SEPTEMBER 4th

Jurassic and Cretaceous of the Northern Calcareous Alps south of Salzburg

By Florian Böhm, Oskar Ebli & Harry Lobitzer

With contributions by Ilona Bodrogi, Ilse Draxler, Edit Filacz, Lenka Hradecka, Zdenek Vasicek

Introduction

The Calcareous Alps south of Salzburg are part of the classical area of Alpine geology and host many stratotype localities of the Alpine Mesozoic. On the first day of our excursion we shall visit the classical area of Adnet quarries, which are famous not only as extraordinary prominent sites of decoration stones, but also in respect of Liassic biostratigraphy. The quarry of Leube Cement Co. shows a complete sequence of Late Jurassic to Early Cretaceous Aptychus Limestones, which are subdivided into several formations, as Oberalm ("Biancone"), Schrambach- and Roßfeld Formation. The latter shows in its upper part spectacular outcrops of (outer) fan sediments including "Wildflysch"-olistostromes. The Late Cretaceous Untersberger Marmor at Fürstenbrunn (Kiefer Quarry) is used as decoration stone as well. Also in this exposure spectacular sedimentological phenomena of a slope can be studied, including slumping structures, channeling, mud- and grain-flows, olistostromes and early stages of "knollenkalk" formation, etc. In addition we shall enjoy outstanding masterpieces of Adnet- and Untersberg- "Marble" sculptures, manufactured by prominent or unknown artists in the early Middle Ages in some renowned churches of Salzburg.

Stop 1.1.: Adnet

The quarries of Adnet are important as suppliers of decorative stones since the Middle Ages (KIESLINGER 1964). They are quarried for Upper Triassic and Lower Jurassic limestones of varied facies and colouring. The quarrying technique applied at Adnet provides excellently cut walls that expose sedimentary structures and facies, especially when the walls are wet.

The Adnet area is situated near the western edge of the **Osterhorn block** (Fig. 3a). This part of the Tirolic nappe system (middle tectonic unit of the Northern Calcareous Alps) is characterized by relatively weak tectonic deformations. Most parts of the Osterhorn block are only slightly faulted. Only Late Jurassic and Cretaceous large-scale gravity sliding provides some complications, mainly in the southern part of the Osterhorn block (PLÖCHINGER 1983, SCHLAGER & SCHLAGER 1973, BERNOULLI & JENKYNS 1970).

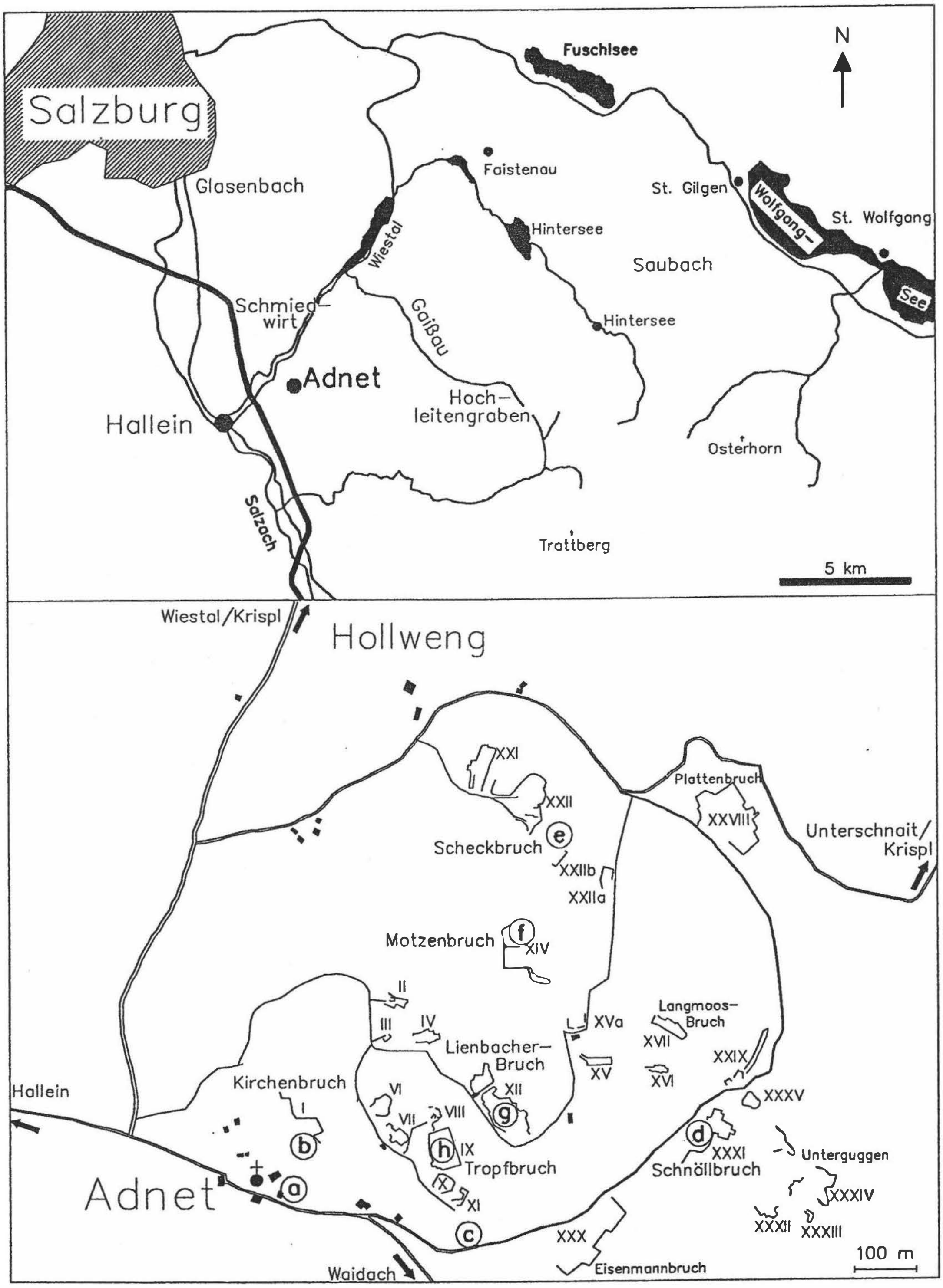


Fig. 3: Location maps: A. Overview of the Osterhorn Block, bordered by the Salzach Valley in the SW and the Fuschlsee-Wolfgangsee depression in the NE. Positions of Adnet and other locations cited in the text are indicated: Schmiedwirt (old Wiestal road), Hochleitengraben (Gaissau), Saubach (Schafbachalm).

B. Sketch map of the Adnet quarries with numbering according to KIESLINGER (1964). Stops along the roundtrip from the Adnet church to Tropf quarry are marked by letters.

A general overview of stratigraphy and tectonics of the area can be found in PLÖCHINGER (1983, 1990). The Rhaetian reefs and surrounding basin facies was described by SCHÄFER (1979) and KUSS (1983). Facies and stratigraphy of the Lower Jurassic at Adnet was recently described by BÖHM (1992), BÖHM & BRACHERT (1993), GALLET et al. (1993), MEISTER & BÖHM (1993), RAKUS et al. (1993), HLADIKOVA et al. (1994), LOBITZER et al. (1994), BÖHM et al. (1995, 1997), DOMMERGUES et al. (1995). Additionally, numerous older studies exist: WÄHNER (1886, 1903), HUDSON & JENKYNS (1969), WENDT (1971), HUDSON & COLEMAN (1978), as well as several valuable reports of M. SCHLAGER (Verh. Geol. B.-A. Wien, 1957, 1966-1970) and a geological map of SCHLAGER & SCHLAGER (1960). KIESLINGER (1964) and the "Heimatbuch Adnet" by KRETSCHMER (1986, 1992) provide a comprehensive overview of the cultural and art-historical aspects of the Adnet limestones.

Additional information on the Adnet quarries (a clickable quarry map and colour slides of the quarries) is available on the world wide web at: http://www.geomar.de/personal/fboehm/adnet.html.

Sedimentation History of the Adnet Area

Near the end of the Triassic a long-stretched, shallow intra-platform basin formed in the northern part of the large carbonate platform of the Northern Calcareous Alps (NCA) (Fig. 4a). Basin formation probably was caused by increasing clastic influx, locally impeding carbonate production. The marly, deeper neritic **Kössen Formation** (KUSS 1983, GOLEBIOWSKI 1991) filled this basin. Its southern rim was lined by bioclastic ramps (STANTON & FLÜGEL 1995), and coral bioherms (SCHÄFER 1979, SCHÄFER & SENOWBARI-DARYAN 1981), e.g. the **Adnet Reef**.

Reef and platform sedimentation stopped by the end of the Rhaetian. A continuation of platform sedimentation into the Liassic, known from the western NCA (FABRICIUS 1959, EBLI 1997), is not found at Adnet. Elevated parts of the platform may have experienced a final subaerial exposure at the Triassic-Jurassic boundary (Satterley et al. 1994), then, continued high subsidence rates led to a quick drowning. The former carbonate platform was covered by (hemi-)pelagic sediments of the Early and Middle Jurassic (Fig. 4b). The reason for this drowning is still a matter of debate. A tectonic break-up of the platform, often discussed as the primary cause, very likely took part only after the drowning was accomplished, at least in the Adnet area (BÖHM et al. 1995). A connection to the global mass extinction at the Triassic-Jurassic boundary (GOLEBIOWSKI 1990, HALLAM & GOODFELLOW 1990) seems likely. It also killed a major part of the Triassic reef builders (HALLAM 1990). The cause for this mass extinction is still unknown (HALLAM 1990). Shocked quartz was found in the nearby Kendlbach section (eastern Osterhorn block) within the boundary clay layer (BADJUKOV et al. 1987) and in the Southern Alps (BICE et al. 1992). However, further evidence for an impact at the Triassic-Jurassic is needed before it can be considered the final cause.

An increasing pelagic influence during the Liassic is visible in the microfacies. It appeared during two short periods, while during most of the time facies changed only slightly. The first change in facies took place around the Hettangian/Sinemurian boundary. It started the deposition of the **Adnet Fm.** (Fig. 5). A possible tectonic cause could be deduced from the frequent occurrence of neptunian dykes during this time. Also, the chemical composition of the Marmorea Crust, formed during this

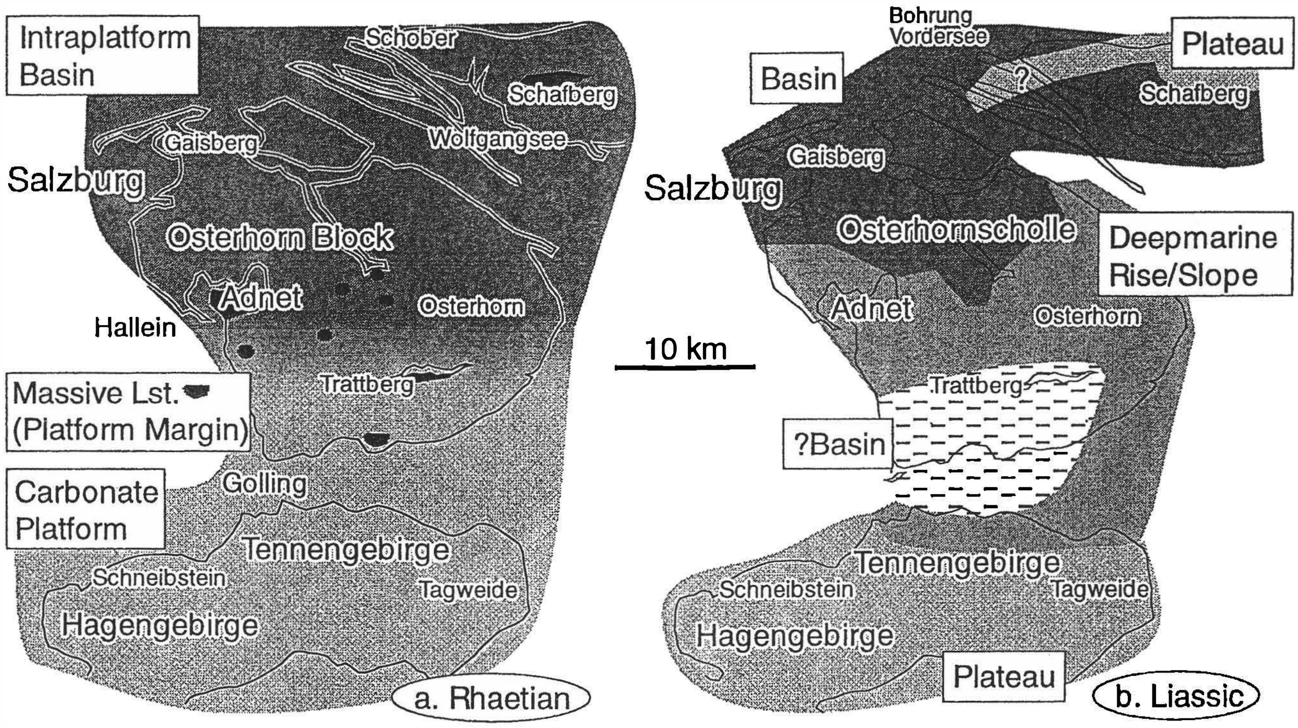


Fig. 4: Facies distribution during the Rhaetian and Sinemurian/Pliensbachian in the Osterhorn block, Hagen- and Tennengebirge. Palinspastik restoration after SPENGLER (1956). a: Rhaetian. An intraplatform basin in the north (Kössen Basin) and a carbonate platform in the south (Dachsteinkalk platform) were interfingering in the southern Osterhorn block. The transition, probably, was a distally steepened ramp (STANTON & FLÜGEL 1995). Massive limestones and the Adnet Reef are found in the transition area. Reef mounds also occur within the Kössen Basin (SCHÄFER & SENOWBARI-DARYAN 1981). The Dachstein Platform was bordered by a reef-rimmed margin to the south, leading to the oceanic Hallstatt Basin (PILLER & LOBITZER 1979, SATTERLEY 1996). For probable complications of the palinspastik restoration leading to a more complex view, see GAWLICK et al. (1994).
b. Sinemurian/Pliensbachian. The Rhaetian relief largely survived its drowning to aphotic waterdepths. However, a new basin started to form in the southern part of the Osterhorn block, positioned between the Adnet rise and the Hagen-Tennengebirge plateau. None of the rises or plateaus reached into photic waterdepths.

period, may point to tectonically induced hydrothermal activities (KINDLE 1990, BÖHM et al. in prep., BÖHM & LOBITZER 1997). However, more conclusive evidences for tectonic activities during this time are lacking. Investigations on facies and biostratigraphy, moreover, point to a long period of non-sedimentation due to strong bottom current activities (WENDT 1971, BÖHM 1992, DOMMERGUES et al. 1995). With that, a long hiatus may pretend an abrupt change in facies.

A second conspicuous change in facies, pointing to a shift to more pelagic conditions, took place during the Middle Liassic. During this period, widespread debris flows point to strong seismic activities (Fig. 5, BÖHM et al. 1995). The rest of

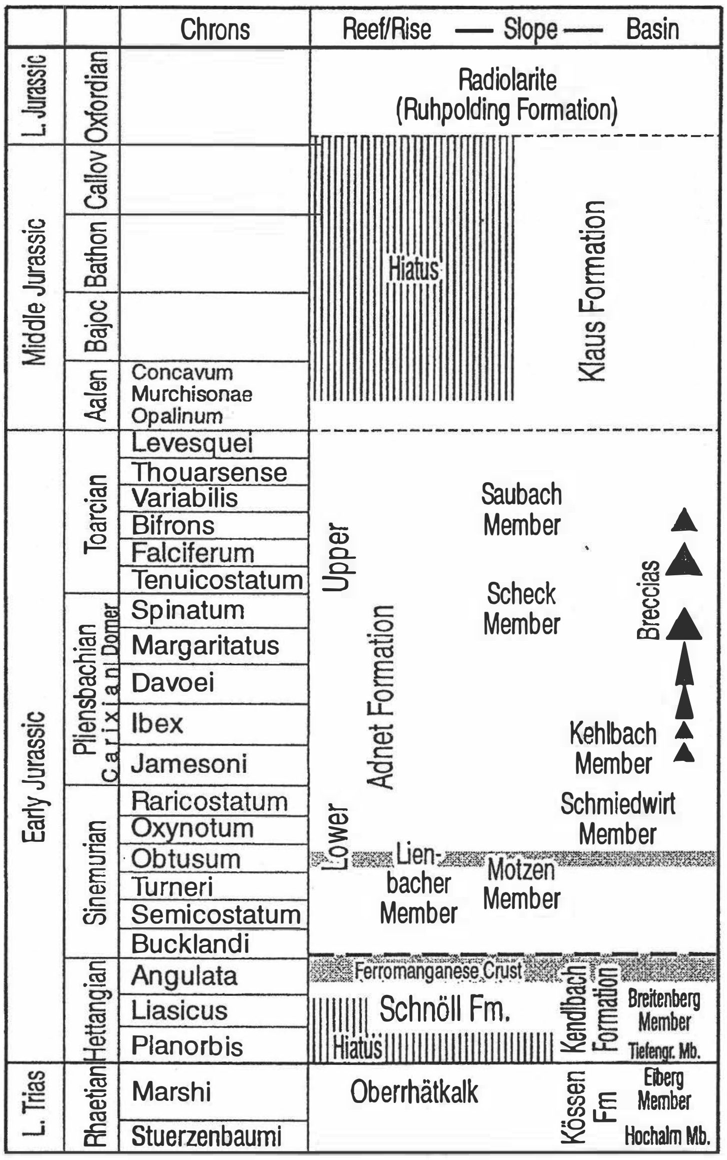


Fig. 5: Stratigraphic overview of the Adnet area. The Rhaetian is represented by the basinal marly Kössen Fm. and the reef limestones of the "Oberrhätkalk". The Hettangian above the reefal areas starts with a hiatus. At the lower slope the varicoloured biomicrites of the Schnöll Fm. were deposited during the middle and late Hettangian. Only in the basin the Kössen Fm. shows a transition into the Kendlbach Fm. without any hiatus. A ferromanganese crust, present in all sections of the Adnet area ("Marmorea Crust"), concludes the Hettangian and forms the base of the Adnet Fm. In its basal parts the Adnet Fm. displays a clear facies differentiation as well as a second ferromanganese crust. During the Middle and Late Liassic breccias and erosive channels are widespread. Middle Jurassic sediments are very rare, or totally absent in many sections. The Late Jurassic Ruhpolding Radiolarites, on the other hand, are omnipresent again. Dashed lines mark the lower and upper boundaries of the Adnet and Klaus Fms. The precise chronostratigraphic positions of the two ferromanganese crusts at the base of the Adnet Fm. are not known. Compiled after BÖHM et al. (1995, in prep.), DOMMERGUES et al. (1995), BÖHM (1992), GOLEBIOWSKI (1990, 1991), KRYSTYN (1971).

