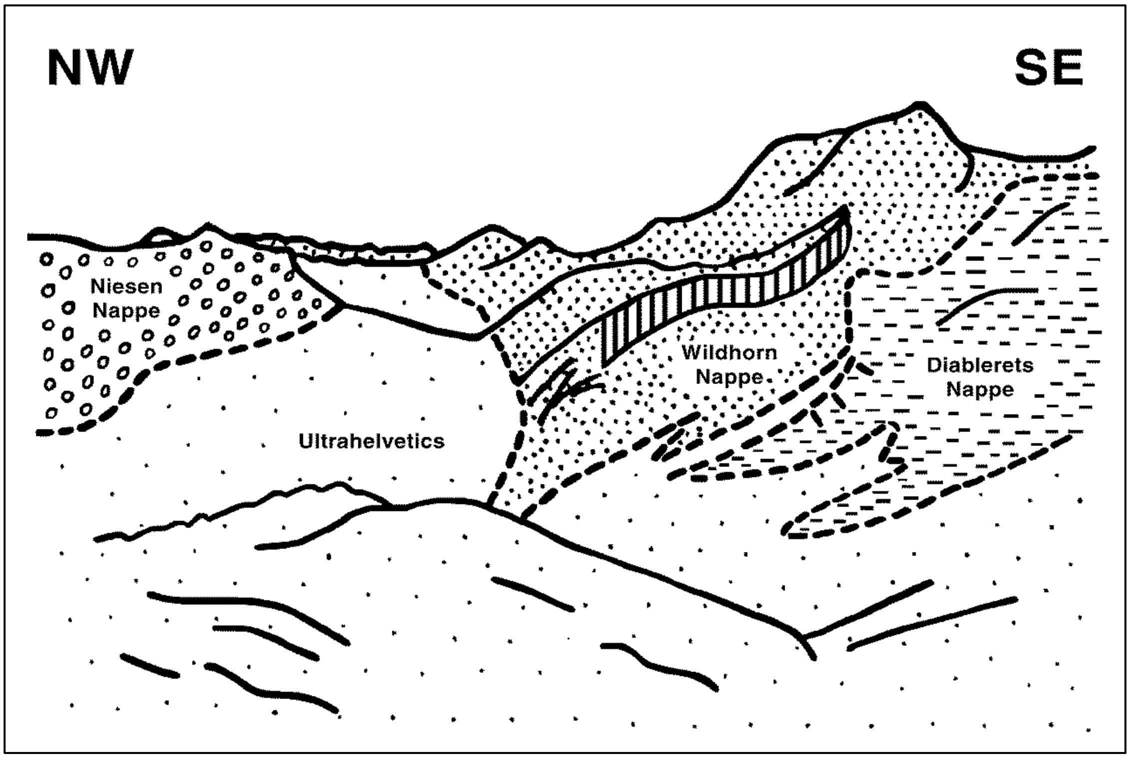


FIGURE 37. Interpretation of the view to the east from the Col de la Croix showing the relationship of the Ultrahelvetic, Niesen, Wildhorn, and Diablerets Nappes. (Modified from Matter et al., in Schweizerische Geologische Kommission 1980, p 272).

GLACIAL ERRATIC NEAR MONTHEY

LOCATION

From the town of Monthey take the road up the hill to the west towards Morgins. Stop at the large hospital. The object of our search is the rock just beyond the north end of the main hospital building. A house has been built on it.

DESCRIPTION

The famous Pierre des Marmettes (Fig. 38) is a glacial erratic, one of several such around this region. It was brought here by the movement of ice when the valley was glaciated. It is composed of Mt. Blanc granite which is not found near this region, and obviously had to be transported for many kilometers. A glacier would be the most likely prospect for performing such a move. The rock, which has an estimated volume of 1824 m^{3,} was described in 1841 by J. de Charpentier who enjoyed showing it to those of his friends who did not believe in glaciation. It is said to have been brought here during the later stages of the Wurm (latest) glaciation.

FIGURE 38. The glacial erratic Pierre des Marmettes. Note the house on top.

On a clear day a panorama of the Prealps (NE) and Helvetides (E) can be seen across the valley of the Rhône towards the east.

A CREATION-FLOOD PERSPECTIVE

The evidence for glaciation, such as the Pierre des Marmettes, and abundant other evidences are convincing indications of an “ice age.” Creationists postulate a single short period of glaciation very soon after the flood; probably brought on by volcanic activity. The fine volcanic ash in the atmosphere from flood activity would occlude the radiant energy from the sun, resulting in cool air. That cool air in combination with abundant moisture from warm oceans would favor rapid glaciation.

OVERTURNED LIMB OF THE MORCLES NAPPE

LOCATION

The overturned limb of the Morcles Nappe (Dents de Morcles) can be seen on the east side of the valley of the Rhône about midway between Bex and Martigny. A good location is above the town of La Rasse (near Evionnaz). A better view is obtained from the town of Mex several kilometers to the west.

DESCRIPTION

Looking at the skyline to the northeast, one sees the classic great cliff of the Dents de Morcles. See Figure 39 and find the thrust plane. The part above this plane is overturned, i.e., the stratigraphic column goes in the reverse direction (younger below older). This is the overturned limb of the Morcles Nappe which had a normal limb above the overturned one. The normal limb, which you can imagine folded back to the south high in the sky, has been eroded away. Below the overturned limb are flysch, Jurassic deposits and the crystalline basement of the autochthon.