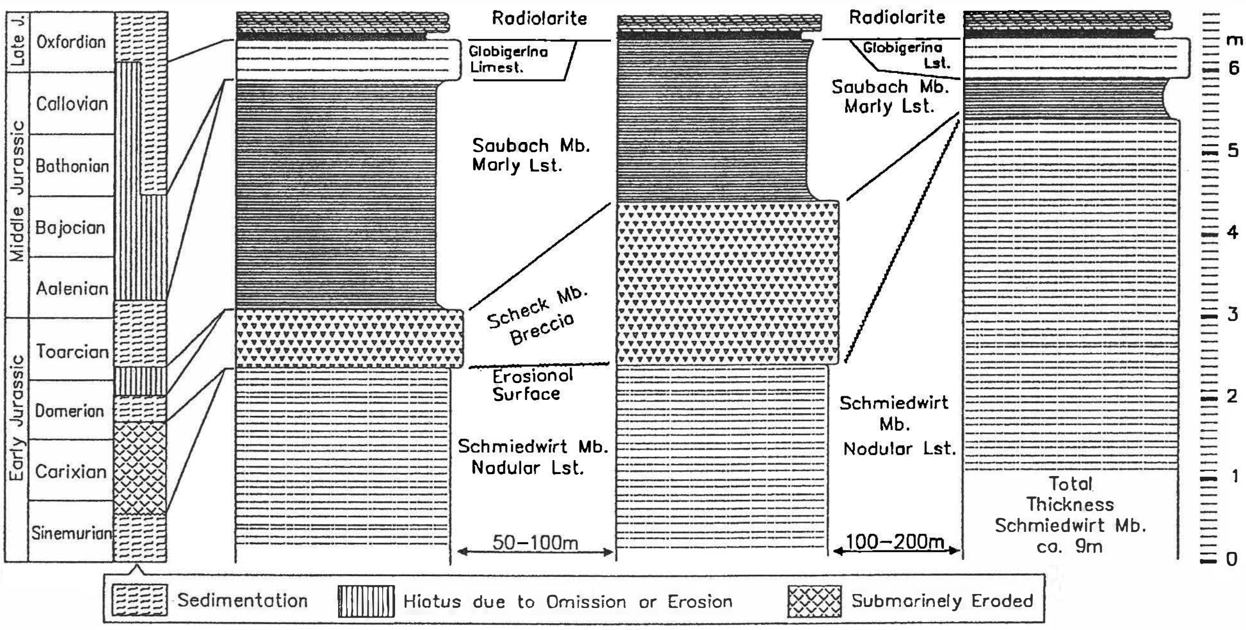


Fig. 6: Late Liassic through Middle Jurassic sedimentation in the Adnet area, exemplified by three sections at Hochleitengraben (ca. 6 km east of Adnet). The successions are characterized by omission, erosion and strongly varying thicknesses. Erosion during the Middle Liassic removed several metres of Adnet limestones (BÖHM et al. 1995). Sediments of the Saubach Mb. are dated from middle Toarcian (Bifrons zone) until Aalenian (KRYSTYN 1971). Higher Middle Jurassic is only present in thin, local lenses of globigerinid and filamentous limestones. Their exact biostratigraphic position (Bathonian-Oxfordian?) is not known. Widespread sedimentation finally resumed with deposition of the Late Jurassic radiolarites (Oxfordian).

the Liassic and most of the Middle Jurassic are represented only by strongly condensed limestones and marls or ferromanganese crusts (Fig. 6). Eventually, during the Callovian/Oxfordian sedimentation started again with the deposition of radiolarites ("Ruhpoldinger Wende", SCHLAGER & SCHÖLLNBERGER 1974, WÄCHTER 1987).

Facies and Stratigraphy of the Rhaetian

The Adnet reef is a time equivalent of the Eiberg Mb. of the Kössen Fm. With that, it mainly grew during the Marshi chrone of the late Rhaetian (GOLEBIOWSKI 1991). It is very unlikely that reef deposition continued to the Liassic, as megalodonts are still present in the uppermost layers of the reef limestones. Additionally, ZAPFE (1963) described *Rhaetavicula contorta* from Tropf quarry (stop 1.1.h), which means that this typical Rhaetian fossil occurs less than 10 m below the top of the reef limestones. Also, Milos Siblik (Prague, pers. comm.), who recently studied the brachiopods of the Adnet reef, found no indications for Liassic taxa.

The Rhaetian of the Adnet area can be divided into four facies zones (SCHÄFER 1979): The **reef core,** characterized by metre-sized colonies of the coral *Retiophyllia* (pl. 1), is visible in few outcrops. That is mainly the Tropf quarry (stop 1.1.h) and the Kirchen quarry (stop 1.1.b). The reef cores are surrounded by oncolitic reef detritus facies of the **upper reef slope**. Adjoining to the NE a belt of fine-grained detrital mud and calcarenitic facies represents the **lower reef slope**. It grades into the basinal limestone-marl rhythms of the Kössen Fm.

The depositional relief at the end of the Rhaetian can be deduced from the thickness differences between basin and reef sections. If the post-Rhaetian compaction of the basinal marls was less than 50%, the relief was about 50-80 m. About the same value can be calculated from the mean slope angle of 10°, deduced from inclinations of geopetal structures. This inherited relief remained largely unchanged during most of the Liassic and had a major control on the Liassic facies distribution.

Facies and Stratigraphy of the Liassic

The early Hettangian is represented by a hiatus above the reef core and on the upper reef slope (stop 1.1.g, Figs. 5, 7). There, sedimentation started only during the late Hettangian with deposition of strongly condensed biomicrites. At the lower slope (stop 1.1.d) the hiatus was shorter. Sedimentation already started during the latest Planorbis chron (early to middle Hettangian) with the grey-red sponge spicule micrites of the Schnöll Fm. (pl. 1/4; GALLET et al. 1993, BÖHM et al. in prep.). Only the basinal sections (e.g. at the Scheck quarry) show a complete succession from the Rhaetian Kössen Fm. to the early Hettangian Kendlbach Fm. (PLÖCHINGER 1982, GOLEBIOWSKI 1990) without a pronounced change in facies.

Obviously, the Liassic sediments prograded above the relief of the drowned Rhaetian reef. Small scale onlap is visible in some of the quarries (stops 1.1.d and 1.1.f). The large scale geometry can best be explained by a **drowning unconformity** (SCHLAGER 1989). The relief built up by reef limestones was too steep for deposition of the muddy Liassic sediments (mud- and wackestones). Contour currents kept the exposed parts of the cemented steep slopes free of sediments. Only sheltered depressions on the slope accomodated sediments (stops 1.1.f and 1.1.g). Later (late Sinemurian) a large sediment drift prograded along the slope, again probably driven by a contour current (stop 1.1.f).

The reef core area probably was repeatedly exposed during the Rhaetian as visible from frequent dissolution and cementation/internal sedimentation of coral skeletons (pl. 1; stop 1.1.h). It is, however, still unknown, if a prolonged phase of subaerial exposure occurred before drowning and if such a emersion could explain

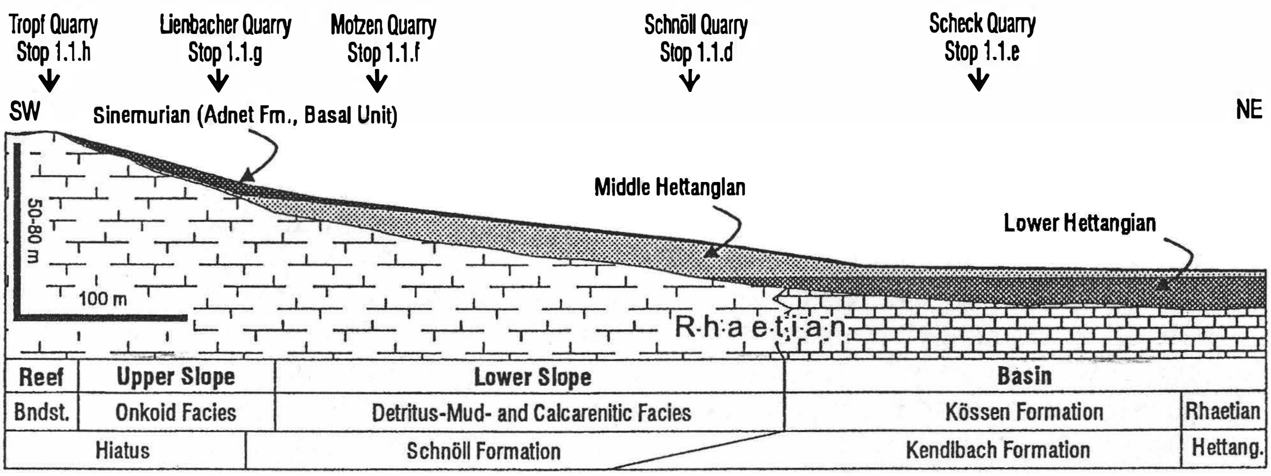


Fig. 7: Schematic reconstruction of the end-Rhaetian and early Liassic relief in the Adnet area. Slightly exaggerated, after BÖHM et al. (in prep.), Rhaetian facies belts after SCHÄFER (1979). Reconstruction mainly based on thicknesses and distributions of formations. The Liassic sedimentary units show a stepwise progradation above the drowned Rhaetian reef.

the early Hettangian hiatus present in upper slope and reef core sections. Few papers have provided specific evidence for such emersions at the Triassic-Jurassic boundary in the Northern Calcareous Alps (SATTERLEY et al. 1994, MAZZULLO et al. 1990). No well-founded evidence for that has been found in the Adnet quarries so far.

At stop 1.1.d an erosional surface overlain by middle Hettangian limestones is exposed. It probably has a submarine origin and developed during an early Hettangian sea-level lowstand, when the lower slope was affected by wave erosion (Fig. 13). Accordingly, it seems possible that the higher parts of the reef structure were subaerially exposed at this time. A combination of low sea-level (sequence boundary) and succeeding drowning (drowning unconformity), as suggested by HALLAM (1990), seems likely for the Adnet reef.

During the late Hettangian (Marmorea chron) sedimentation reached the upper slope (Fig. 5). At the same time, however, a period of sediment starvation started at the slope as well as in the basin. It eventually led to the formation of a widespread **ferromanganese crust**. Formation of this condensed succession coincides with a global sea-level lowstand (HAQ et al. 1988). It can be explained by increased current activities (BÖHM 1992).

Above this crust sedimentation of the red limestones of the Adnet Fm. started during the higher Sinemurian. Three different lithofacies can be distinguished (Fig. 5): The **Lienbacher Mb.** (pl. 2/3; stop 1.1.g) and the **Motzen Mb.** (pl. 2/2; stop 1.1.f) are restricted to the upper, steeper parts of the slope, covering a small-scale relief of the Rhaetian reef slope. The Lienbacher Mb. is made up by condensed red limestone, typically rich in intraclasts surrounded by ferromanganese incrustations. The Motzen Mb. is represented by crinoidal micrite. Both members developed most typically during the early or middle Sinemurian. The thin-bedded nodular limestones of the **Schmiedwirt Mb.** (pl. 2/1) are found along the lower slope and basin margin (stops 1.1.d and 1.1.e). These are mud- and wackestones with few bioclasts. The basal part of the Schmiedwirt Mb. is strongly condensed (<1m). Most of it's thickness was deposited during the late Sinemurian (MEISTER & BÖHM 1993, DOMMERGUES et al. 1995).

Early Pliensbachian sediments have not been found in the Adnet area, so far. Probably, they were mostly eroded by the debris flows of the later Pliensbachian (BÖHM et al. 1995). A debrite deposited during this period is the **Adnet Scheck Breccia** (pl. 2; stop 1.1.e). It came to rest at the base of the drowned reef slope. The source area was the upper slope. The lack of mud in this initially matrix-rich debris flow can be explained with flushing by escaping pore-fluids during rapid settling of the catastrophic flow (ZALASIEWICZ et al. 1997). Early diagenetic cementation in a submarine environment flushed by bottom currents preserved the loosley packed depositional fabric (HUDSON & JENKYNS 1969, HUDSON & COLEMAN 1978, BÖHM 1992).

Deposits of the Late Liassic are only locally found in the Adnet area. They mainly outcrop in some old tumbledown quarries southeast of quarry XXXI. These are primaryly marl-rich, often strongly condensed, partly turbiditic red limestones. They are well-known from the surroundings of Adnet (Saubach Mb., BÖHM et al. 1995). This facies probably was deposited until the beginning of the Middle Jurassic (Aalenian, KRYSTYN 1971).

Nannofacies of Schnöll and Adnet Formation

The ultrafabric of representative samples of Schnöll and Adnet Formation was studied by SEM, using crushed samples, which were neither polished, nor etched, but only gold-sputtered. Most probably polishing/etching would have been a more proper method for identifying nannofossils and *Schizosphaerella* sp. However, the method applied displays clearly the state of grain preservation and the microfabric. In addition we used EDAX for identifying non-carbonate grains and areas of silicification.

In general the Schnöll and Adnet Formation shows micritic to fine-microsparitic limestone fabrics. Diagenetic alteration - evidenced by recrystallisation into microsparitic grain fabrics - and grain-corrosion are abundant features and explain the scarce findings of identifyable biota. Occasional silicification of carbonate grains is typical for the Schnöll Fm. and probably can be explained by the abundant occurrence of silicisponges. Enrichments of clay minerals, mica and of other non-carbonate grains are typical for zones of pressure solution, as e.g. stylolites. Coccolithophorida and *Schizosphaerella* sp. are comparatively scarce and always strongly corroded. Also calcispheres, sponge spicules and mollusc shell debris can be scarcely identified.

Stop 1.1.a: Church of Adnet

Topics: Facies Types of Adnet Quarries. Decoration and dimension stone.
Stratigraphy: Upper Rhaetian Limestone, various Liassic limestones of Adnet Group (Hettangian-Pliensbachian, ? Early Toarcian).

Since Roman time Rhaetian and Liassic limestones ("marbles" in the sense of polished stones) have been quarried in Adnet. Depending on the fashion of a period, the various decoration stone types of Adnet have been mined in different amounts through time. Likewise as the Untersberger Marmor (Stop 1.3), also the various Adnet limestones should be used as polished stone for interior decoration only. Inscriptions on gravestones in Adnet cemetery clearly demonstrate the fast weathering of polished Adnet- and Untersberg "marbles" as a consequence of agressive waters (acid rain). The rich illustrated books by KIESLINGER 1964 and by KRETSCHMER 1992 (the latter is available at Adnet tourist office) provide excellent guidebooks through the Adnet quarries and may serve art lovers as an unique source of information in respect of the prominent usage of Adnet marble in central European art of sculpture.

LOBITZER (in WAGREICH et al. 1996) makes an attempt of a detailed description of all types of decoration and dimension stone encountered in the late Gothic church of Adnet. In the sequel some of the most important commercial names of limestones ("marbles") from Adnet will be listed in stratigraphic order, because most of these brand names represent mappable rock units and are proposed as rock formation- respectively member names of Adnet Limestone Group by BÖHM et al. (in press):

"Tropf": The name is used for coral bearing white, red, grey or greenish Oberrhätkalk/Upper Rhaetian Limestone (pl. 1/1-3). "Tropf" means drop, because the corals of "*Thecosmilia*"-type resemble drops of water. The pinnacle-shaped reef structure of Upper Rhaetian Limestone of Kirchholz hill shows a thickness of more than 100 m in the central part and pinches out/interfingers with Kössen intraplatform-basin sediments. Part of the "Tropf" is chemically very pure ($CaCO_3$>99%, MgO<0,6%, Fe_2O_3<0,03%, SiO_2<0,05%) and shows an albedo >90%, which qualifies the "Weißtropf" as potential high-grade GCC-filler raw material. In the Adnet church "Tropf" is used as polished stone at the entry-portal, in the pulpit and as pillars in the Communion row a.o.

"Schnöll": The "Schnöll" represents the variegated coloured basal formation of the Adnet Limestone Group (Hettangian) and - though only a few meters thick - surely shows the most diversified lithologies (pl. 1/4-6). Grey, greenish-grey, pinkish/white mottled, a.o. colour varieties, often with casts of ammonites, brachiopods and siliceous sponges make this stone an object in great demand. Discolouring along fractures attributes attractive bright colour patterns. The upper part of the "Schnöll" occasionally comprises yellowish/cream coloured varieties rich in ammonites and foraminifera. This socalled Enzesfeld Limestone never exceeds thicknesses of a few decimeters and shows the characteristic Marmorea-Fe-Oxyde crust on its top. In the church of Adnet variegated polished slabs of Schnöll can be studied in the Communion-rows and in the left column in front of the altar.

The Sinemurian Adnet Fm. s.str. overlies the Marmorea-Crust of the Schnöll Fm. Three members can be distinguished, all of them showing a characteristic red colour. The "Lienbacher" Member can be considered as Adnet Limestone pure and simple. Polished slabs are used as decorative table-tops in classic Viennese cafeterias. In the Adnet church the staircase to the pulpit, the pulpit in part, the polished column left in front of the altar and the holy-water font in front of the main entrance portal are made of "Lienbacher". From the quantitative point of view even more important is the "Schmiedwirt" Member (old name "Wimberger"), which shows the greatest thickness of all types of Adnet Limestones (quarried in the Wimberg- or Plattenbruch). The "Schmiedwirt" respectively "Wimberger" is a red thin-layered nodular and flasered limestone, in general poor in fossils (pl. 2/1). The "Wimberger"/"Schmiedwirt" is especially suited as unpolished mass product, e.g. as decorative floor-covering (Adnet-church), for staircases, garden-walls (Adnet cemetery p.p.) and is also part of the main portal of Adnet church. The name "Schmiedwirt" Member was coined by BÖHM (BÖHM et al. 1995) in order to replace the name "Wimberger". The locus classicus of the "Schmiedwirt" Member is a quarry at Schmiedwirt, north of Adnet, where the complete section of this member is exposed. In the Adnet quarries, however, the upper part of the "Schmiedwirt" has been eroded in the Middle-Late Liassic and was resedimented as "Scheck"-Breccia.