FIGURE 39. View of the Dents de Morcles. The arrow at the right indicates where the Morcles Nappe (above the arrow) slid over the more fixed layers below. Here the layers of the Morcles Nappe are reversed, due to recumbent folding from the south (right). The arrow at the left, which is within the Morcles Nappe, points to the lower margin of the thin, dark Gault (Upper Cretaceous) layer. Just below is the thick Nummulitic limestone layer (Eocene). Standard geologic interpretations would suggest some 45 million years between these two layers; yet the thin Gault shows little evidence of any erosion for 45 million years (remember the Morcles layers are reversed here).

A CREATION-FLOOD PERSPECTIVE

In this overturned limb one can see a paraconformity (disconformity) with a supposed gap of 45-55 million years. Examine the picture and the cliff. The paracomformity lies between the darker Gault (estimated at about 100 million years ago) and the Nummulitic (estimated at about 44 million years ago), which on the hillside lies just below the Gault. There does not seem to be much erosion of the thin Gault (on its lower side in this overturned limb) during this 45 million (or more) year gap. This is an example of a number of such paraconformities that are widespread, yet very flat. The absence of erosion at these “gaps” suggest that the time gap is not real. The peneplain concept is an inadequate explanation.

FIGURE 40. Panorama from Gornergrat looking towards the west.

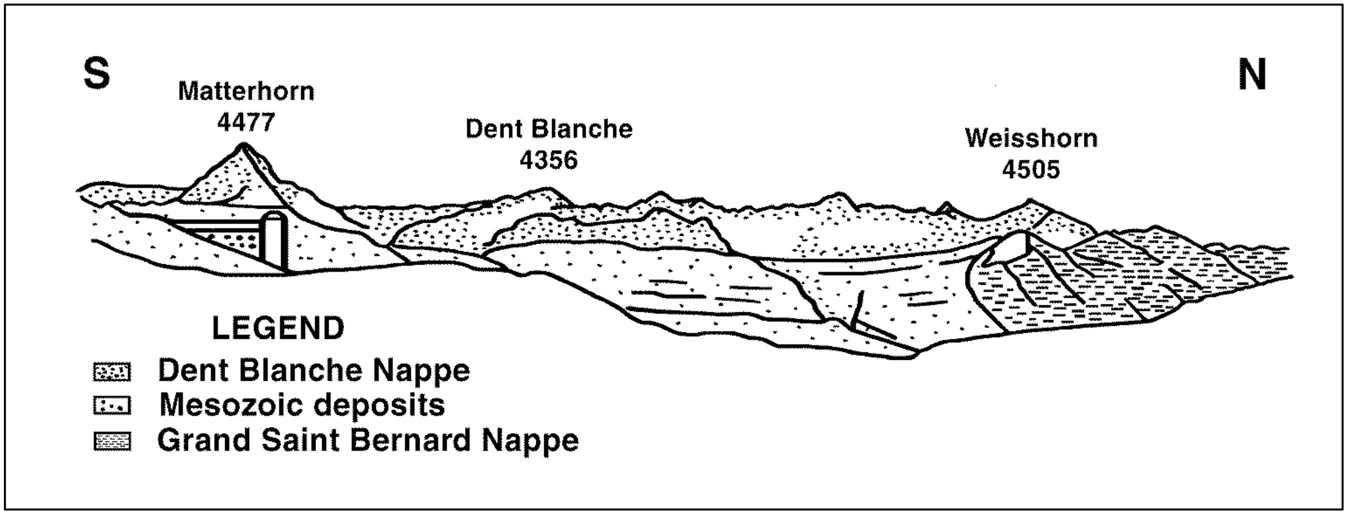


FIGURE 41. Interpretation of the panorama from Gornergrat looking towards the west.

FIELD LOCALITIES IN THE ZERMATT AREA

GORNERGRAT PANORAMA

LOCATION

Take the cog railroad from Zermatt to Gornergrat. At Gornergrat take the path to the south of the hotel to the viewpoint above and east of the hotel.

DESCRIPTION

This is a classic area for the study of the Penninic nappes. There are three main nappes here, dipping significantly to the west. The first is the Monte Rosa Nappe which is below the viewpoint and forms the hills to the northeast and southeast, including Castor to the south but not Pollux (which is composed of Mesozoic deposits). Hsü (1993, p 90) questions the validity of the Monte Rosa Nappe. The second nappe is the Grand Saint Bernard Nappe which can be seen to the northwest and is best identified by looking at the dashed pattern on Figure 41 and comparing it to the panorama you see to the west (Fig. 40).

Also by looking at the same sketch you should be able to identify the Dent Blanche Nappe (closely stippled) which includes the Matterhorn (4478 m). The rest (loosely stippled) is mostly Mesozoic deposits of carbonates, schists, ophiolites, etc. The town of Zermatt (1620 m) lies on these deposits.

As you look to the southwest you will note the Gorner Glacier and its branches. Note the lateral and medial moraines. The gray rocks just above the glacier represent fresh serpentine of the Mesozoic units, while the more brownish rocks above represent more weathered serpentine.