Relatively little known and used is the third facies development of red Adnet Limestones, the "Motzen" Member. Quarrying has been started again a few years ago. The "Motzen" is a rather monotonous red bedded micritic limestone with dispersed coarse crinoids (pl. 2/2). Blocks of "Motzen" are incorporated in the wall surrounding the Adnet cemetery.

Certainly the most famous rock of Adnet quarries is represented by the "Scheck" Member (pl. 2/4-6). The name "Scheck" means speckled or maybe better fitting is "tabby" - dotted as a cat. The "Scheck" represents a submarine gravity debris-flow breccia consisting of poorly sorted clasts derived from escarpments of Adnet Limestone (e.g. "Lienbacher") as a consequence of strong seismic activity. The lumina between the clasts are cemented by various generations of carbonate cement. The resedimentation of the "Scheck" took place in the Late Pliensbachian or Early Toarcian. The "Scheck" represents the upper member of Adnet Group s.l., overlain only by a thin sheet of crinoid-bearing marls, which can be considered as equivalents of the Toarcian Saubach Member. The genetic aspects of the "Scheck" are in discussion for a long time. BÖHM et al. (1995) and ZALASIEWICZ et al. (1997) provide the latest contributions. In the church of Adnet "Scheck" is extensively used from the main portal, to the pulpit, for a modern baptismal, a.o.

Stop 1.1.b: Kirchenbruch - Rhaetian Reef and Jurassic Fissures

Topics: Late Rhaetian reef limestones with coral colonies and megalodontids. Jurassic fissures.
Stratigraphy: Upper Rhaetian, Marshi zone.

At the Kirchenbruch, just behind the Adnet church, a recently cut wall exposes massive Rhaetian reef limestones rich in corals and megalodonts. The quarry shows the oldest strata exposed at Adnet. About 40 m vertical thickness of Rhaetian reef limestones are exposed here. Above the top of the quarry 10 to 20 additional metres are exposed in quarry IX (stop 1.1.h) until the Triassic-Jurassic boundary is reached. A borehole drilled in the nearby Eisenmann quarry (situated at the road to stop 1.1.d) penetrated more than 100 m of Rhaetian reef limestones but did not reach its base. A total thickness of ca. 150 m can be estimated from comparison with the contemporaneous Rhaetian reef mounds in the surroundings of Adnet (Feichtenstein, Rötelwand, PLÖCHINGER 1990, SCHÄFER 1979).

Vertical neptunian dykes, filled with red Jurassic sediments are common in the Kirchenbruch. As exposed in this quarry, they cut at least to a depth of 50-60 m through the Rhaetian. Their formation already started during the Hettangian. This is evident from fillings of typical Enzesfeld limestones (upper Hettangian) in the rear parts of the quarry. Fissures filled with radiolarite (Oxfordian) show the continuation of tensional fracturing until the Late Jurassic.

The Kirchenbruch is situated at the southwestern rim of the block carrying the Rhaetian and Liassic outcrops. This block is cut off at its southern edge by a major fault. The southern block was lowered by several hundreds of metres. Therefore, south of Adnet up to the southern rim of the Osterhorn block only Upper Jurassic and Cretaceous rocks are found. The Rhaetian limestones immediately adjacent to the fault show traces of a strong, ductile deformation.

Stop 1.1.c: Regional Overview - Tectonics and Topography

Topics: Overview of the Adnet basin and the Salzach valley, the Rossfeld and Dürrnberg (Hallstatt nappe), Göll reef and Reiteralm nappe (Juvavic nappe).

Stop 1.1.d: Rotgrauschnöll Quarry - Structures and Facies of the Early Post-Drowning Sediments.

Topics: Outcrop of the Schnöll Formation. Submarine carbonate sand fan. Submarine erosional unconformity. Hardgrounds and ferromanganese crusts. Syn-drowning sponge fauna. Onlap structures. Synsedimentary collaps structures. Liassic fissures.

Stratigraphy: Schnöll Fm. (Adnet Group), Hettangian. Adnet Fm., Basal Unit, Sinemurian.

The Rotgrauschnöll quarry is situated beside the road through the valley east of the Adneter Riedel. The quarry is positioned at the east side of the valley at the bottom of the Unterguggen (Fig. 3b). At the western side of the valley a fault runs along the foot of the Adneter Riedel, which has downfaulted the Unterguggen block by roughly 30-40 m. The quarry, which was extensively exploited during the past few years, exposes limestones of the Hettangian and the lower part of the Sinemurian Adnet Fm. Further to the east some abandoned quarries show the continuation of the Stratigraphic sequence up to the Upper Liassic. This is one of the rare occurrences of Upper Liassic in the Adnet area. Sedimentary structures and sedimentology of the Schnöll quarry were recently described by BLAU & GRÜN (1996).

The quarry is divided in two parts. The left (northeastern) part exposes a 5 m thick section of reddish-yellowish limestones of the upper Schnöll Fm. These are biomicrites with sponge spicules and crinoids. Large hexactinellid sponges are very

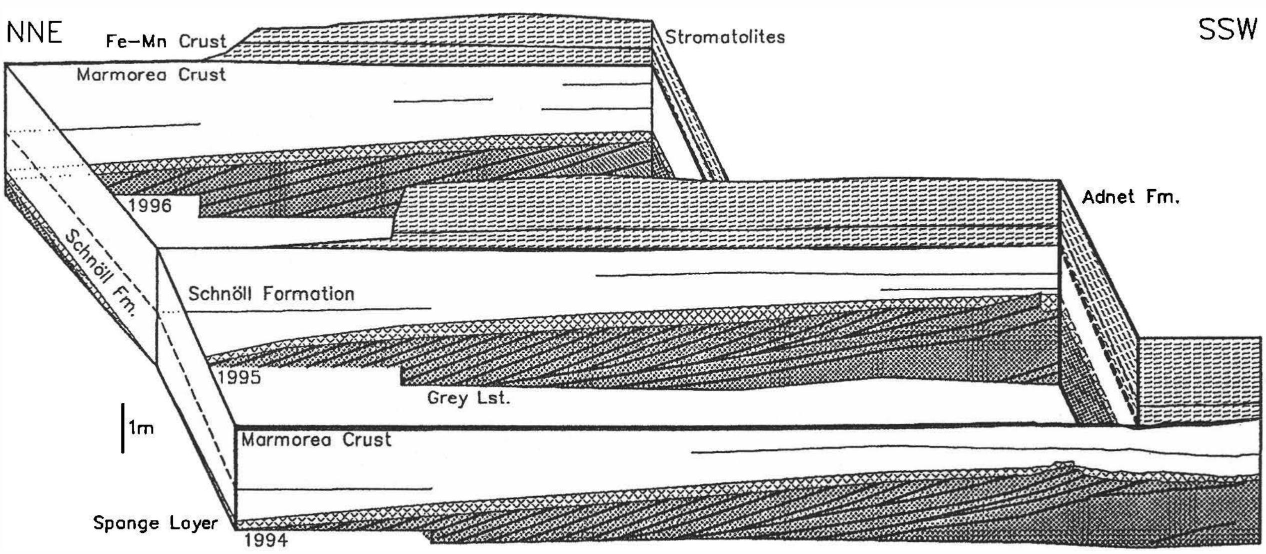
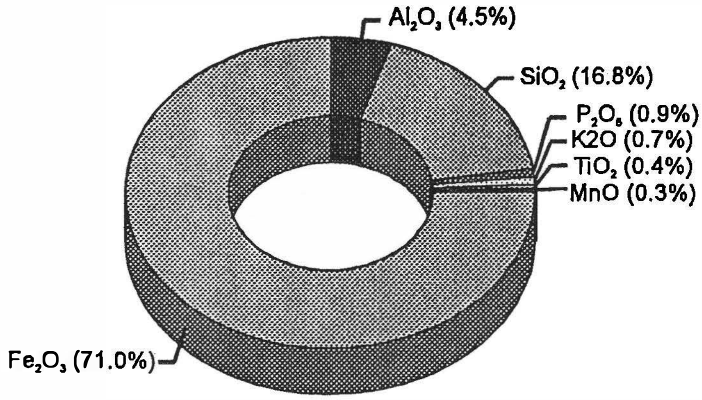
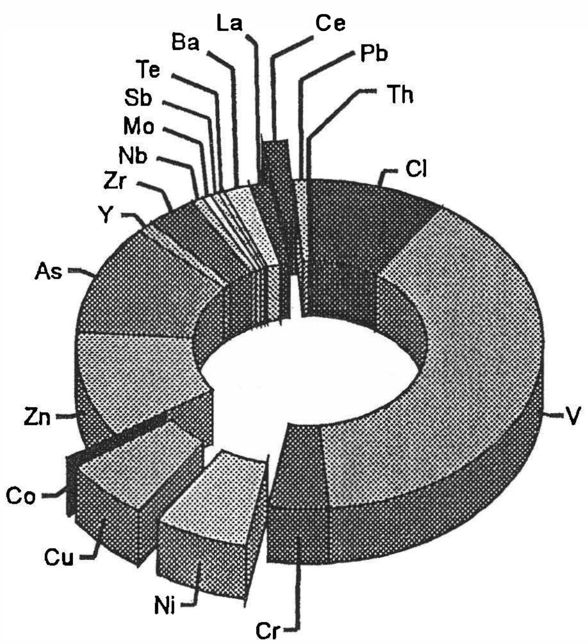


Fig. 8: Tectonically restored three-dimensional view of the Schnöll quarry, reconstructed from three different quarrying states since 1994. The Marmorea Crust and geopetal infills parallel to the crust are used as reference level for tectonic back-rotation. Crossbedding of the grey limestones is shown schematically. They display a slightly wavy surface, dipping to the northeast, which is onlaped by the wedge of the upper Schnöll Fm. In constrast, the Adnet Fm. above the Marmorea Crust shows no thickness changes.



Major Elements
(Means of 3 Samples)



Trace Elements
(Means of 3 Samples)

Fig. 9: Weight percentages of some major and trace elements from XRF analyses of the Marmorea Crust from differrent locations of the Osterhorn Block. Note the very low Mn-content! The trace elements Ni, Cu, Co and Ce are present in very low concentrations only. These elements would be much more enriched if the crust were precipitated from normal marine water. Thus, the element concentrations point to an anormal composition of the water from which the crust precipitated, e.g. a hydrothermal component (KINDLE 1990). From BÖHM et al. (in prep.), BÖHM & LOBITZER (1997). Major elements are converted to values of carbonate-free samples.

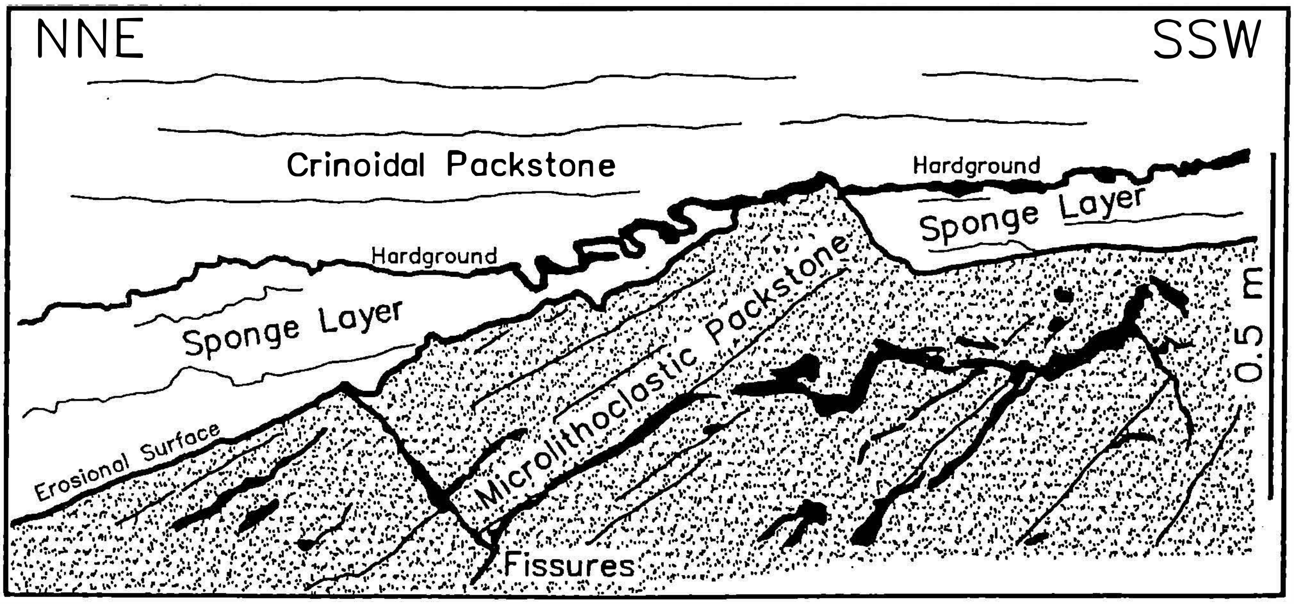


Fig. 10: Sketch of a wall in the southwestern part of Schnöll quarry showing the erosional surface at the top of the crossbedded unit (? lower Hettangian, microlithoclastic packstones). Crossbedding is partly traced and partly crossed by fissures. Parts of the beds are broken off at the erosional surface. The resulting relief is nearly leveled by the overlying sponge layer (Schnöll Fm., middle Hettangian). It is capped by a ferromanganese crust, overlain by crinoidal packstones of the upper Schnöll Fm. The latter show increasing thickness towards the northeast (Fig. 10). Rotgrauschnöll quarry, Adnet, May 1992.

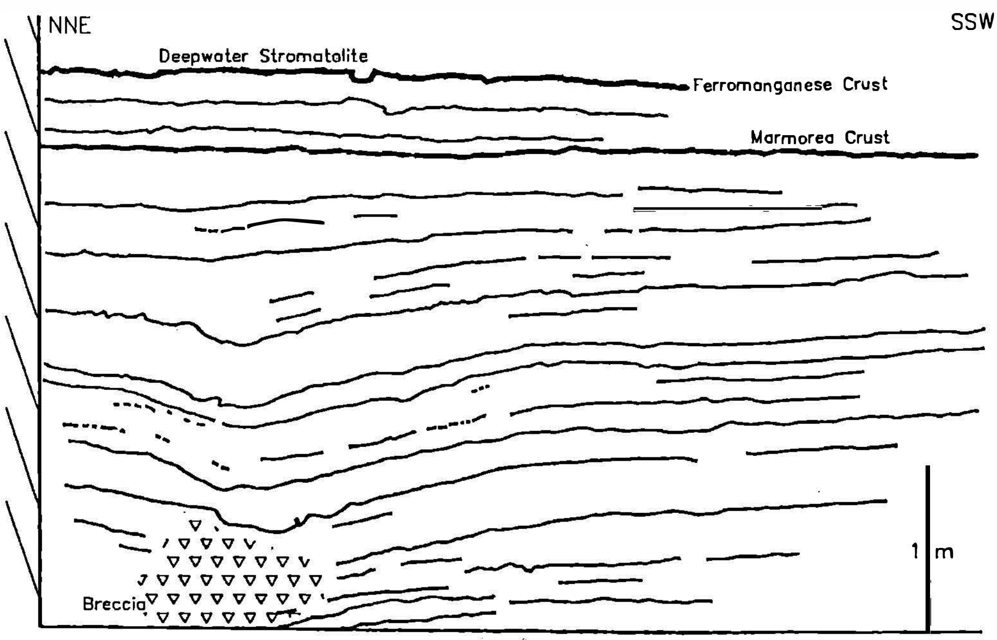


Fig. 11: Collapse structure at Schnöll quarry. Bedding planes bend down towards a depression, which forms above a breccia of intraformational clasts. The depression is leveled just below the Marmorea Crust, which is overlain by ca. 0.5 m of Adnet limestone and another ferromanganese crust. The upper crust is covered by deepwater stromatolites. Middle part of Rotgrauschnöll quarry, Adnet, April 1993.

frequent in the lower part. A layer with stromatactis structures occurs about 1.5 m above the ground. The crinoid-rich facies starts above this layer, ending with a conspicuous ferromanganese crust (Fig. 9), called Marmorea Crust (WENDT 1971, BÖHM et al. in prep.). The crust contains a very rich ammonite fauna of the Late Hettangian and perhaps Early Sinemurian (mainly *Schlotheimia marmorea*) described in numerous studies (e.g. WENDT 1971, LOBITZER et al. 1994, DOMMERGUES et al. 1995, BLAU & GRÜN 1996). The crust can be traced throughout the quarry. Additional ferromanganese crusts, as well as non-mineralized hardgrounds occur within the Schnöll Fm. The sediments immediately below the Marmorea Crust are characterized by a very rich and well-preserved foraminiferal fauna (BÖHM et al. in prep., BLAU & GRÜN in press, BLAU & GRÜN 1996, BÖHM 1992).

Above the Marmorea Crust the sequence continues with the red limestones of the Adnet Fm. (Schmiedwirt Mb.). It is a thin-bedded nodular limestone. The base is formed by a less well-bedded thick layer, which ends about 0.5 m above the Marmorea Crust, and is capped by another ferromanganese crust. This crust is overgrown by deepwater stromatolites (BÖHM & BRACHERT 1993).

As visible mainly in the southwestern part of the quarry, the primarily red limestones are partly bleached and the crusts are pyritized. Very likely this is a secondary, late diagenetic effect (see GALLET et al. 1993). In some places a connection of the bleached parts with fractures or faults is visible as well.

The sedimentary sequence below the Marmorea Crust is markedly different in the southwestern (right) part of the quarry. Towards the southwest a layer of grey cross-bedded limestones appears at the quarry floor (Fig. 8). These are peloidal grain- and packstones (pl. 3). The Schnöll Fm. overlies this cross-bedded unit with an erosional unconformity (pl. 3/3, Fig. 10). It starts with a decimetre-thick layer rich in siliceous sponges (pl. 1/5). The age of this layer is middle Hettangian according to ammonite-findings (BÖHM et al. in prep.). This layer is very pyrite-rich and capped by a mineralized hardground. The following sequence up to the Marmorea Crust has a strongly reduced thickness compared to the northeastern part of the quarry. Towards the southwest (i.e. towards the former reef) these crinoidal packstones (biopelmicrite, pl. 1/6, pl. 4) thin out to a thickness of only 1 m.