The first two nappes (Monte Rosa and Grand Saint Bernard) are traditionally considered Penninic in paleogeographic origin (see Figs. 1 and 31). In the Alps there has been a general move from S-N; however, the southern part of the Grand Saint Bernard Nappe (the part you can see which is called Mischabel) is interpreted as having moved to the south by backthrusting. The Grand Saint Bernard Nappe (Mischabel) does not appear to have been subjected to the high degree of metamorphism found in the Mesozoics surrounding it; hence, it is assumed to have slipped in after the metamorphism. The Dent Blanche Nappe (which includes the Matterhorn) comes from the Austro-Alpine paleogeographic domain. This is usually interpreted as coming from a more southerly continent and being thrust north (probably during the Oligocene) to its present location.

When one considers how much effort it takes to lift a 50 kg object, one can only wonder at the energy involved in moving these mountains around, above, and under each other.

GORNER GLACIER BELOW GORNERGRAT

LOCATION

Take the cog railroad to Rotenboden. The glacier can be reached by taking a leisurely walk (about 6-7 km round trip) along the cover of the Monte Rosa Nappe. Take the path to the south and then east along the south flank of Gornergrat until you reach the glacier.

DESCRIPTION

The path to the east will go down through the cover (Permian and above) of the Monte Rosa Nappe and eventually reach the crystalline basement of the nappe before you reach the Gorner Glacier. Along this path are several kinds of metamorphic rocks or minerals indicative of metamorphic changes due to heat and/or pressure. The degree of metamorphism in the Alps tends to be high in this region, while it decreases gradually to the northwest. There is little left by the time you get to the Helvetide nappes. As you proceed down the path, look at the rocks along the side. Your geological astuteness may permit you to pick out the following rocks and special indicators of metamorphism.

Schists (Schistes Lustré, Bündner Schiefer) with shiny grayish mica
Quartzite — angular and sometimes schistose
Quartz pebbles in larger rocks
Bluish glaucuphane schist
Dark greenish, sometimes smooth, serpentine
Granitic rocks from the crystalline basement of Monte Rosa Nappe (there are several kinds of these)
Small brown-red garnets in crystalline rocks

On the way down also notice the Gorner Glacier and branches, including dark medial and lateral moraines, crevasses, sources, direction of flow, etc. At the edge of the glacier note the cracks in the ice and the bed it flows on. The smoothed-over rocks with striations (grooves) at the sides of the glacier are part of the Monte Rosa Nappe basement. Their rounded pattern gives them the name of roche moutonné (sheep rocks) (Fig. 42). The

FIGURE 42. Smooth mounded rocks called roche moutonné (sheep rocks) formed by the action of the Gorner Glacier on the crystalline basement of the Monte Rosa Nappe. Note the striations on the rocks in the lower left corner.

Gorner Glacier reaches a thickness of 200-300 m in the valley. It travels slowly at the rate of only a few meters per year. The glacier was much larger in the early 1880s. During the early Middle Ages and late Roman period one could travel readily from Zermatt to Italy, indicating less glaciation than what is seen now. Earlier the glaciers reached to Lake Geneva which has been gouged out to below sea level as a result of glacial activity.

A CREATION-FLOOD PERSPECTIVE

The degree of metamorphism in this region can be the basis for raising some interesting time questions. The pressure required for some metamorphic mineral assemblages here suggest an overburden with a depth of at least 30 km. More recently some suggest 100 km and even more than 300 km (Dobrzhinetskaya et al. 1996) for part of the Alps. If one should assume that metamorphism was 30 - 150 million years ago, as is proposed by the generally accepted geologic time scale, it would mean the Alps must have been eroded at a rate of at least 60 times faster than the probable world average of 30 m per 1 million years (corrected for humankind's agricultural pursuits). Something seems wrong. And if Alpine erosion *is* that rapid, one wonders why older mountain ranges of the world have not been flattened by erosion a long time ago.

This raises the question of general rates of erosion and the existence of continents and mountains. They would be expected to have been eroded away a long time ago. It has been argued that repeated uplift to form new mountains has occurred, and this would provide a source area for the sediments of the geologic column. The presence of very "old" mountain ranges such as the Caledonides of northern Europe and the presence of much of the geologic column in many parts of the world seem to mitigate against this idea, since the process of uplift and erosion would destroy old mountain ranges, and the geologic column in them would have been recycled many times during this time, yet much of it remains. At the rate of erosion of 30 m per 1 million years, the present continents would have been eroded, on an average to sea level, 150 times in 3 billion years. Of course, they can only be eroded once. At an average erosion rate, none of the geologic column or continents should still be present. The present rates of erosion pose a question for the standard geologic time scale.

FIELD STOPS IN THE JURA MOUNTAINS

REEF STRUCTURE AT MARES QUARRY

LOCATION

From Saint-Germain-de-Joux (which is located 12 km northwest of Bellegarde-sur-Valserine, eastern France), go north towards Echallon for about 1 km. Turn left towards Plagnes and very soon make a second left on the private road to the Mares Quarry which lies ahead to the west. The quarry has been used for mining abrasives and the ripening of cheese.

DESCRIPTION

This locale is part of the vast Kimmeridgian (upper part of the Jurassic) coralline complex of the Western Jura. Kimmeridgian ammonites below the complex and Portlandian ammonites above have placed this locality in the Upper Kimmeridgian. This region is interpreted as a back reef facies (see Fig. 11). To the east and much further south there is a massive coralline limestone which is often recrystallized and which may represent a reef.

FIGURE 43. Close-up view of fossil coral from the Mares Quarry. The block is about 1½ m long. Note the parallel arrangement of the numerous coral branches.

The region around the entrance to the quarries should be examined carefully for fossils, noting their orientation. Remember that corals usually grow vertically; a few grow horizontally. Coral heads (Fig. 43) are common here. Stromatoporoids (extinct sponge-like organisms that form layered deposits) are occasionally present. Above the opening of the caves a sedimentary carbonate breccia layer is described.

The coral heads are described as growing in large columns and are said to go as far as 40-50 m below the floor of the quarry. The part exposed here represents the top region of this sequence of coral deposits. Between the coral units is a pseudo-oölithic deposit, reported to show no bedding; hence, it is assumed that it was deposited rapidly and the coral also grew quite rapidly to keep from being buried. Burial eventually caused death of the coral. The breccia above the coral is interpreted as representing a shallow, high-energy environment.

A CREATION-FLOOD PERSPECTIVE

The orientation of the coral gives an equivocal picture as to whether this could be a true reef environment. Mostly horizontal growth (represented by the horizontal coral here) is not common to present reefs but would be expected in a transported deposit, since a horizontal position is more stable. It should also be noted that the presence of coral heads not in position of growth is not a good criterion of an allochthonous deposit, since heads not in position of growth occur on present reefs when they break down during storms, etc. The presence of all heads in position of growth would be a strong indication of autochthonous formation, but the mixed picture here would fit either an allochthonous or autochthonous model. Probably the most serious objection to interpreting this as a true reef environment is the reported absence of bedding in the pseudo-oölithic rock matrix between the coral. It is difficult to conceive of no bedding being formed by changing depositional environments during the many years it would take for the coral heads to grow. More rapid transport may be represented here.

STRUCTURE OF THE JURA AT LE PONT

LOCATION

One of the best places to view the relationship of the various structures of the Jura is at the town of Le Pont. There is a small hill to the southwest of the junction between Lake Brenet and Lac de Joux. A walk up the hill will give a spectacular view of the region. On a clear day the view from the Dent de Vaulion (top of hill to the east) will show the broader relationships.

DESCRIPTION

This location shows the relationship of many structural elements and changes involved in the formation of the Jura (Fig. 44); it will also challenge your geometric capabilities. There are at least three different displacement factors here. Consulting the map (Fig. 45) will help envision the changes.

1. Note the folding of the Jura producing elongated anticlines and synclines. The Lac de Joux to the south lies in one of these synclines. The NE-SW direction of these folds is prominent. At this location (just north of Lac de Joux) you are on a small anticline. The Risoux to the north (Fig. 45) is a large anticline, and to the south beyond the Lac de Joux is another anticline. These structures are characteristic of the fold Jura. Larger, boxlike anticlines form the tabulate Jura to the north.

FIGURE 44. The Lac de Joux looking SW from Dent de Vaulion. The lake, which is elongated in a NE-SW direction, lies in one of the many folds of the Jura Mountains. The direction of the lake reflects the SE-NW compressional direction of the formation of the Jura.

2. To the east the abrupt ending of the Lac de Joux is related in part to the Pontalier wrench fault which is a left lateral fault. See Figure 45 and note the relationship of faults F-1 to F-2 and to F-3. F-2 is in the hills just above the town of Le Pont.
3. The most conspicuous change in the region is the Dent de Vaulion (Fig. 45) thrust sheet which forms the high peak to the northeast. Faults F-2 to F-5 on the map outline the limits of the thrust. This thrust goes over part of the anticline (A-3) on which we are standing. On the map, also note the offset of A-1, S-1, and A-2 across the Pontalier wrench fault. Confirmation of this relationship is found in the train tunnel that runs to the east of Lake Brenet, going from W-E. First surficial deposits are found, then A-3, S-2, and A-2.

In the Risoux to the north a well drilled in 1960 to a depth of 1958 m revealed a double sequence of the formations. This surprise has led to the suggestion of a NW-facing thrust sheet (Risoux Nappe). This would result in 10 km of shortening of the original Jura deposits. The simple original model of simple epidermis folding for the Jura is obviously too simple.

Another basic question regarding the folding of the Jura is the cause of the lateral compression. Did pressure come from the south through the molassic basin? Since this molassic basin is hardly folded at all and is overridden to the south by the Prealps, this model is doubted. Possibly deeper events may (also) have been involved.