The grey crossbedded limestones, forming the base of the succession, show a very similar microfacies as the lower Hettangian Kendlbach beds. However, the distinction between the Kössen and Kendlbach Fm. based on microfacies is very difficult. A Rhaetian age, therefore, cannot be excluded. The crossbedding and microfacies allow an interpretation of the beds as a submarine fan, deposited at the base of the drowning reef slope (Fig. 13). After correction for tectonic tilt, the crossbeds dip towards the northeast with an angle of 20°. That is approximately ownslope. Also, the surface of this unit dips slightly (5°) to the northeast, which agrees well with the expected slope angle near the base of a reef slope (Fig. 13, KENTER 1990).

The erosion of this surface very likely took place in a submarine setting. That is evident from the typical marine carbon and oxygen isotope values measured in micritic matrix near the top of the unit (^{13}C+2.5‰ PDB, ^{18}O-1.1‰ PDB, Fig. 12, BÖHM et al. in prep.). BLAU & GRÜN (1996) discuss the origin of this discontinuity and also prefer a submarine interpretation. The grey limestones are cut by fissures, often terminating at the erosional surface (Fig. 10). The fissures are filled by red limestone. Their tensional origin is evident from the lack of dissolution-enlarged cavities and the good fit of corresponding fissure walls (BLAU & GRÜN 1996).

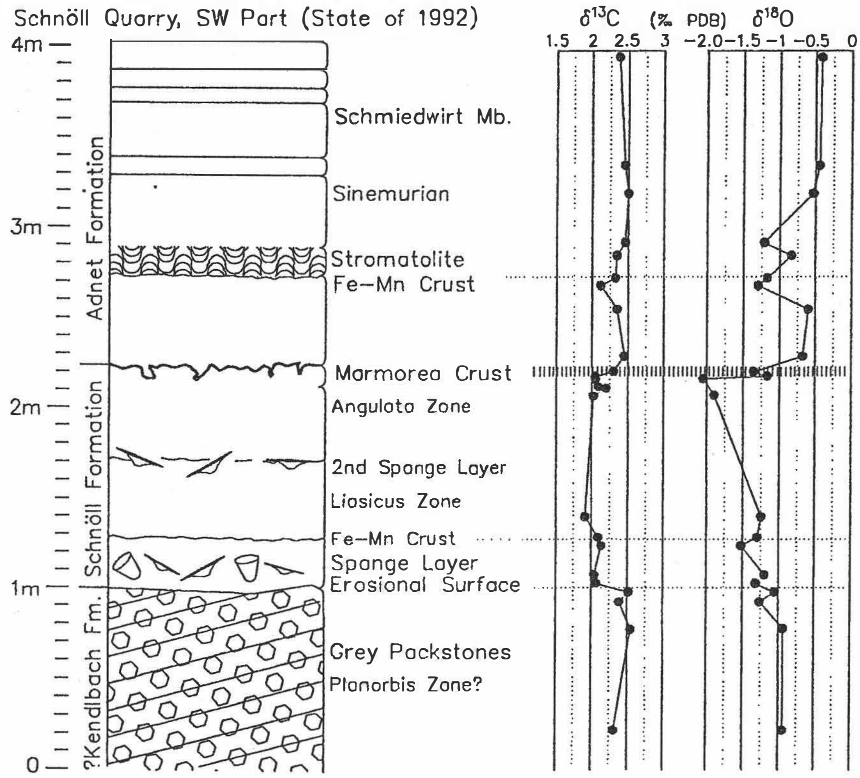


Fig. 12: Stable isotope record of rock matrix in the southwestern part of Schnöll quarry. Section from crossbedded basal unit to basal Adnet Fm. Carbon and oxygen isotope values just below the top of the crossbedded unit are not compatible with an subaerial origin of this erosional surface. Carbon isotope values of the Schnöll Fm. are slightly reduced compared to the underlying and overlying limestones. Oxygen isotope values of the Adnet Fm. are significantly higher than those of the underlying units. They agree very well with values measured in higher parts of the Adnet Fm. at the Schmiedwirt quarry (Fig. 17). They point to formation/recrystallization below a pycnocline. Measurements by M.M. Joachimski, Geological Institute Erlangen. External precision better than 0.05 permil, all values in permil PDB.

A detailed structural analysis of these dykes, necessary for their interpretation, is still lacking. BLAU & GRÜN (1996) took these neptunian dykes as evidence for a tensional tectonic event. They interpreted the eastward dipping top surface of the crossbedded unit as a result of eastward tectonic tilting. We rather suggest that the dip of this surface reflects the primary slope of the Adnet reef or of the submarine fan and not a synsedimentary tectonic tilt. The strongly increasing thickness of the lower Schnöll Fm. northwest of the Schnöll quarry (up to 9 m in quarry XVII) contradicts an eastward tectonic tilt, while it can easily be explained by a slightly curved depositional slope of the drowned reef mound. We also see the possibility that the generation of neptunian dykes may have been caused by the collapse of a large cavity (Rhaetian karst cavity?) below the quarry, which is suggested by structures reminding of sink-holes visible in the middle of the quarry (Fig. 11), as

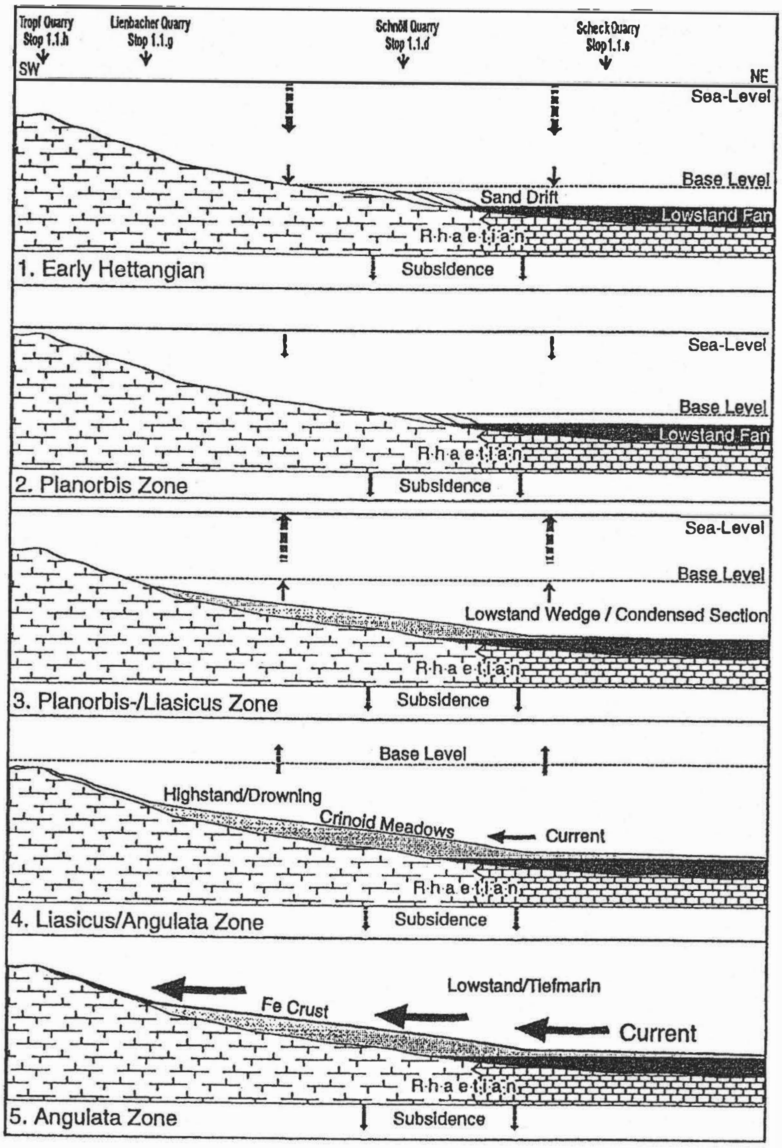


Fig. 13: Sequence stratigraphic interpretation of the Hettangian at Adnet: 1.: Early Hettangian, Pre-planorbis/Planorbis chron. Falling sea-level, late highstand/early lowstand systems tract (LST). Basal Kendlbach beds form as a lowstand fan from turbidites shed from the platform margins. Higher parts of the platform emerge. At the base of slope a carbonate sand fan develops (Schnöll quarry). At the higher slope wave action erodes or prevents sedimentation. 2. Planorbis chron. Sea-level at lowest point. Even the sand fan at the base of the slope is eroded by wave action. Only in the basin sedimentation continues (lower Breitenberg Mb., lowstand fan). 3.: Late Planorbis/Liasicus chron. Rising sea-level, late LST and transgressive systems tract. Rising base level allows onlap of the lower Schnöll Fm. at the lower slope as a lowstand wedge. Poorly oxygenated, nutrient-rich bottom-water foster dense sponge populations. Drowning of the platform. Reduced input of siliciclastic sediments and condensed sedimentation of glauconite-rich limestones in the basin. 4. Liasicus/Angulata chron. Highstand systems tract. Change to sedimentation of crinoidal limestones in Schnöll and Kendlbach Fm. by better oxygenation and reduced nutrient input. Progressive platform drowning. 5. Angulata chron. Sea-level falls again, but has no immediate influence as drowning has already increased waterdepth substantially. Indirect influence through enhanced current activity. Strong condensation and finally formation of ferromanganese crust.

described below. Other possibilities for generating the dykes could be gravity sliding (WINTERER et al. 1991) or sea-floor cementation (SHINN 1969). With the currently available data, however, a conclusive interpretation is not possible.

Two conspicuous structures with downward bending bedding planes (Fig. 11) can be seen in the middle part of the quarry. Near the quarry floor a breccia forms the base of the structure. Higher beds are less strongly bended and the last bed below the Marmorea Crust finally levels the depression. Bedding-parallel and vertical fissures (BLAU & GRÜN 1996) point to a tensional formation of the structures. In concert with the breccia they reflect the presence of a collapsed cavity below the quarry floor. The collapse occured shortly before the formation of the Marmorea Crust. Its cause is still unknown. A break-down of a Rhaetian karst cavity or a tensional fracture seem possible.

A noticable feature of the erosional surface on top of the crossbedded limestones is its dense population of siliceous sponges (pl. 1/5). This sessile fauna is in strong contrast to the corals and calcareous sponges inhabiting the Rhaetian reef. The siliceous sponges represent a transitional hardground fauna settling in a deeperwater environment generated during the drowning. These sponges are far less common in sediments above the sponge layer. On hard substrates of the Sinemurian Adnet Formation sponges are very rarely found, while sponge spicules are still very common.

A revealing feature for interpreting the sedimentary environment is the onlap of the crinoidal Schnöll limestones on the relief of the submarine fan. While the sponge layer shows a very constant thickness throughout most of the quarry, the overlying muddy sediments were first deposited in the sheltered depression beside the sand fan (Fig. 8). This points to a strong bottom current, favouring the settling of sessile suspension feeders (sponges, crinoids), while preventing the sedimentation of mud on the slightly inclined hard substrate of the sponge layer. The change from a sponge to a crinoid dominated fauna points to environmental changes.

Microfacies of Limestones from the Schnöll Quarry

This description focuses especially on the basal parts of the sequence exposed in the Schnöll quarry. The Adnet Fm. and the Lower Schnöll Fm. are only shortly touched. For further information see BÖHM (1992) and EBLI (1997).

Basal Crossbedded Unit ("Kendlbach limestones")

MF 1: Microlithoclastic Pelbiomicrite to -sparite with Echinoderms (pack- to grainstone):

The main components of this lithology are microlithoclasts and peloids, varying in abundance between 20-50%. The microlithoclasts are mostly well to moderately rounded and have a diameter of up to 1.1 mm. Mostly they can be interpreted as intraclasts, whereas also some clasts represent strongly micritized bioclasts, especially echinodermal remains. Sometimes the peloids are very densly packed, and then have stylolithic contacts.

The biogenic components are mainly represented by echinoderms (<30%) and debris of often thick-shelled bivalves and brachiopods (<10%). Foraminifera are rather rare (4-12 individuals/cm^2). Miliolids dominate, followed by arenaceous foraminifera and the rare lagenids. Sometimes the echinodermal remains and tiny fragments of bivalves are encrusted by cyanobacteria.

The micritic matrix is often recrystallized to microspar. Sometimes it has a yellowish colour. In this case the components are often surrounded with fibrous A-cement, dog-tooth cements (length of up 0.056 mm, width of 0.024 mm) or bladed calcite (length 0.12 mm, width 0.08 mm). Pyrite is finely dispersed in the sediment, but can also be enriched in small patches.

The matrix can also be primarily washed out. This is the case in the cross-bedded layers where micritic and sparitic foresets change. This sedimentological characteristics are mostly obscured by post-depositional phenomena, especially by diagenetically induced growth of calcite (pl. 3/1-2, 4-5). Elongated bioclasts as bivalves are well orientated.

At the top of such a redeposited sequence a very fine-grained, cross-bedded sediment (diameters between 0.008-0.04 mm) is relicticly preserved. It is interpreted as the finest part of a calci-turbidite. The sequence starts with a parallel-laminated fine-grained sediment (plane-bed, more proximal calci-turbidite) followed by a mostly non-erosive inverse graded biomicrite, that exhibits in its upper parts a coarse-tail-grading. One lithoclast has the extraordinary diameter of 4,5 mm! Due to this sedimentary features this sediment is interpreted as a debris-flow.

Upper Schnöll-Formation (Guggen Mb.)

The contact to the underlying crossbedded unit is a sedimentary discontinuity, therefore erosive and sharp. The underlying surface is strongly bioeroded, with borings that penetrate several mm down into the rock. The partly dichothomous borings (pl. 3/3: B) are filled by a yellow-brown phosphorous, or a dark Fe/Mn-rich sediment, indicating a time of very slow or non-sedimentation after their construction The same sediments are preserved only in pockets of this relief and sealed by a very thin sparitic crust with a thickness between 8-20 micron (pl. 3/3: arrows) that can also lie directly upon the rocks of the crossbedded unit. Therefore, sedimentation was only possible in depressions.

Also the microfacies and the biota change abruptly. Noteworthy are neptunian dykes cutting deep into the rocks of the Schnöll-Fm. and ending at the contact to the crossbedded unit. The dykes (pl. 6) are filled either by a densely packed echinodermal biosparite to micrite, having sometimes a high lithoclast content, or by a fine siltitic sediment. Filling was polyphase, as indicated by lamination.

The contact to the normal sediment is mostly very sharp, sometimes pronounced by stylolites. Only rarely the dykes grade continuously into the sediment, indicating fracturing of the rocks in a semi-lithified stage. In thin-sections 2 generations of dykes can be identified.

The sediments of the Schnöll Fm. in Quarry XXXI mostly correspond to MF-type 2.2. MF-types 2.1. and 2.3. to 2.5. represent end members that are linked with this microfacies by a continuous spectrum of mixing of the distinctive biogens and allochems.

Cyano-oncoids are very characteristic components of the Schnöll-Fm., Guggen Mb. They consist of massive, only rarely laminated micrite. JENKYNS (1972) termed such components as "pelagic ooliths" or "micro-oncoids". For their genesis the sediment-binding activity of cyanobacteria was responsible (op. cit.).

MF 2.1, Bivalve-gastropod biomicrite (wackestone), pl. 3/3:

Shell fragments of bivalves, gastropods and echinodermal remains (together 15-20%) constitute this sediment type. The foraminiferal fauna includes most forms characteristic for the Schnöll Fm., but reveals low densities. Bioclasts can be impregnated by Fe/Mn-oxides or by yellowish-brown phosphorous precipitates. Cyano-oncoids are missing!

MF 2.2, Echinoderm-Foram-Biomicrite with cyano-oncoids (wackestone to packstone). pl. 4/1, 3:
The sediment mainly consists of echinoderms (10-25%), spicula (3-10%), thick-shelled ostracodes (3-15%) and bivalve debris (5-15%). Further components are gastropods (ca. 2,5%), and the omnipresent cyano-oncoids. Angular intraclasts (pl. 4/1: arrows) reveal the synsedimentary reworking of the sediment. The characteristic foraminifera reach abundances of 15-34 individuals/cm^2. Involutinids dominate over Lagenids, Miliolids and the rare arenaceous forms. Sclerites of holothurians (*Theelia* sp.: pl. 5/5) occur in one sample. Serpulides and the microproblematicum *Globochaete alpina* are rare. The matrix of the sediment is a reddish-yellowish to grey micrite to microsparite, often exhibiting stromatactis structures, filled by a coarse spar. In some samples the foraminifera, other biogens or the meshwork-structure of echinoderms are filled with glauconite. This mineral can also be enriched around sponges. Pyrite is especially abundant in the basal parts of the Guggen member. and occures in patches or is finely dispersed in the sediment. Bioturbation is common in some layers.

MF 2.3. Bivalve-Ostracod Biomicrite with Cyano-Oncoids (Wacke- to Packstone), pl. 4/2:
The reddish-white mottled sediment consists mainly of the debris of thick-shelled bivalves (20-30%), ostracodes (<10%), spicula (10-15%) and gastropods. Cyano-oncoids and lithoclasts (together 5-7,5%) are reddish-brown in colour.

MF 2.4, Cyano-Oncoidal Biomicrite (Packstone), pl. 4/4:
In some layers the cyano-oncoid content is enriched up to 50%. The components are surrounded by a grey micritic to microsparitic sediment. Echinoderms reach up to 10%, and are therefore rarer as in MF 2.1., as is also true for the other above mentioned biogens. Vagile foraminifera in the sediment reach abundances up to 13 individuals/cm^2. The faunal composition is the same as in MF 2.3. (In 10, Lag. 5, Mil 4)

MF 2.5, Spiculite with Cyano-Oncoids (Wackestone), pl. 5/1:
Spicula of mostly hexactinellid sponges (20-40%) are the main bioclasts. Echinoderms (5%), cyano-oncoids (1- max. 5%), rare foraminifera and remains of gastropodes and bivalves complete the spectrum. The matrix is often a bioturbated, silicified dark-grey peloidal to pure micrite. Sometimes the spicula are fully replaced by pyrite, or only the axial-channels are impregnated (pl. 5/4).
In contrast to the sponge-fragments (pl. 5/2-3) that are characterized by a cubic meshwork of spicula, the spicula are more randomly orientated in this MF-type. They also have a layered occurence due to disintegration and redistribution by current-activity, whereas the sponge-fragments have a patchy distribution.