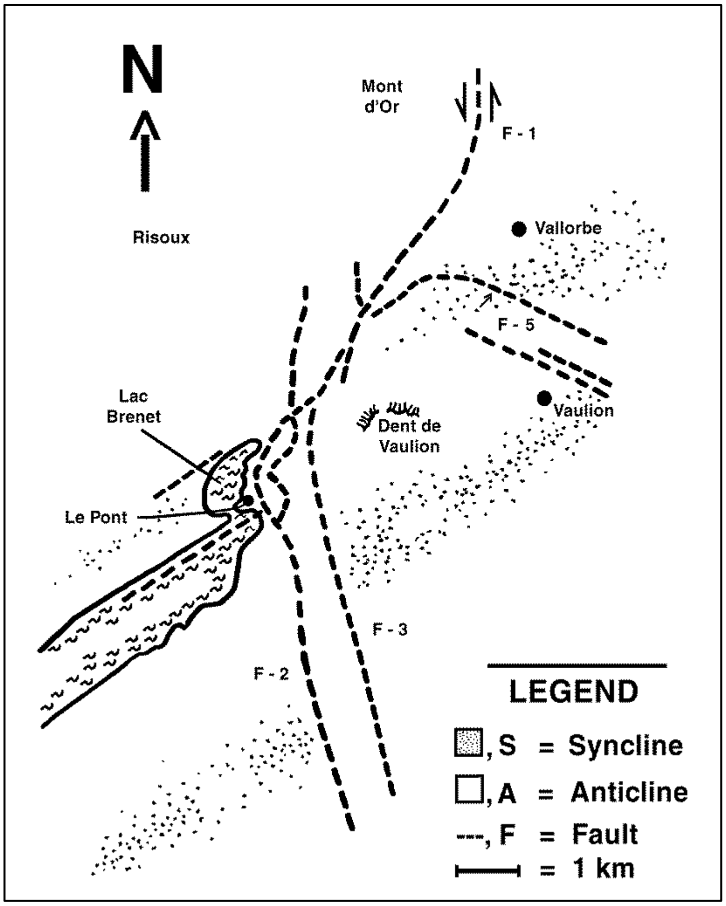


FIGURE 45. Map of the main structural elements around Le Pont, Switzerland. (Modified from Aubert 1959 and Chauve 1975, in Schweizeriche Geologische Kommission 1980).

REFERENCES

Contents

Page intentionally left blank

STRATIGRAPHIC COLUMN

(SELECTED FOR UNITS USEFUL IN THE ALPS)

Erathem	**System**	**Series**	**Selected European Stages**	**Other Groupings**	**Assumed Age in M.Y.**
Cainozoic		Holocene			0
	Quaternary	(Recent)			
		Pleistocene			
		Pliocene	Piacenzian		2
	Tertiary		Zanclian		
		Miocene	Messinian		5
			Tortonian		
			Serravallian	Neogene	
			Langhian		
			Burdigalian		
			Aquitanian		
		Oligocene	Chattian		24
			Rupelian		
		Eocene	Baratonian		34
			Lutetian	Paleogene	
			Ypresian		
		Paleocene	Thanetian		55
			Montian		
			Danian		
Mesozoic		Upper	Maastrichtian		65
			Campanian		
			Santonian	Senonian	
	Cretaceous		Coniacian		
			Turonian		
			Cenomanian		
		Lower	Albian	Gault	99
			Aptian		
			Barremian	Urgonian	
			Hauterivian		
			Valanginian	Neocomian	
			Berriasian		
		Malm	Portlandian		142
			Kimmeridgian		
	Jurassic		Oxfordian		

Erathem	System	Series	Selected European Stages	Other Groupings	Assumed Age in M.Y.
		Dogger	Callovian		159
			Bathonian		
			Bajocian		
			Aalenian		
		Lias	Toarcian		180
			Pliensbachian		
			Sinemurian		
			Hettangian		
	Triassic	Upper	Rhaetian		206
			Norian		
			Carnian		
		Middle	Ladinian		227
			Anisian		
		Lower	Scythian		241
Paleozoic	Permian	Upper	Tatarian		248
			Kazanian		
		Lower	Kungurian		256
			Artinskian		
			Sakmarian		
	Carboniferous				290
	Devonian				354
	Silurian				417
	Ordovician				443
	Cambrian				495
Precambrian					545

INTRODUCTION TO INTRODUCTORY PETROLOGY

"THE FIVE MINUTE ROCK COURSE"

Petrology is the study of rocks. **Rocks** are aggregates of minerals of varying size, composition, physical characteristics and origin. This latter factor is especially important in present classification schemes.

The **minerals** which form rocks are composed of atoms that are organized into highly defined substances with more or less constant physical and chemical properties. Examples of minerals include diamond, rock salt, graphite, quartz, etc.

A rock, on the other hand, is not so well defined; it can consist of a single or many minerals mixed in various proportions, sizes, etc. The important features of a rock can tell us much about its past history, and this is particularly important as one considers the past history of Earth.

There are three major groups of rocks — igneous, sedimentary, and metamorphic. Their major features will be described below.

IGNEOUS ROCKS

These rocks are formed by the congealing of hot molten material called magma. The hardening of a molten volcanic flow would be an example. Hardening can take place either below or above Earth's surface. Some identifying characteristics of igneous rocks are:

Usually not in layers, at least, not fine layers
Hard and massive
Interlocking mineral crystals

EXAMPLES

Basalt — fine crystals, dark in color from the more rapid cooling of magma.

Granite — consisting of coarse, light and dark interlocking crystals, not in layers, often from slow cooling of magma, but can also be of metamorphic origin.

Ophiolite — group of medium to dark igneous rocks including basalt, derived in part by metamorphism and associated with the development of a geosyncline.

Volcanic breccia — hardened coarse, angular particulate products of volcanoes.

SEDIMENTARY ROCKS

These rocks are formed by the cementing together of fragments aggregated together by various transport mechanisms such as moving water, wind, flowing ice, etc. An example would be the cementing together by minerals of sand particles on a beach to form beachrock or sandstone. Some identifying characteristics of sedimentary rocks include:

Layering
Particulates often rounded by transport
Sorted according to size by transport

EXAMPLES

Anhydrite — hard whitish rock composed of anhydrous calcium sulfate.

Claystone — massive, indurated clay particles.

Conglomerate — cemented round to subround pebbles in a finer matrix.

Dolomite — carbonaceous sedimentary rock, often greyish-tan in color, with a dominance of the *mineral dolomite which is a calcium-magnesium carbonate.*

Evaporite — composed primarily of minerals such as rock salt, gypsum, anhydrite, thought to have originated by the evaporation of saline solutions.

Gypsum— soft whitish rock composed of hydrous calcium sulfate.

Limestone — usually massive calcium carbonate, often white to grayish, produced by precipitation of lime from seawater either inorganically or by living organisms.

Marl — usually composed of fine impure calcium carbonate with some clay. An ill-defined term.

Sandstone — cemented sand.

Sedimentary breccia — composed of coarse angular clasts and originating from a sedimentary process.

Shale — cementing of fine particles, finely laminar.

METAMORPHIC ROCKS

These rocks originate from igneous, sedimentary, or other metamorphic rocks. They are altered physically or chemically or both, producing a new kind of rock. These changes occur essentially in the solid state and can be either minor or of such a nature as to completely change the characteristics of the original rock. An example would be the changing of a shale into a slate by shearing pressure. Characteristics of metamorphic rocks are:

Generally laminated

Original structures out of shape, hard to identify

Contains mineral assemblages characteristic of metamorphic changes

Examples

Gneiss — foliated rocks with alternating mineral bands, usually formed from coarser grained rocks, layer greater than 1 mm in thickness.

Granite — coarsely crystalline rock, consisting of light and dark (usually) minerals, sometimes derived by the metamorphism of sedimentary rocks, also of igneous origin.

Marble — from limestone, usually not in layers, altered and bent carbonate crystals.

Mylonite — compact, fine-grained rock produced by extreme mechanical granulation and shearing during metamorphism.

Phyllite — compact, fine grained, usually intermediate between a slate and a schist. Does not cleave as perfectly as a slate.

Schist — strongly foliated crystalline rock, easily split, originating from fine-grained rocks, layers 1 mm or less in thickness.

Serpentine — rock with a black to green, greasy luster, soapy feel, derived from metamorphism, magnesium-rich rocks.

Slate — compact, fine grained, very fine layers, can be split into slabs and plates, usually from shale.

GLOSSARY OF SOME GEOLOGICAL TERMS

(CONSULT THE "INTRODUCTION TO PETROLOGY" AND THE "STRATIGRAPHIC COLUMN" FOR ROCK AND STRATIGRAPHIC TERMS)

ALLOCHTHONOUS — originating from elsewhere, transported.

ANTICLINE — a fold which is convex upward.

AUTOCHTHONOUS — indicates no transport, *in situ*.

BACK REEF — the area between a reef and the mainland.

BOUMA SEQUENCE — the characteristic sequence of complex sedimentary structures deposited by a turbidity current.

CARBONATE — a mineral formed in part using carbonate ions. Limestone is a common example, consisting of calcium carbonate.

CARBONATE COMPENSATION DEPTH — the depth in the ocean where the solution of carbonate exceeds the rate of deposition. Presently this is usually several thousand meters below sea level.

CIRQUE — a steep-walled semicircular recess situated high on a mountain and produced by glacial erosion. It is commonly at the head of a glacial valley.

CLAST — the individual constituent of a sedimentary rock. It can be from clay size to boulder size.

CONVOLUTE — wavy, disorganized, crumpled sedimentary layers, often occurring between parallel layers.

CORALLINE — pertaining to corals and related features of coral, such as reefs, etc.

CORDILLERA — an assemblage of mountain ranges with a general parallel arrangement.

CYCLOTHEM — a term applied to the repeat unit of a cyclic sedimentary sequence.

DEBRIS FLOW — a moving mass of a mixture of rock and mud with a dominance of the clasts being larger than sand size.

DETRITUS — transported fragmental material derived from the breakdown of rocks.

EPIDERMIS FOLDING — folding of the epidermis (sedimentary layers or superficial cover layers) in contrast to a more stable basement which is not so involved in the folding.

EUSTATIC — changes in sea level that are worldwide, not local

FACIES — the characteristic textures of a particular rock unit. May refer to rock type, fossil content, etc.

FAULT — a fracture plane in a geologic unit in which there is some observable displacement.

FLYSCH — a sedimentary deposit of thin units of marls, sandstones, conglomerate, graded deposits, often alternating in nature. May include turbidites.

FOLD — a bend in an originally planar rock structure.

FOLIATION — the planar structural features of a rock that result from the flattening of the constituent grains in the metamorphic process.

FORELAND — the stable area next to an orogenic belt towards which the belt was thrust. See **Hinterland**.

FORE REEF — the seaward side of a reef.

FORMATION — a group of rock strata or a body of igneous or metamorphic rock that has certain unique characteristics common to the unit and differing from adjacent units, usually of mappable size.

GEOSYNCLINE — an extensive elongated downwarped region of Earth's surface in which sediments and volcanic rocks have accumulated to great thicknesses.

GRADED BED — a sedimentary layer which has the coarsest material at the base and becoming finer as one proceeds towards the top.

HINTERLAND — the area on the side of an orogenic belt away from the direction of the thrust. See **Foreland**.