Enzesfeld limestone
The Enzesfeld limestone is represented at Schnöll quarry and Lienbacher quarry by a thin condensed layer (hardground), below the Marmorea Crust.
MF 4, Echinoderm-Foram-Biomicrite with Gastropodes (Wacke- to Packstone), pl. 6, 7:

This lithology is characterized by a high content of foraminifera (up to 60 individuals/cm^2; especially Involutinids) that occur with echinoderms (<25%), ostracodes, gastropodes and debris of bivalves, brachiopodes and ammonites. The microproblematicum *Globochaete alpina* is common. Pelagic crinoids (pl. 7/3) occure. Intercalated hardgrounds can consist of brownish-yellow phosphatic sediment or of dark Fe/Mn-oxides, the latter being massive (pl. 8/1) or laminated (pl. 8/2). In one case a radiolaria (pl. 8/3) survived diagenetical solution due to the fact, that it was incorporated in a massive crust!
Spicula are mostly rare, only in some samples they have a greater abundance (up to 5%). Moreover, in other samples more or less intact sponges occure. The matrix can bear a very high content of calcareous nannoplankton (pl. 7/2, 5, 6). Intraclasts occur locally. Noteworthy is a platy lithoclast in a sample from Lienbacher quarry (max. diameter: 2,5 mm, pl. 7/4), that was eroded from the underlying Rhaetian neritic limestones.

Adnet Formation
In the investigated section only the Basal Unit of the Adnet Formation was sampled. It exhibits a rather uniform microfacial appearence.
MF 5, Bioturbated Ostracod-Echinoderm-Mollusc Biomicrite (Wackestone), pl. 8/3-4: As the most important group of biogens, ostracodes, filigrane mollusc-shells and echinodermal remains reach up to 20%. Of special interest are very tiny remains of pelagic crinoids (pl. 8/3). Additional spicula, very fine-grained and therefore no more determinable biogenic detritus, the microproblematicum *Globochaete alpina*, and forams appear. In several patches the bioclasts are strongly recrystallized, and the ghosts are filled by a mosaic of relatively dark microsparite. The darker matrix of the sediment is bioturbated and contains several irregular nodules, that are only sometimes surrounded by Fe/Mn-coatings.

Stop 1.1.e: Scheck Quarry - Mid-Liassic Debris Flow

Topics: Outcrop of the Adnet Formation, Schmiedwirt and Scheck Member. Nodular limestone. Channel erosion and fabrics of the Scheck breccia.
Stratigraphy: Adnet Fm., Sinemurian/Domerian (lower and middle Liassic).

The Scheck quarry consists of several neighbouring smaller quarries, where the most popular of the Adnet decorative stones is exploited: the Adnet Scheck. It is a unique breccia with often deep-red clasts of Adnet limestone and big pores filled by lightgrey spar (pl. 2/4-6).

The Scheck is a special variation of the very common middle and late Liassic breccias of the Osterhorn block (Fig. 5, 15, BÖHM et al. 1995). These Liassic breccias usually are strongly compacted with densly packed components mainly of Adnet limestone and very few matrix of dissolution-resistant residuals (pl. 2/6; BÖHM 1992). This kind of breccia can be observed at the base of the Scheck breccia at Scheck quarry. However, in the upper part of the Scheck, the primary micritic matrix was largely elutriated by escaping pore waters during settling of the debris flow components (ZALASIEWICZ et al. 1997). Residues of the primary micrite matrix are locally preserved, e.g. above the large tabular blocks seen in the upper part of the wall (liferaft structures). Resettling of some fine matrix after

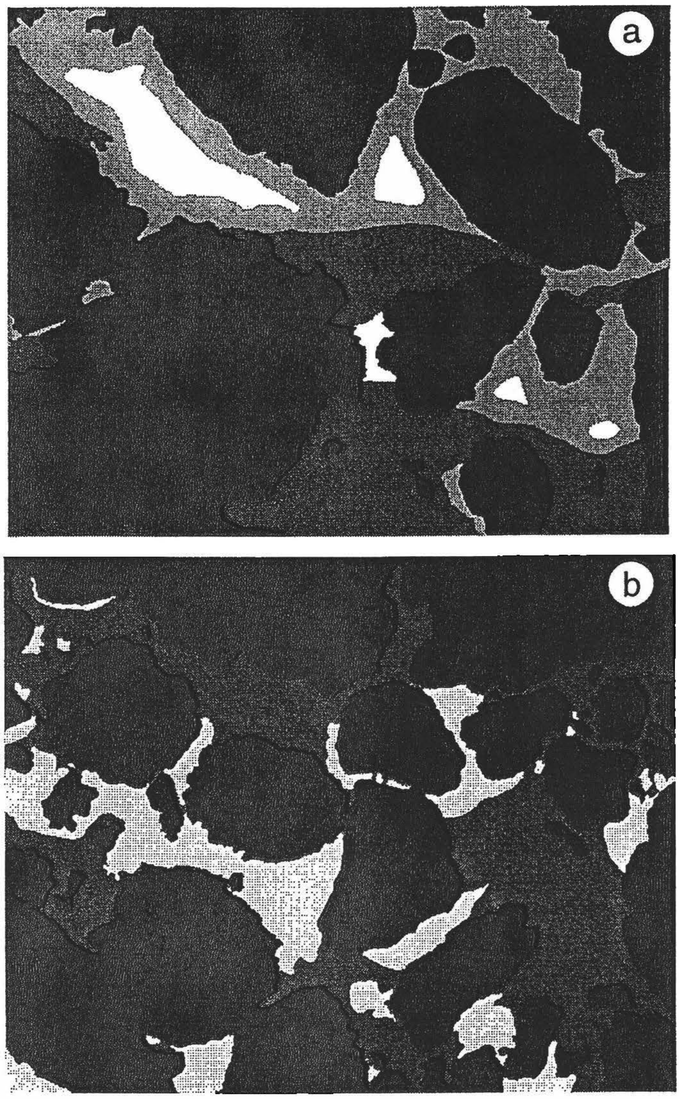


Fig. 14: Microfabric of the Scheck breccia: a. vertical section, clasts (black), matrix (mud- and wackestones, darkgrey), early radiaxial fibrous cement (light grey), and late blocky calcite (white). Width of the displayed area is 3.5 cm. Note geopetal bridge above clasts in the middle of the drawing. b. horizontal section. Cements (lightgrey) not differentiated. Note the very irregular distribution of matrix. Clasts=67%, matrix=21%, cement=12%. Width of the displayed area is 6 cm.

deposition of the flow led to the formation of flat-topped geopetal bridges above clusters of clasts (Fig. 14a, ZALASIEWICZ et al. 1997). Subsequent cementation by radiaxial-fibrous high-Mg calcite (WÄCHTER 1986, BÖHM 1992) stabilized the primary fabric and prevented the strong compaction found in the non-cemented parts of the breccias. A second, probably late Liassic, generation of marine internal sediment was locally infilled after the first cementation, filling most remaining pore-spaces (ZALASIEWICZ et al. 1997). During burial remaining pores were filled by blocky, luminescent spar. Some pore spaces, however, remained open and display the euhedral crystal faces of the late blocky calcite. In some pores a late burial infill of red crystal debris can be seen.

The thick early marine cements are evidence of an active circulation of pore fluids, probably driven by bottom currents. The isotopic composition of the cements (Fig. 16) rules out a meteoric diagenesis (Hudson & Coleman 1978). Considerably

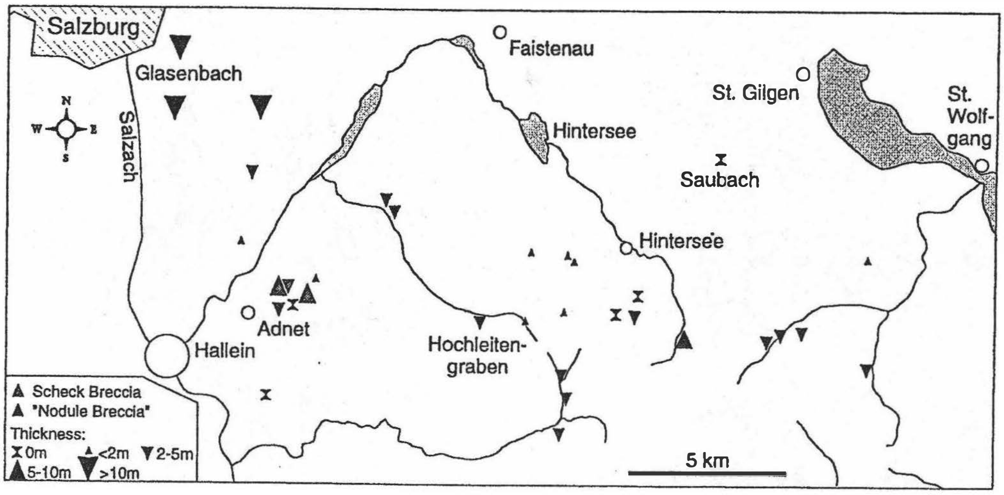


Fig. 15: Distribution and thicknesses of the Scheck breccia and equivalent breccias of the Scheck Mb. in the Osterhorn block. Areas with higher thicknesses are predominately in the NW (Glasenbach, Adnet). The Scheck with spar-filled interparticle pores is only found at Adnet. From BÖHM et al. (1995).

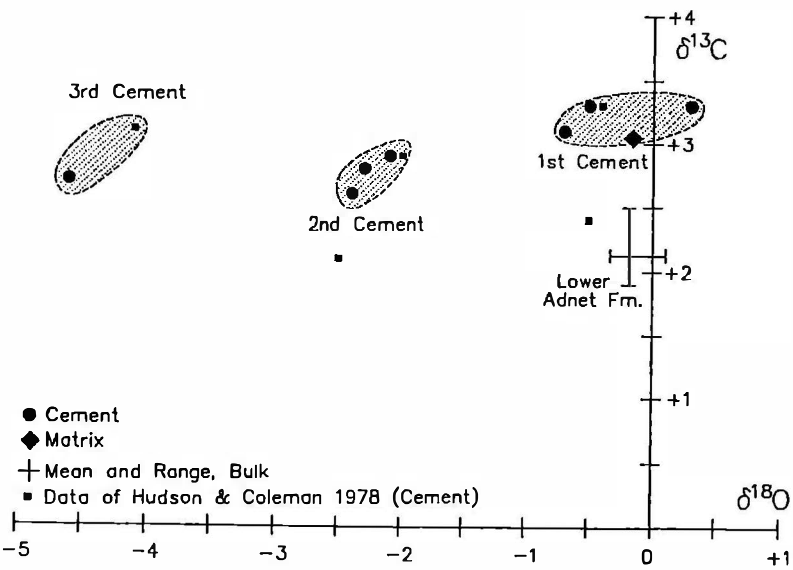


Fig. 16: Stable isotopes of cements and matrix of the Scheck breccia. Three generations of cement, differing in their luminescence (cement 1: blotchy luminescence, radiaxial fibrous; 2: non-luminescent, fibrous-scalenohedral; 3: brightly luminescent, blocky spar; BÖHM 1992), show a clear shift in oxygen isotope values, while carbon values are almost constant. This is an expected trend during increasing burial. The irregular shape of the pores hampers the selective sampling of the individual cement generations. This might explain the partly considerable differing and strongly varying values measured by HUDSON & COLEMAN (1978). Matrix and cement 1 show a clearly marine isotope signature. High oxygen isotope values point to deposition or recrystallization below the mixed ocean surface layer. The matrix of nodular limestones of the Adnet Fm. (mean value of 21 samples) shows identical oxygen but significantly lower carbon isotope values compared with the matrix of the Scheck. Isotope measurements by M.M. Joachimski, Geological Institute Erlangen. External precision better than 0.05 permil, all values in permil PDB.

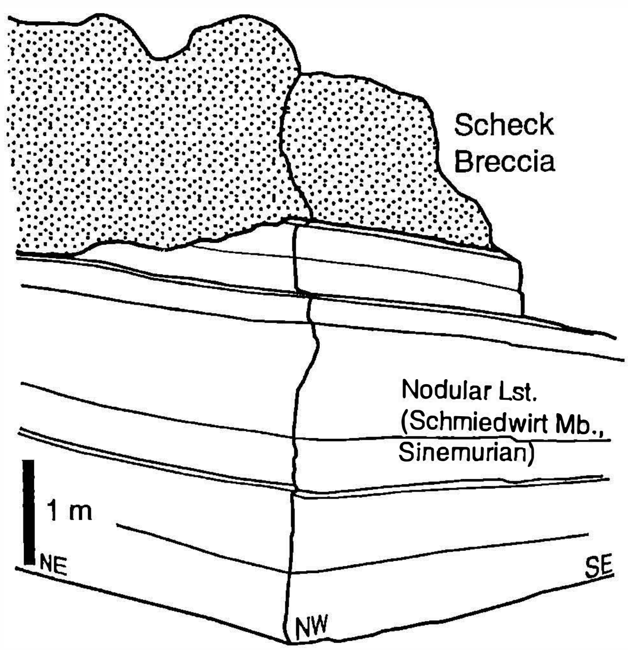


Fig. 17: Erosive contact of the Scheck breccia at quarry XLI, Adnet-Wolfgrub. The breccia (upper Pliensbachian) fills a channel in nodular limestones (Schmiedwirt Mb.) of the middle Sinemurian (Obtusum zone). From BÖHM et al. (1995).

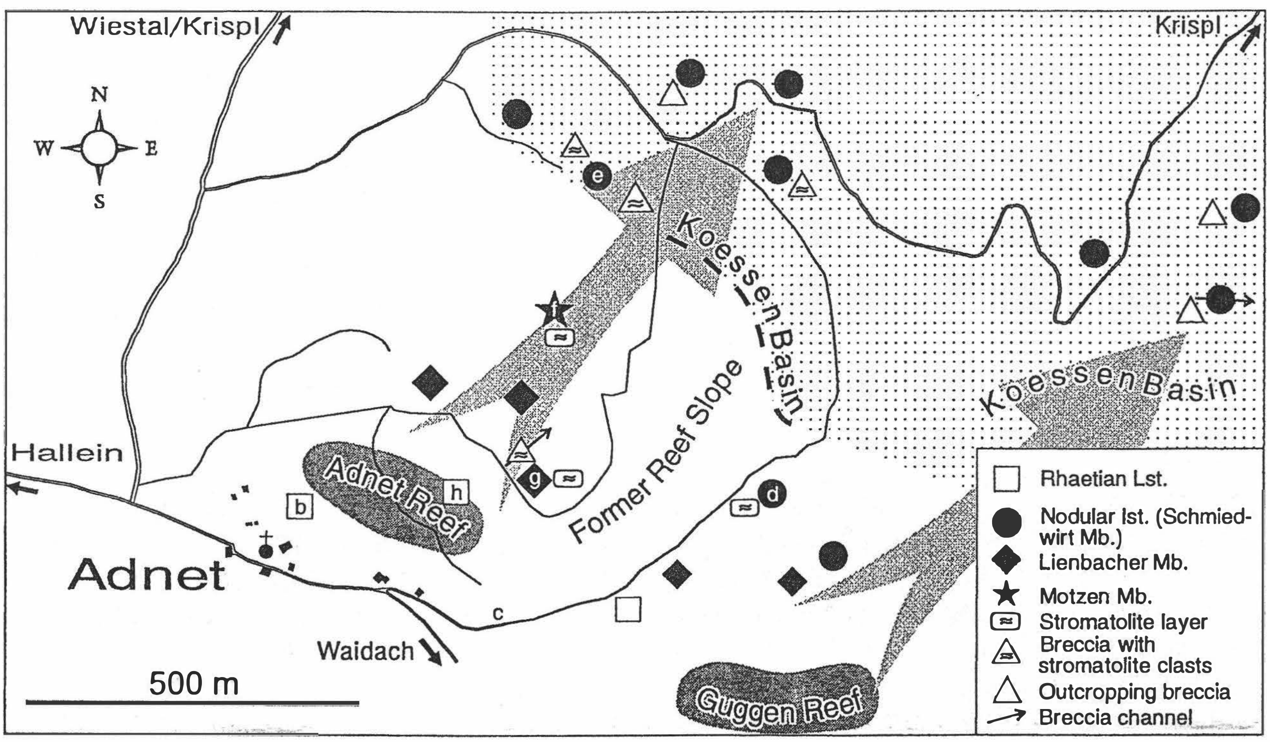


Fig. 18: Scheck outcrops and Sinemurian facies distribution of the Adnet area with the infered transport direction of the Scheck breccia. The debris flow probably followed the drowned reef slope, which during the middle Liassic was still largely unchanged. From BÖHM et al. 1995. Symbols mark positions of quarries and the respective facies. Letters in the symbols refer to stops.

decreasing oxygen and slightly decreasing carbon isotope values of the later cements (Fig. 16) are consistent with an increasing temperature and slight modification of the pore-fluids (rock-buffered system) during burial.
Early investigators suggested an *in-situ* origin of the Scheck (e.g. HALLAM 1967). This was disproven by several later authors (HUDSON & JENKYNS 1969, GARRISON & FISCHER 1969, BERNOULLI & JENKYNS 1970, BÖHM 1992, BÖHM et al. 1995, ZALASIEWICZ et al. 1997). The Scheck and the equivalent middle/late Liassic breccias originated from submarine debris flows (see also WÄCHTER 1987). For example, an inverse grading at the base and a concentration of large blocks of different facies in the upper part of the breccia can be observed in the Scheck quarry. In an other outcrop the gradual transition to graded crinoidal limestones at the top of the Scheck was observed (BÖHM 1992).

The breccias are often found in erosional channels (Fig. 17). From the orientation of the channels together with the facies distribution of the Adnet Fm., providing the breccia clasts, the approximate transport direction of the debris flow can be reconstructed (Fig. 18). Fragments of the layer of deepwater stromatolites, deposited at the slope of the drowned Adnet reef (stops 1.1.d, f, g), are especially large, conspicuous and common components (pl IV/2). The flow was probably initiated at the upper slope: At the Lienbacher quarry (stop 1.1.g), situated near the upper slope break, a gradual transition from *in-situ* Adnet limestones to a breccia with metre-sized clasts is seen near the top of a wall. The Scheck was transported roughly 0.5 to 1 km from there and came to rest at the toe of the slope.

The channel erosion visible in the Scheck quarry led to a strong erosion of the Adnet Fm. underlying the Scheck. Up to 15 m of sediment were removed locally (BÖHM et al. 1995). At the Scheck quarry the breccia (upper Pliensbachian or lower Toarcian) rests on nodular limestones of the middle Sinemurian. That is, the lower Pliensbachian and parts of the Sinemurian were eroded by the debris flow.