ISOCLINE — a fold whose limbs are parallel.

JOINT — a fracture in a rock without displacement. It is often planar.

KLIPPE — a transported block of rock that is isolated from its source either by sliding or by erosion of the thrust sheet from which it originated.

LAMINA — very thin sedimentary layer, commonly in the mm range or thinner.

LOAD CAST — the bulbous projection of an overlying layer into the one below due to unequal loading.

MAGMA — molten fluid within Earth's interior formed from the melting of rock.

MATRIX — the finer-grained material filling the space between larger particles or fossils, etc.

MOLASSE — an extensive mixed sedimentary deposit resulting from the early erosion of a mountain range such as north of the Alps.

MORAINE — accumulation of larger aggregates of unsorted glacial drift by the action of a glacier.

NAPPE — an extensive body of rock that has moved by recumbent folding or overthrusting.

ORGANIC REEF — a wave-resistant ridge or mound built by sedentary organisms showing relief above the surroundings.

OROGENY — the process of mountain formation.

OVERTHRUST — a near-horizontal thrust fault of wide extent usually many km^2.

PALEOGEOGRAPHIC DOMAIN — the location of a particular geologic area at a particular time in the past.

PARACONFORMITY — an unconformity in which there is no erosional surface and the beds below and above are parallel, a non-sequence.

PARAUTOCHTHONOUS — not transported very far, intermediate between autochthonous and allochthonous.

PELAGIC — pertaining to the open sea but not the sea floor.

PENEPLAIN — a widespread featureless (flat) land surface presumably produced by long, continuous subaerial erosion.

PSEUDO-OÖLITHIC ROCK — rock composed of small spherical pseudo-oöliths (oöliths without the defining internal structure). Sometimes with ill-defined outlines.

RECUMBENT FOLD — an overturned fold as in a nappe or other geologic unit.

REEF — a projecting outcrop of rocks.

RELIEF — unevenness of Earth's surface.

ROCHE MOUTONNÉE — smoothed off, mounded rock usually a few meters in size, produced by the action of glaciers.

SACCHAROIDAL — a rock texture term used for rocks having a sugary appearance.

SHEET — a large, widespread tabular mass of rock.

STRATIGRAPHY — science of the strata of Earth's crust, dealing especially with the characteristics, sequence of layers, and the time factors of this sequence.

SYNCLINE — a fold which is concave upward.

TALUS — rock fragments at the base of a steep slope or an extensive slope of such fragments.

TECTONIC — related to structural or orogenic features of Earth's crust.

TERRIGENOUS — originating from land surfaces in contrast to a marine origin.

THRUST FAULT — a fault whose surface is more horizontal than vertical and in which the direction of movement of the two parts is compressional.

TILL — heterogeneous mixture of clay-boulder clasts resulting from the action of glaciers.

TURBIDITE — a sedimentary rock deposited by a turbidity current.

TURBIDITY CURRENT — a downhill, underwater density current consisting of a suspension of sediments. The current has a greater density than water, flows with a characteristic pattern, leaving a characteristic deposit.

UNCONFORMITY — an interruption in deposition in a sedimentary sequence. A gap in the stratigraphic record.

VARVE — layer of sediment usually consisting of a coarse and fine portion, and thought to have been deposited during one year.

VERGENCE — the direction of inclination or overturning of a fold.

WILDFLYSCH — a kind of flysch characterized by large, usually unsorted blocks and contorted beds.

WENCH FAULT — a lateral fault with a more or less vertical fault surface.

SOME REFERENCES ON THE DEVELOPMENT OF ALPINE CONCEPTS

Ager DV, Brooks M, editors. 1977. Europe from crust to core. NY: John Wiley & Sons.

Aubouin J. 1980. Geology of Europe: a synthesis. Episodes 1980(l):3-8.

Bailey ER. 1935. Tectonic essays: mainly Alpine. Oxford: Clarendon Press.

Chauve P. 1975. Jura. Guides Géologiques Régionaux. Paris: Masson & Cie.

Collet LW. 1974. The structure of the Alps. Reprint of the 1935 ed. Huntington, NY: Robert E. Krieger Publishing Co.

Coward MP, Dietrich D. 1989. Alpine tectonics — an overview. In: Coward MP, Dietrich D, Park RG, editors. Alpine tectonics. Geological Society Special Publication 45. Oxford, London, and Edinburgh: Blackwell Scientific Publications, p 1-29.

Debelmas J. 1980. Alpine Europe. Episodes 1980(l):28-32.

Dietrich D, Casey M. 1989. A new tectonic model for the Helvetic nappes. In: Coward MP, Dietrich D, Park RG, editors. Alpine tectonics. Geological Society Special Publication 45. Oxford, London, and Edinburgh: Blackwell Scientific Publications, p 47-63.

Dobrzhinetskaya L, Green HW (II), Wang S. 1996. Alpe Arami: a peridotite massif from depths of more than 300 kilometers. Science 271:1841-1845.

Flügel E. 1982. Evolution of Triassic reefs: current concepts and problems. Facies 6:297-328.

Geological Survey of Austria. 1980. Austria: outline of the geology of Austria. Guidebook for Excursions, 26th International Geological Congress (July 1980, Paris). Abhandlungen der Geologischen Bundesanstalt 34. Vienna: F. Berger & Sohne.