Stop 1.1.f: Motzen Quarry - Sedimentation on a Slope

Topic: Outcrop of the Adnet Fm, Motzen Mb., onlap structures, prograding contourite.

Stratigraphy: Adnet Fm., Sinemurian (lower Liassic).

This is a relatively new outcrop exposing sediments of the Sinemurian palaeoslope. These are reddish to red, thin to medium bedded crinoidal limestones of the Motzen Mb (pl. 2/2). They overlie grey massive Rhaetian limestones of the distal reef slope. Centimetre-thick relics of grey-red Hettangian limestones (Schnöll Fm.) and a ferromanganese crust are preserved only in small sheltered lenses and pockets of the Rhaetian surface.

As visible from geopetal infills, this quarry is still in its original position. There is no perceptible tectonic tilt. That is, the inclinations of the bedding planes (Fig. 19) reflect the palaeoslope. The Sinemurian sea-floor was dipping to the north with an inclination of roughly 15°.

The Rhaetian relief is onlaped by the crinoidal limestones (Fig. 19). Like in the Lienbacher quarry (stop 1.1.g) the onlap direction is towards the west, while the large-scale Rhaetian slope rather was inclined towards the north to northeast (Fig. 18). We therefore suggest that the Rhaetian top surface visible in this quarry rather

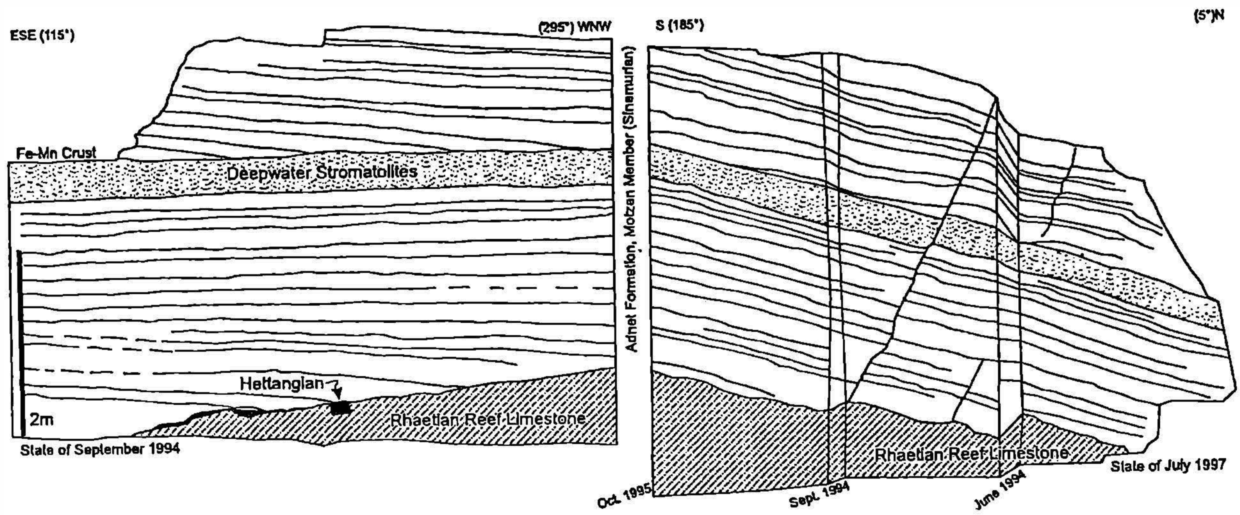


Fig. 19: View of two walls in the Motzen quarry (stop 1.1.f). Note different striking directions of the two walls. There is no detectable tectonic tilt in this quarry, therefore the bedding inclinations represent the original slope. A ridge-like structure of grey massive Rhaetian limestone with a steeply northeastward inclined surface is visible in the right part of the quarry. Small relics of Hettangian sediments occur in sheltered lenses and pockets of this surface. Onlap of Sinemurian Motzen limestones is most obvious in east-west direction (left view), but almost absent in up-slope direction (north-south, right view). Probably the crinoidal Motzen filled a small-scale Rhaetian relief, modulating the large-scale slope, which was dipping northward. Above the ferromanganese crust capping the stromatolite layer, dipping direction of the Motzen changes. The overlying beds prograde towards the west. We propose that this progradation along the northward inclined slope was driven by a contour current. These crinoidal biomicrites therefore probably represent a contourite.

represents a local depression running down-slope, filled by the Sinemurian crinoidal limestones.

There is almost no onlap in the Sinemurian slope direction, as visible on the right hand wall (western side) in Motzen quarry (Fig. 19, right). Only where the Rhaetian surface is inclined by more than 15° the Sinemurian strata onlap. Probably, 15° was the angle of repose of the crinoidal sediments. These visible geometries are best explained by a contour current sweeping along the slope and preventing sedimentation, except for the sheltered depression beside a some metres high Rhaetian ridge running down the slope. Contemporary sediments at the toe of the slope have a thickness of less than 1 m (e.g. Schnöll quarry).

A layer of deepwater stromatolites occurs about 3 m above the floor (BÖHM & BRACHERT 1993). On the eastern (left) wall asymmetric growth of the stromatolite domes provides additional evidence of the northward inclined palaeoslope. The stromatolite layer is covered by a ferromanganese crust. Strata above this crust show a different attitude. These are probably crossbeds prograding towards the west (Fig. 19). Again, the situation is best explained by a contour current sweeping along the slope and driving a sedimentary wedge towards the west.

An alternative explanation for the depositional geometries would be, to assume two phases of synsedimentary tectonic tilt, each by roughly 10 degrees. However, this would require a third tilt, bringing the block back to its original Sinemurian position. We found no indication of such tilting in the inclinations of geopetal infills (BÖHM et al. in prep.). Further, a by-chance restoration of the original position is rather unlikely. We therefore reject a tectonic interpretation.

Stop 1.1.g: Lienbacher Quarry - Proximal Debris Flow and Deepwater Stromatolites

Topics: Outcrop of the Adnet Fm., Lienbacher Mb. Condensed layer with deepwater stromatolites and ferromanganese crust. Prograding unit. Proximal debris flow.

Stratigraphy: Adnet Fm., Sinemurian and Domerian.

The Lienbacher quarry is one of the largest quarries at Adnet. It is situated very close to the Rhaetian reef core (Tropf quarry, stop 1.1.h). Limestones of the Sinemurian Lienbacher Mb. are exploited there. The Lienbacher Mb. is distinguished from the Schmiedwirt Mb. (stop 1.1.e) by thicker bedding, the lack of nodular fabrics and the frequent occurrence of intraclasts with ferromanganese coatings (pl. 2/3). These clasts often are encrusted by the foraminifer *Bullopora* and penetrated by microborings.

Entering the quarry from the east, one finds to his right a layer with stromatolitic structures about 4 m above the quarry floor. BÖHM & BRACHERT (1993) interpreted these structures as deepwater stromatolites. They were generated by microbial films binding sedimentary particles, producing a faint lamination. In contrast to supra-/intertidal stromatolites these structures lack fenestral pores and shrinkage cracks. Moreover, they always carry a pelagic fauna (ammonites and nannoplankton in this case). Typical particles of shallow-water carbonates (ooids, grapestones etc.), as well as calcareous algae are lacking. Deepwater stromatolites typically occur in condensed sequences (BÖHM & BRACHERT 1993).In this case a ferromanagnese crust is found in the middle of the stromatolite layer, pointing to a long period of non-sedimentation. The microbes forming the stromatolites probably belonged to the fungi or autotrophic bacteria. They were only able to survive during periods of very low sedimentation rates. Estimated water depth during their growth was probably in the order of some hundreds of metres (BÖHM 1992).

At the NE striking walls the asymmetric growth of the stromatolite domes reflects the inclination of the palaeoslope. As seen from the inclinations of geopetal infills, the block of the Lienbacher quarry is slightly tilted towards the southwest (BÖHM et al. in prep.). Tectonic restoration reveals a Sinemurian and Rhaetian palaeoslope of roughly 10-15° dipping to the northeast. This agrees well with the asymmetric stromatolite domes.

Like in the Motzen quarry the strata below the stromatolite layer wedge out against a ridge of Rhaetian massive limestones, outcroping in the northwestern part of the quarry (see end of this stop). However, the Liassic beds thin out to only half a metre thickness, while equivalent strata, underlying the stromatolites southeast of the ridge (major part of the quarry), have a thickness of at least 4 m.

Again, like at the Motzen quarry, a prograding unit is seen above the crust capping the stromatolites. Direction of progradation in this case is to the northwest, i.e. along the slope. However, in this case the prograding beds are stromatolitic. They probably represent a prograding biostrome.

At the main wall of the quarry, a two metres thick layer at the top of the wall is strongly brecciated (Fig. 20). Many clasts are decimetre-sized or even up to one metre large, angular and show irregular orientation. Fragments of the stromatolite layer are very frequent. They are partly positioned upside down. The matrix is a red marl. Some spots show a Scheck fabric with spar-filled pores. Laterally the breccia passes into a strongly fractured zone leading to the regular bedded Adnet limestones (Lienbacher Mb., Upper Sinemurian, DOMMERGUES et al. 1995). At the plateau above the quarry the breccia can be traced for some 20 m towards the northeast (50° in 1993). This breccia most likely represents a proximal equivalent of the Scheck. The connection with a fracture zone shows that large fragments of already lithified limestone were mobilized here. The presence of large fragments of the stromatolite layer shows that erosion cut at least one metre deeper further upslope. The Rhaetian reef slope may have continued some 50 m towards the southwest, were it probably leveled out at the reef core exposed at the Tropf quarry.

Leaving the quarry to the west one passes a recently exposed wall of Rhaetian reef limestones, overlain by some centimetres of Hettangian Enzesfeld limestone and the Marmorea crust (pl. 7) followed by the Sinemurian Lienbacher Mb. with the stromatolite layer just above the base. This is probably the same Rhaetian ridge that could be seen at the Motzen quarry. The Rhaetian is rich in framebuilders, mainly corals. The palaeo-reef-slope had an inclination of ca. 15° towards the northeast. It has now a slight tectonic tilt to the southwest. The road leading to this wall is partly "paved" by the Marmorea crust, which in this place caps the Rhaetian. Considering the slight tectonic tilt one can well envisage the slightly hummocky end-Rhaetian relief with an overall dip towards the northeast.

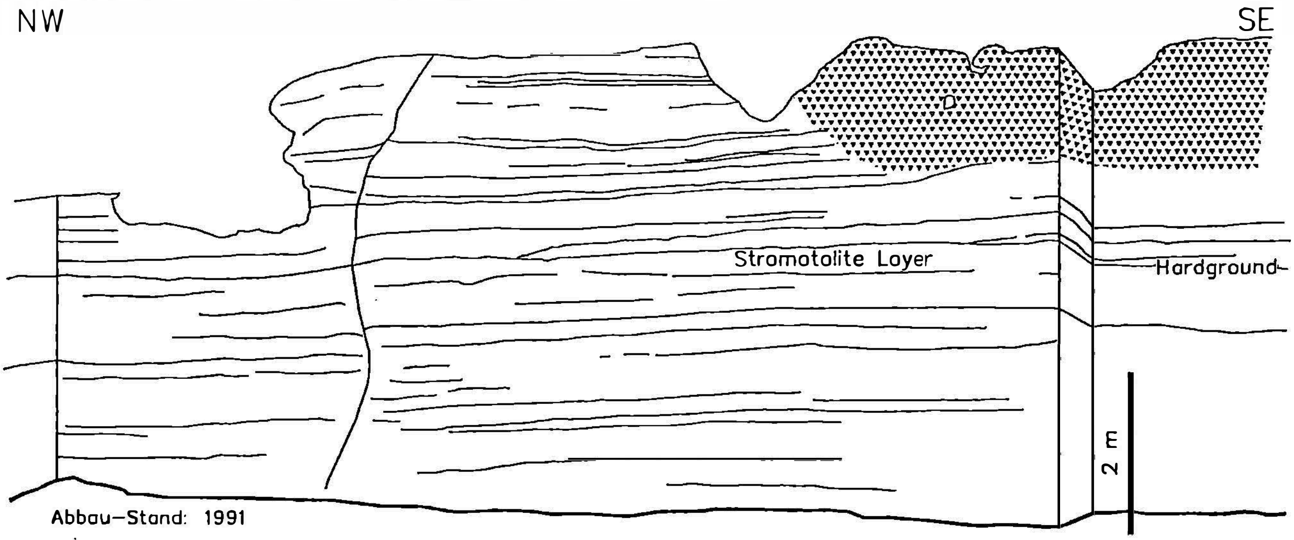


Fig. 20: View of the big quarry wall at stop 1.1.g, Lienbacher quarry. About 3 m above the ground the stromatolite layer capped by a ferromanganese crust can be seen. It is overlain by the prograding unit. The breccia at the top of the wall (proximal Scheck breccia with metre-sized clasts) is shown schematically.

Stop 1.1.h: Tropf Quarry - Rhaetian Coral Reef

Topics: Outcrop of the Late Rhaetian reef limestones, reef core facies, reef organisms. Toppled coral colonies, dissolution.

Stratigraphy: Upper Rhaetian, Marshi zone.

The Tropf quarry is the most famous of the Adnet quarries. It is world-famous as an unique outcrop of a Rhaetian reef with metre-sized coral colonies (FLÜGEL 1981: Fig. 12, HUBBARD et al. 1990). A detailed investigation by SCHÄFER (1979) made the Adnet reef a classic example of a Late Triassic coral reef. Unfortunately during the past years most walls became unsightly or were removed by quarrying.

The Adnet reef was one of the first reefs in earth history that were dominated by modern corals. Reefs of the Ladinian-Norian still were dominated by sponges. A possible cause for this faunal change and the great success of the corals as reef builders could have been the acquisition of zooxanthellate algae (COATES & JACKSON 1987, STANLEY 1988, FLÜGEL 1981, 1984).

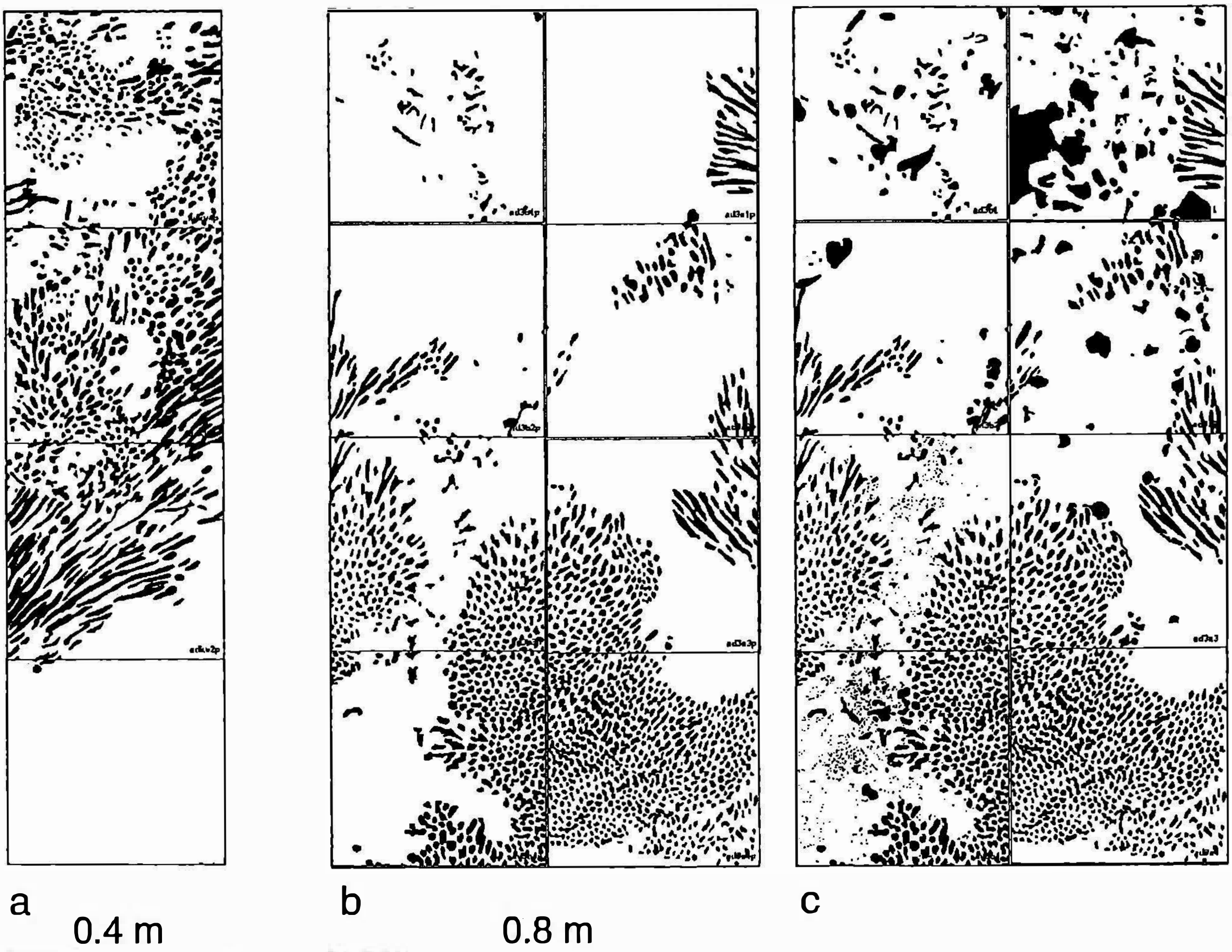


Fig. 21: Views of quarry walls at the Tropf quarry. a: Colonies of the coral *Retiophyllia* form dense thickets in the central part of the quarry (wall removed in summer 1997). b: Horizontal section of a big *Retiophyllia* colony and several small fragments of colonies. c: Same view as in b, but additional components are displayed: At the top fossil debris of the platy coral *Astraeomorpha* and calcareous sponges, down left fine-grained sand of the dasyclad alga ?*Diplopora adnetensis*. Drawings created from 1:1 copies of the quarry walls using the method of WEIDLICH et al. (1993), after WEIDLICH et al. (1992).

Big coral colonies of the genus *Retiophyllia* (formerly called "*Thecosmilia*") dominate the outcrop (Fig. 21, pl. 1/1-3). Two varieties (?species) can be distinguished by their size (SCHÄFER 1979). Other reef builders like "hydrozoans", sphinctozoan sponges or platy corals (*Astraeomorpha*) occur only rarely, mainly in patches of fossil debris (Fig. 21b,c). A patch dominated by platy corals is, however, now visible at the base of the big wall in the center of the quarry. It forms the core of the reef and is overgrown by coral thickets of *Retiophyllia*.