Ginsburg RN. 1971. Landward movement of carbonate mud: new model for regressive cycles in carbonates. American Association of Petroleum Geologists Bulletin 55:340.

Giovanoli F. 1979. A comparison of the magnetization of detrital and chemical sediments from Lake Zurich. Geophysical Research Letters 6(4):233-235.

Hsü KJ. 1960. Paleocurrent structures and paleogeography of the Ultrahelvetic Flysch basins, Switzerland. Geological Society of America Bulletin 71:577-610.

Hsü KJ. 1989. Time and place in Alpine orogenesis — the Fermor Lecture. In: Coward MP, Dietrich D, Park RG, editors. Alpine tectonics. Geological Society Special Publication 45. Oxford, London, and Edinburgh: Blackwell Scientific Publications, p 421-443.

Hsü KJ. 1995. The geology of Switzerland: an introduction to tectonic facies. Princeton, NY: Princeton University Press.

Hsü KJ, Schlanger SO. 1971. Ultrahelvetic Flysch sedimentation and deformation related to plate tectonics. Geological Society of America Bulletin 82:1207-1218.

Hunziker JC, Desmons J, Martinotti G. 1989. Alpine thermal evolution in the central and the western Alps. In: Coward MP, Dietrich D, Park RG, editors. Alpine tectonics. Geological Society Special Publication 45. Oxford, London, and Edinburgh: Blackwell Scientific Publications, p 353- 367.

Hurford AJ, Flisch M, Jäger E. 1989. Unravelling the thermo-tectonic evolution of the Alps: a contribution from fission track analysis and mica dating. In: Coward MP, Dietrich D, Park RG, editors. Alpine tectonics. Geological Society Special Publication 45. Oxford, London, and Edinburgh: Blackwell Scientific Publications, p 369-398.

Lambert A, Hsü KJ. 1979. Non-annual cycles of varve-like sedimentation in Wallensee, Switzerland. Sedimentology 26:453-461.

Lemoine M, editor. 1978. Geological atlas of Alpine Europe and adjoining Alpine areas. NY: Elsevier Scientific Publishing Co.

Lombard A, editor. 1967. Geologischer Führer der Schweiz. Basel: Wepf & Co.

Lombard A, Gansser A, editors. 1962. Guidebook for the International Field Institute: the Alps. Falls Church, VA: American Geological Institute.

Middleton GV, Bouma AH. 1973. Turbidites and deep-water sedimentation. Society of Economic Paleontologists and Mineralogists Pacific Section, Short Course, Anaheim, California.

Milnes AG. 1978. Structural zones and continental collision, central Alps. In: Burns KL, Rutland RWR. editors. Structural characteristics of tectonic zones. Tectonophysics 47:369-392.

Oxburgh ER. 1968. The geology of the eastern Alps. London: The Geologists' Assn.

Pfiffner OA, Lehner P, Heitzmann P, Mueller S, Steck A, editors. 1997. Deep structure of the Swiss Alps: results of NRP 20. Basel: Birkhäuser Verlag.

Piller WE. 1981. The Steinplatte reef complex, part of an Upper Triassic carbonate platform near Salzburg, Austria. Society of Economic Paleontologists and Mineralogists Special Publication 30:261-290.

Reijmer JJG,Ten KateWGHZ, Sprenger A, SchlagerW. 1991. Calciturbidite composition related to exposure and flooding of a carbonate platform (Triassic, Eastern Alps). Sedimentology 38:1059-1074.

Rutten MG. 1969. The geology of Western Europe. NY: Elsevier Publishing Co.

Satterley AK. 1994. Sedimentology of the Upper Triassic reef complex at the Hochkönig Massif (Northern Calcareous Alps, Austria). Facies 30:119-150.

Satterley AK. 1996. Cyclic carbonate sedimentation in the Upper Triassic Dachstein Limestone, Austria: the role of patterns of sediment supply and tectonics in a platform-reef-basin system. Journal of Sedimentary Research 66(2):307-323.

Schweizerische Geologische Kommission, editor. 1980. Switzerland: an outline of the geology of Switzerland. Guidebook for Excursions, 26th International Geological Congress (July 1980, Paris). Basel: Wepf & Co.

Stanton RJ, Jr. 1988. The Steinplatte, a classic Upper Triassic reef — that is actually a platform-edge sandpile. Geological Society of America Abstracts with Programs 20(7):A201.

Taylor B, editor. 1995. Backarc basins: tectonics and magmatism. NY and London: Plenum Press.

Trumpy R. 1960. Paleotectonic evolution of the central and western Alps. Geological Society of America Bulletin 71:843-908.

Trümpy R. 1991. The Glarus nappes: a controversy of a century ago. In: Muller DW, McKenzie JA, Weissert H, editors. Controversies in modern geology: evolution of geological theories in sedimentology, earth history and tectonics. London, San Diego, and NY: Academic Press, p 385-404.

Wilkinson BRH, Opdyke BN, AlgeoTJ. 1991. Time partitioning in cratonic carbonate rocks. Geology 19:1093-1096.

Wurm D. 1982. Mikrofazies, Paläontologie und Palökologie der Dachsteinriffkalke (Nor) des Gosaukammes, Österreich. [Microfacies, paleontology and palecology of the Dachstein Reef Limestones (Norian) of the Gosaukamm Range, Austria.] Facies 6:203-296.

Notes

Notes

Notes