Many of the coral colonies lie upside down. Many corals have been completely dissolved and later filled by cement or internal sediments (pl. 1/1-3). This points to an early meteoric influence, an assumption that is, however, not confirmed by stable isotope values (Fig. 22). Many colonies are abraded at discontinuity surfaces.
The fine-grained sandy matrix between the corals is very rich in dasycladaceans. *Diplopora adnetensis* dominates this flora (FLÜGEL 1975, SCHÄFER 1979). In the upper part of the walls a some metres thick layer of sediment free of corals can be seen. Megalodonts are frequent in this facies (ZAPFE 1963). At the very top of the Rhaetian, however, normal coral limestones occur again.

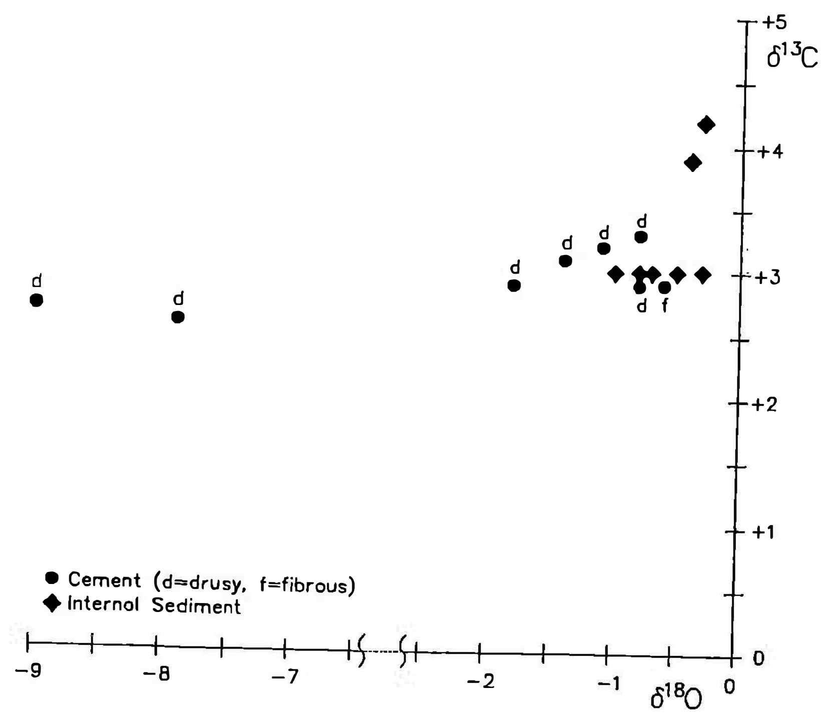


Fig. 22: Stable isotopes of cements and internal sediments in pores (framework pores and dissolved corals) in the Tropf quarry. Except for two samples of drusy cement, all values are typical for a marine environment. Oxygen isotope values are rather high for the normal marine milieu that most likely can be assumed for the Adnet reef. They might be explained by recrystallization or cementation in colder deepwater after drowning. The oxygen isotopes of the drusy cements show a trend to more negative values. This can best be explained by cementation during increasing burial. The very high carbon isotope values of +4 permil could be caused by a high aragonite content of the sediments and recrystallization in a closed system. Measurements made by J. Hladikova at the isotope lab of the Czech Geological Survey in Prague.

Stop 1.2: Quarry of Leube Cement Company/Gartenau

Topic: Continuous sequence from Late Jurassic to Early Cretaceous (Late Valanginian) pelagic limestones and a hanging coarse clastic, respectively "Wildflysch" development.

The quarry of Leube Cement Co. on Guthratsberg in Gartenau exposes an unique section of Tithonian to Late Valanginian pelagic Aptychus Limestones and various distal fan sediments of the late Early Cretaceous (Hauterivian-?Barremian) (Plate 10, Fig. 1). The quarry represents one limb of an anticlinal fold (Schneiderwald-Antiklinale), which owes its origin to diapiric uplift caused by Permian evaporites of the "Haselgebirge" Group. Probably due to shearing of bedding planes in the course of anticlinal fold tectonics, macrofossils are rather scarce and consist of rare findings of aptychus, belemnites and trace fossils. However, the microfossils, especially the calpionellids, are frequent and in general well preserved. Repeated redeposition of nannofossils and calpionellids is a frequent phenomenon in pelagic limestone/marl sequences of Aptychus Limestone-type. Several papers deal with the geology of this fine exposure, e.g. PLÖCHINGER 1974 ff. WEIDICH 1990 describes the foram-assemblages, HOLZER (in PLÖCHINGER 1976) and KAISER-WEIDICH & SCHAIRER 1990 the calpionellids and an extensive manuscript by BODROGI et al. 1990 deals with all afore mentioned fossil groups including dinoflagellates, respectively pollen and spores. Recently also aptychus were collected and determinations by VASICEK (unpubl.) provide unexpetedly precise biostratigraphical data.

The Tithonian-Early Berriasian Oberalm Limestone ("Biancone") shows the typical development of a deeper-water limestone: grey, cherty, dm-bedded with comparatively small amounts of light-greenish clayey intercalations and yellow allodapic interlayers - the socalled Barmstein Limestone (STEIGER 1981). The uppermost quarry level in the southeast is mined-out and mostly recultivated, however, it showed spectacular allodapic coarse-grained breccias with clast sizes up to 10 cm. The clasts of this very coarse-grained Barmstein-Breccia and also of the arenitic Barmstein Limestone contain shallow water biota with a foram-assemblage rich in taxa and poor in individuals with *Protopeneroplis trochangulata* SEPTFONTAINE, *Conicospirillina basiliensis* MOHLER, *Nautiloculina oolithica* MOHLER, *Pseudocyclammina* lituus YOKOYAMA, *Trocholina alpina* (LEUPOLD), *Nubecularia reicheli* RAT, etc. which indicate Early Berriasian age. Also calcareous algae, as e.g. *Clypeina jurassica* FAVRE, *Salpingoporella annulata* CAROZZI, *Cayeuxia anae* DRAGASTAN and other biota, e.g. *Tubiphytes morronensis* CRESCENTI and *Bacinella irregularis* RADOICIC are characteristic for these allodapic Barmstein interlayers.

According to the opinion by the main author of this chapter (LOBITZER), which is in contradiction to the current teaching-doctrine, the carbonate platform of Plassen Limestone persisted into the Early Cretaceous and terminated earliest in the early Berriasian. This Malmian-Berriasian carbonate-platform represents the source of material for the allodapic Barmstein Limestone intercalations.

The reworked micritic clasts of Oberalm Formation, however, show a typical Tithonian Tintinnid-assemblage with *Crassicolaria* ssp. The Oberalm Fm. itself is dominated by radiolarians, sponge spicules and calpionellids. A foram-assemblage poor in taxa and specimens (*Lenticulina-Spirillina*-Zone zensu WEIDICH 1990) is characteristic for the Oberalm- and Schrambach Fm. as well. *Lamellaptychus* *beyrichi* (OPPEL) and *Punctaptychus punctatus* VOLZ also indicate Tithonian-Early Berriasian age of the Oberalm Fm.

Without sharp boundary the Oberalm Limestone Fm. grades into the Middle/Late Berriasian-Early Valanginian Schrambach Limestone Fm. - as indicated by calpionellid assemblages (Plate 10, Fig. 2; Plate 11, Fig. 1). In the latter generally speaking chert is less frequent, allodapic interlayers of Barmstein type are missing and marly/clayey interlayers increase in abundance. The colour of the pelagic limestone changes slightly from grey to greenish-grey. In the hanging part of this sequence - just below the peach-red/pinkish/greenish layers of the Anzenbach Beds - forams indicate (Early) Valanginian age: *Dorothia* cf. *zedlerae* MOULLADE, *D.* cf. *trochus* (REUSS), *D.* cf. *kummi* (ZEDLER), *Spiroloculina* sp., *Lenticulina ouachensis ouachensis* SIGAL, *Pseudonodosaria* sp. Also calpionellids, e.g. *Cadosina* cf. *vogleri*, a.o. confirm an Early Valanginian age of these marker beds.

The characteristic Anzenbach Beds (Plate 10, Figs. 2,3; Plate 11, Fig. 1) mark the transition to the Aptychus Limestone of Lower Roßfeld Fm. They strongly resemble the Oberalm and Schrambach Fm., however, the Tintinnid-Radiolarians-Foram-assemblages and the aptychus indicate ± Middle Valanginian age: *Paalzowella feifeli* (PAALZOW), *Calpionellopsis* sp., etc. The uppermost part of the Lower Roßfeld Fm. consists of greenish-grey thin-bedded marly limestones (Plate 10, Figs. 2,3). Luckily these layers yielded *Lamellaptychus trauthi* RENZ & HABICHT and *L.* cf. *mendrisiensis* RENZ & HABICHT, which indicate (the lower part of the) Late Valanginian. Thin-sections show micrite/microsparite with detritic quartz and pyrite and repeated reworked calpionellids.

The hanging part of the profile shows spectacular outcrops in the clastic Upper Roßfeld Fm. (Plate 10, Figs. 2,3,4; Plate 11, Figs. 2,3).

The immediate basis of the coarse-clastic spectacular "Wildflysch" series is represented by an 1 m thick layer of soft brown sandy marls (Plate 10, Fig. 4). They hold a nannoflora with *Cruciellipsis cuvillieri, Watznaueria barnesae,* cf. *Polycostella beckmanni, Parhabdolithus embergeri* and *Nannoconus steinmanni* and a poorly preserved uncharacteristic foram-assemblage dominated by agglutinated taxa, e.g. *Saccamina* sp., *Dorothia kummi* (ZEDLER), *Ammodiscus tenuissimus* (GUEMBEL), *Psammosphaera* sp. and a few calcareous forms as *Lenticulina nodosa* (REUSS), *L.* sp. and *Vaginulina arguta* REUSS. Planktonic foraminifera are absent. Late Valanginian/Hauterivian age is likely.

The arenitic/fine-brecciated limestones of the Upper Roßfeld Fm. are rich in biota, dominated by rhodophyta (*Archaeolithothamnium* sp., *A. rude* LEMOINE; *Solenopora* sp.) and crinoids. Calpionellids (e.g. *Calpionellopsis nowaki, Calpionella alpina, Crassicollaria* sp., *Cadosina* sp. point to Hauterivian age of these beds. The stratigraphic age of the spectacular "Wildflysch" (olistolites) can be inferred as Hauterivian-Barremian (WEIDICH 1990; BODROGI et al. Manuscript): Plate 10, Fig. 4.

Historic adits - used towards the end of World War II temporarily by the headquarters of the German army - expose fresh outcrops in the various formations of Aptychus Limestone. Complementary to the unpublished report by PERRY 1975, also DRAXLER (in BODROGI et al. 1990) investigated the marly intercalations of the lower Roßfeld Fm. in respect to palynomorphs. The microflora shows excellent preservation and is rich in taxa. The spectra consist of marine plankton and land-derived palynomorphs. Reworking of stratigraphically older palynomorphs is frequent (e.g. Permian taxa of the Haselgebirge and Jurassic forms). Trilete sporomorpha (as *Cicatricosisporites* and *Appendicisporites*) are common elements and point to Hauterivian-Barremian age. The flora is dominated by pteridophyta and gymnosperms, which points to near-shore vegetation. Bisaccate pollen are also abundant and most probably can be considered as elements of the hinterland. Monolete spores have not been encountered. Monolete Schizeales are considered as important floral elements from the Albian onwards. Also angiosperms are missing in the assemblages.

Stop 1.3. "Untersberger Marmor" of Kiefer Quarry, Fürstenbrunn.

Topic: Slope carbonates, mass- and debris flows, initial stages of nodular limestone formation; dimension stone.
Stratigraphy: Gosau Group, Untersberg Limestone ("Marble"). Age under discussion, opinions vary from Late Turonian-Coniacian-Santonian.

Besides the various types of limestones of the Adnet quarries (Stops 1.1: Rhaetian Tropf and Liassic limestones of Adnet Group) the Untersberg "Marble" represents the most traditional decoration stone quarried in the Salzburg region (KIESLINGER 1964). As a consequence of weathering due to acid rains - likewise as the Adnet limestones - also the polished limestones of the Untersberg Formation can be recommended without reserve for interior decoration only.

However, many sculptures, fountains and dimension stone building facades made by Untersberg "Marble" determine the townscape of Salzburg and can be admired during our stroll through the town.

At present Untersberger Marmor is quarried only in Kiefer Quarry at Fürstenbrunn on the northern slope of Untersberg.

The basal Gosau Group of Untersberg region is represented by boehmitic bauxite and breccias, which fill a palaeokarst relief on top of Late Triassic Dachstein Limestone, respectively of Late Jurassic Plassen Limestone. The Gosau Group of this region has been dealt with in detail by the excellent paper by LEISS 1988. The latter considers the bauxite as transported marine resediment.

On top of the - partly bauxite infilled - palaeokarst relief the Untersberger Marmor is deposited, which is exposed in spectacular three-dimensional outcrops in the Kiefer Quarry.

The Untersberger Marmor was deposited on a slope, respectively represents a toe-of-the-slope development (Plate 12, Fig. 1). Geopetal fabrics indicate an original inclination of the slope of 10-15°. The typical Untersberger Marmor represents a detritic carbonate sediment-mixture derived from the Gosau carbonate-platform and from the slope, with a considerable share of extraclasts, the latter consist predominantly of Dachstein- and Plassen Limestone. Ubiquitous recrystallization renders determination of biota difficult. Due to staining by fine-dispersed bauxite-mud the basal part of the Untersberger Marmor is characterized by pink colour and tiny bauxite clasts and ore grains. Further upward in the sequence the colour turns to yellowish, however, the tiny red bauxite clasts are still present, giving the limestone the name "Forellenmarmor" (brook trout mottled). The hanging parts of the Untersberger Marmor are definitly white, showing an albedo of ± 90% and much better grain-sorting. The overlying grey marls represent sediments of the outer shelf, respectively of the upper bathyal with *Globotruncana* ssp., etc. (LEISS 1988). Especially the basal parts of the sequence show extensive bioturbation and trace fossils of the *Thalassinoides/Ophiomorpha*-type. Clasts are frequently bored by *Lithophaga alpina*. The most important bioclasts are rudists, more scarcely corals, bryozoans, hydrozoans, coralline algae and foraminifera. The lower and middle part of the Untersberger Marmor exposes spectacular phenomena of an inclined carbonate slope, such as erosional channels with scour and fill structures, slumping, olistolites, mass- and debris flows with angular boulders, plasticlasts and initial stages of nodular limestones, such as marl-flaser breccias. Graded bedding and grainflows with reversed grading are widespread features of channel fillings (Plate 12, Figs. 2,3).

Acknowledgements

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Plate 1: Rhaetian Reef Limestones and Hettangian Schnöll Formation

1. Rhaetian reef limestones: Coral thickets of *Retiophyllia.* Only some small patches of the Rhaetian reef limestones are red-coloured and most of this popular "Rot-Tropf" is already exploited. Note the large cavity filled with several generations of internal sediments. Many corals are dissolved and filled by cement and/or red micrite.

2. Grey variety of the Rhaetian coral reef limestones (mainly *Retiophyllia* colonies). Most corals are dissolved and partly filled by red, yellow and green-grey internal sediments as well as fibrous and blocky cements. Marmormuseum at Adnet.

3. Colourful coquina in the Rhaetian reef limestones from Kirchenbruch (quarry I). Marmormuseum at Adnet.

4. Hexactinellid sponges in the Langmoos Mb. of the Schnöll Fm., middle Hettangian, from Langmoos. Marmormuseum at Adnet.

5. Sponge layer with pyritized sponges and lithoclasts at the base of the Guggen Mb., Schnöll Fm., middle Hettangian. From Rotgrauschnöll quarry (quarry XXXI, stop 1.1.d). Entrance to main building of the Kiefer Company, Hallein.

6. Crinoidal limestone of the Guggen Mb., Schnöll Fm. (middle Hettangian) with hexactinellid sponges. From Rotgrauschnöll quarry (quarry XXXI, stop 1.1.d). Marmormuseum at Adnet.

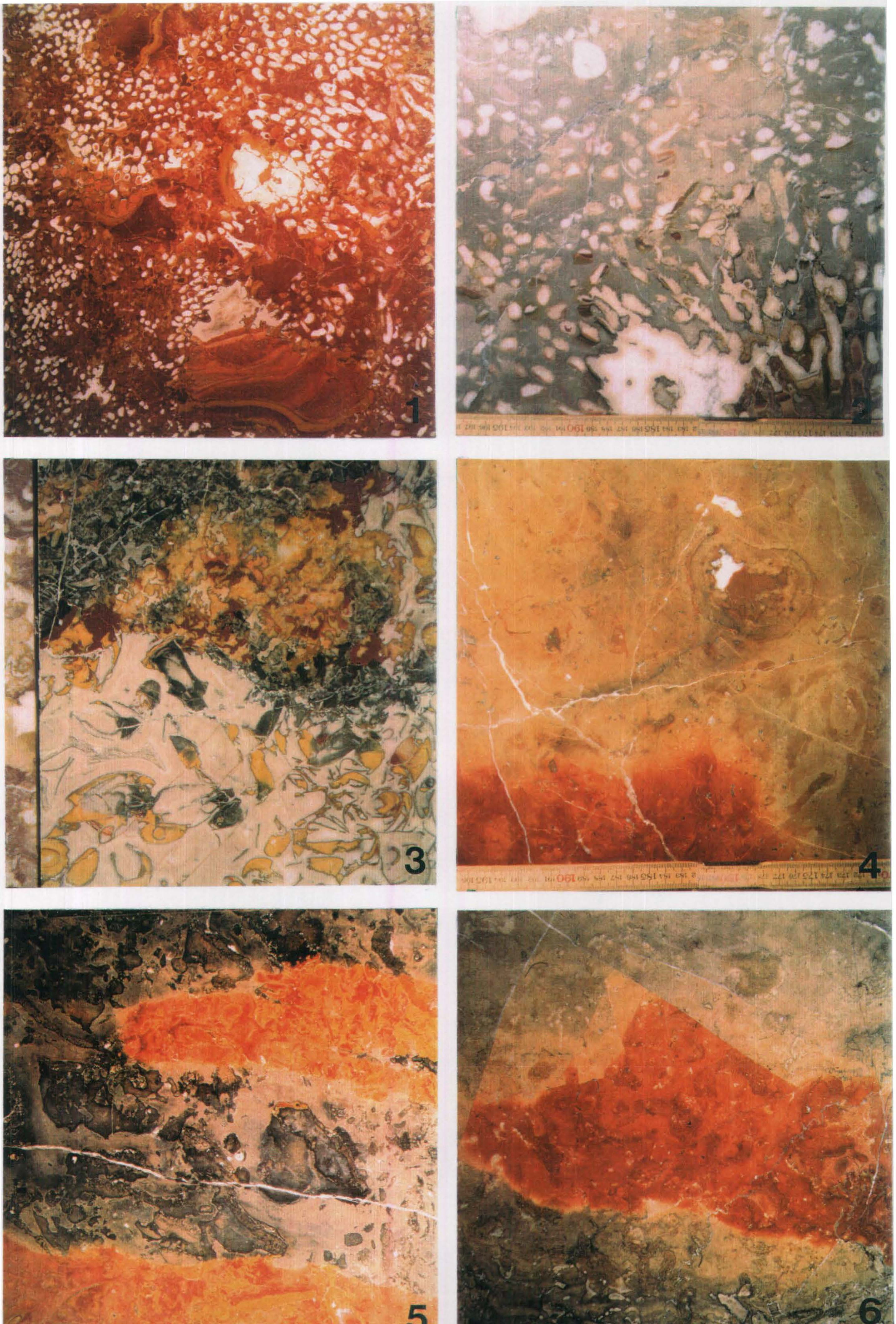
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Plate 2: Sinemurian Lower Adnet Formation and Middle Liassic Scheck Breccia

1. Typical nodular limestone of the Schmiedwirt Mb., Adnet Fm. Light red nodules floating in a dark red marly matrix. Some of the nodules contain small, dark-rimmed intraclasts.

2. Crinoidal dark-red limestone of the Motzen Mb., Adnet Fm. A mudstone-filled ammonite, cut obliquely is visible at the top. Note the lack of nodular fabrics contrasting with the limestones of the Schmiedwirt Mb. Large segments of crinoid columnae are typical for the Motzen. Dark-rimmed intraclasts are common. Marmormuseum at Adnet.

3. Red limestones of the Lienbacher Mb., Adnet Fm. mostly lack nodular fabrics. Dark-rimmed intraclasts, encrusted by ferromanganese rims are very common. Marmormuseum at Adnet.

4. Scheck breccia: Clasts of limestones of the Lienbacher and Schmiedwirt Mbs. forming a framework filled with a first generation of internal sediment and several generations of marine and burial cements. The primary colour of the Scheck was red. However, as often observable in the Adnet limestones secondary bleaching (often bound to faults and fractures) led to pink and grey colours.

5. Scheck breccia with a large clast of the deepwater stromatolite layer (exposed *in situ* e.g. at quarry XII). Other clasts are limestones of the Lienbacher, Motzen and Schmiedwirt Mbs. Entrance to main building of the Kiefer Company, Hallein.

6. Densly packed, uncemented variety of the Scheck breccia. This lithology is found in the basal layer and in distal occurrences of the Scheck debrites (e.g. at Gaissau). Marmormuseum at Adnet.

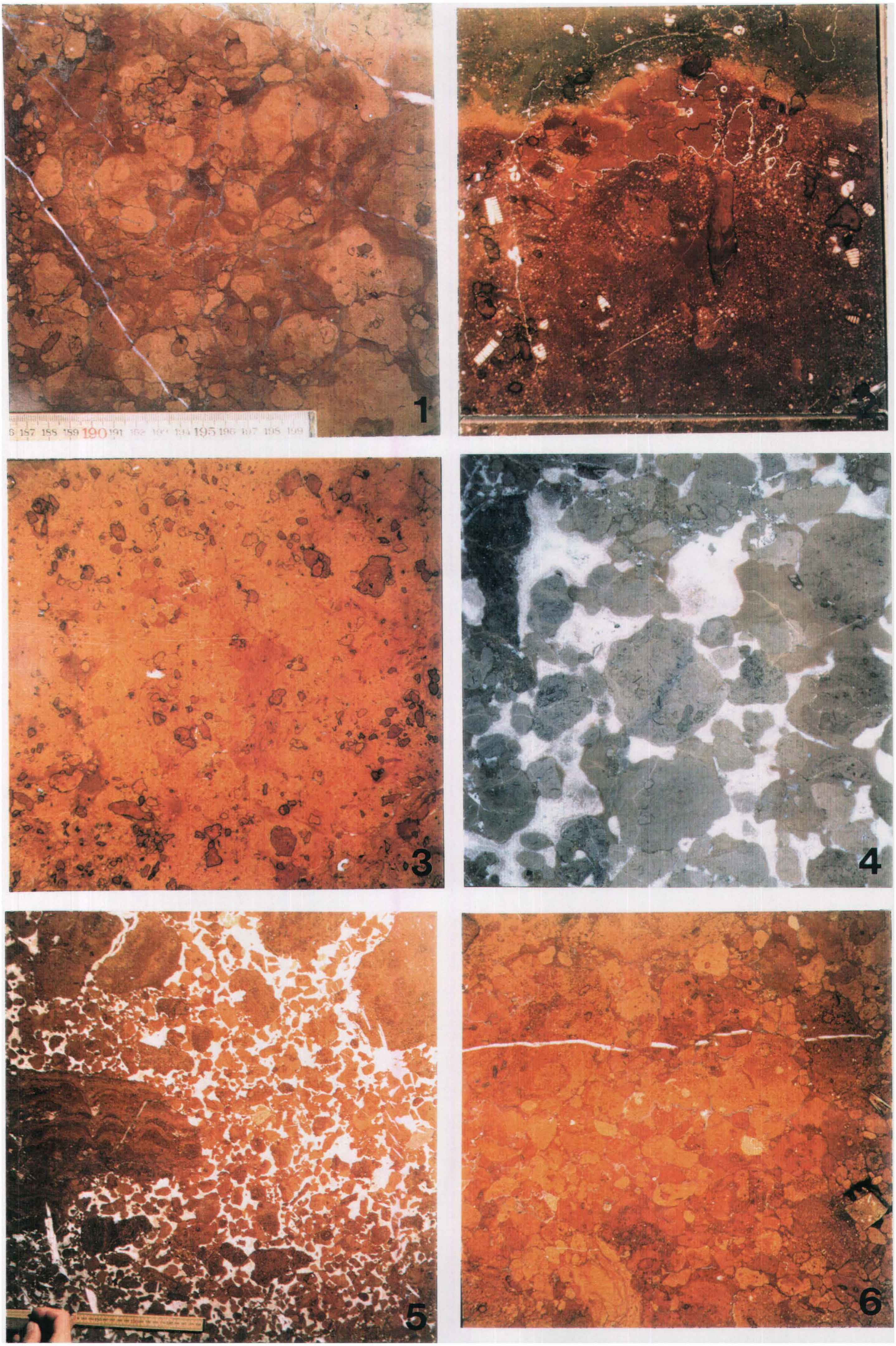
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Plate 3: Microfacies and Sedimentary Characteristics of the Kendlbach and Schnöll Fm.

1, 2, 4, 5: Resedimentation is a common feature of the Kendlbach-Formation (cross-bedded unit). Fig. 1 illustrates in its lower part a mostly sparitic cemented layer rich in microlithoclasts and strongly micritized bioclasts (mostly echinoderms; compare also figs. 2, 4, 5). Sessile foraminifera (*Planiinvoluta carinata*, fig. 5: P) and syntaxial rim cements growing around echinodermal remains are common (fig. 5: arrow).
Only rarely micritic areas are preserved (fig. 2). Due to their alternation with sparitic layers and their parallel orientation they are interpreted as relicts of a low-angle cross-bedding. Growth of secondary calcite into this layers is evident (e. g. fig. 2: arrows). The top of this layer exhibits a rippled surface, overprinted by secondary calcite, consisting mainly of a mosaic of blocky and rare fibrous calcite (fig. 4). This surface is followed by a fine-grained graded sediment, interpreted as a distal calciturbidite. The base of the fine-grained sediment is also only relicticly preserved (fig. 1: arrow). The next resedimented cycle starts with a finely laminated siltitic sediment that is also interpreted as a distal calci-turbidite. At the base of the following micritic to microsparitic packstone a sharp increase in size of components is visible. The base of this resediment is mostly non-erosive. Only some components were pushed into the sediment due to loading. This is indicated by the deformation of underlying fine-grained sediment (fig. 1, 4). The lower part of this sediment exhibits inverse grading, whereas in the upper part a coarse-tail grading is developed. Due to this sedimentary features this resediment is interpreted as a debris flow. (Sample Sch14).

3: The contact Kendlbach Fm. - Schnöll Fm. is clearly erosive. Filigrane, partly dichothomous borings (B) penetrate the rocks of the Kendlbach Fm down to several mm depth. They are filled with Fe/Mn-rich sediment. Of interest is a very fine sparitic coating of the discontinuity surface (arrows 1) and a relictic preserved Fe/Mn-sediment (arrows 2). The Schnöll Fm. is represented by the MF-Type 2.1., a Bivalve-Gastropod Biomicrite (wackestone). (Sample Sch1)

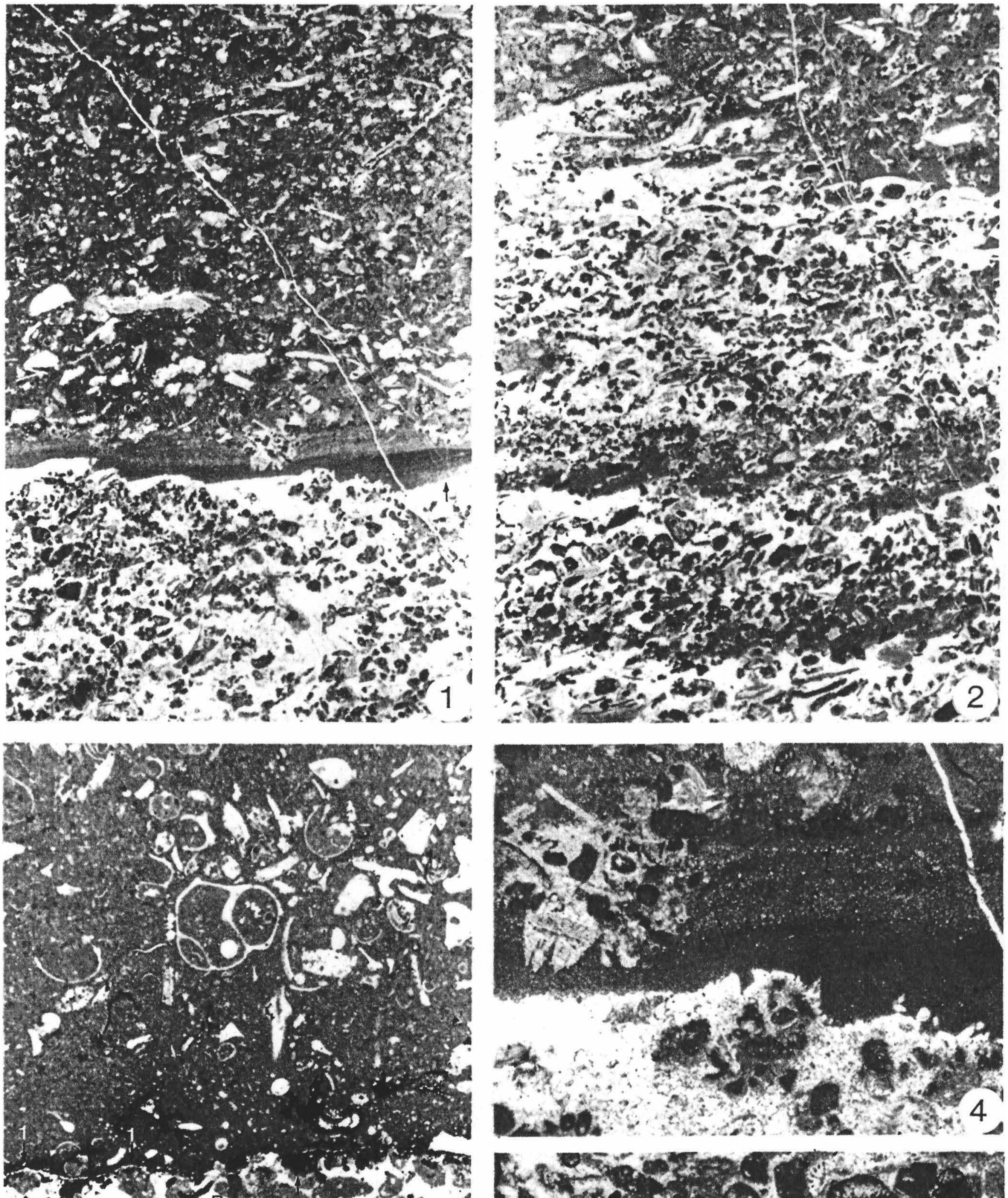
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Plate 4: Microfacies of the Schnöll Fm. (Guggen Mb.)

1, 3: MF-Type 2.2. Echinoderm-Foram-Biomicrite with Cyano-Oncoids (Wackestone to Packstone). The sediment is characterized by a high content in foraminifera (Involutinids: I; Lagenids: L), echinoderms and ostracods. The overview (Fig. 3) exhibits also a high amount of cyano-oncoids. Some intraclasts (Fig. 1: arrows) occur. Fig. 1: Sample RGS 8/1. Fig. 3: Sample Spong 6B

2: MF-Type 2.3.: Bivalve-Ostracod Biomicrite with Cyano-Oncoids (Wacke- to Packstone). The high content of thick-shelled bivalve debris and ostracodes, together with cyano-oncoids are a distinctive feature of this sediment. Note the good orientation of elongated bioclasts. Sample Lien I.1; x 10.

4: Microfacies 2.4.: Cyano-oncoidal Biomicrite (Packstone). This sediment reveals a very high content of cyano-oncoids. Encrusted particles are shell debris, spicula, microproblematica (M: see also plate F1), foraminifera, the serpulid worm *Spirorbis* (S) and gastropods. Note euhedral cubic pyrite (lower middle and right) and the geopetal fillings of bioturbation (arrow). Sample XVII A 7

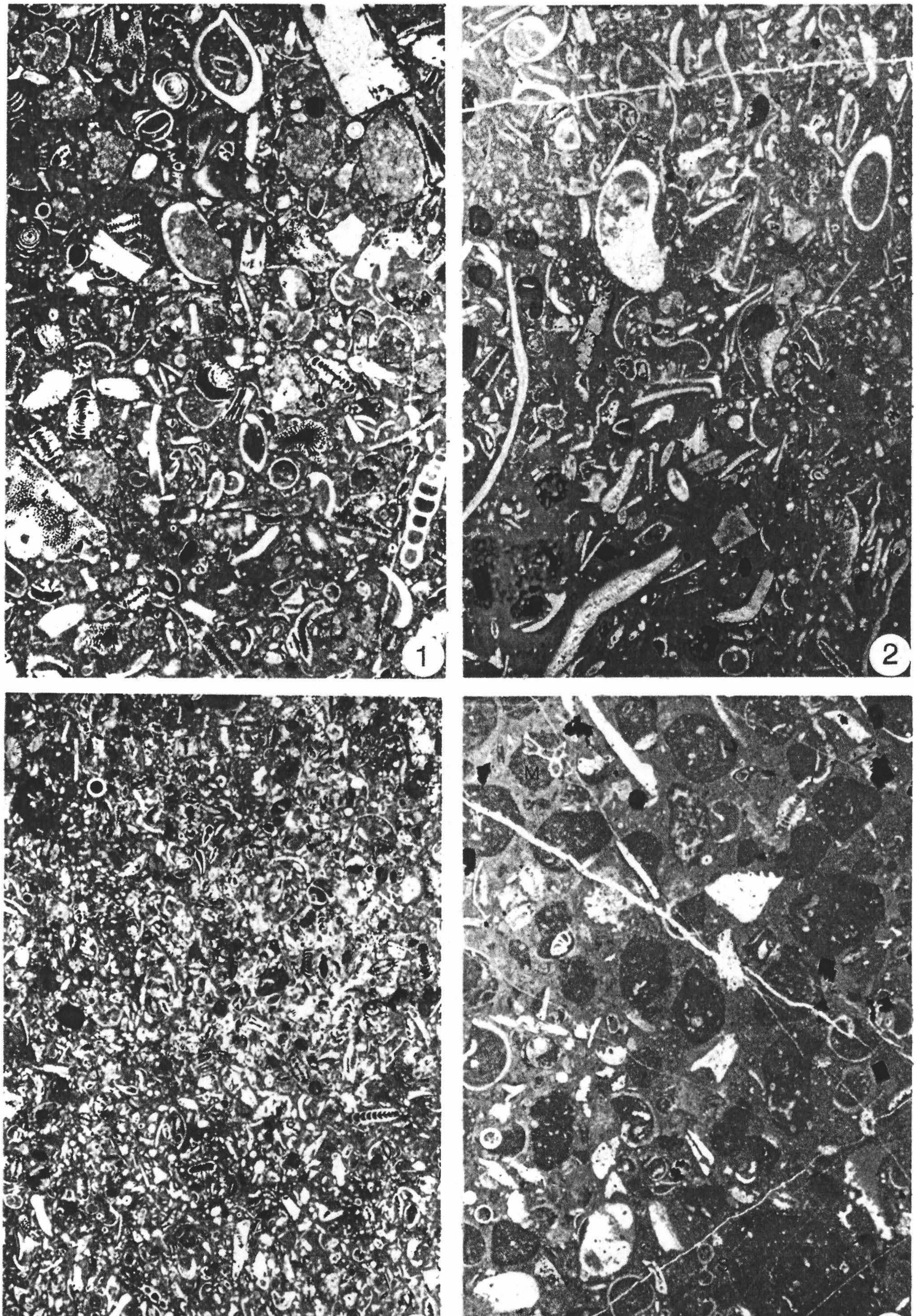
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Plate 5: Microfacies, Sponges and Holothurians of the Schnöll Fm.

1: MF-Type 2.5.: Spiculite with Cyano-Oncoids (Wackestone). Dominant spicula are arranged rather randomly. Note high degree of bioturbation. Sample RGS 4

2, 3: Sponges are characterized by original cubic arrangement of spicula. Both sponges exhibit characteristics of abrasion and are therefore transported and embedded in sediments of MF-Type 2.2. Note geopetal (stromatactis-like) fillings of irregular burrows in fig. 2. Fig. 2: Sample RGS 7; Fig. 3: Sample RGS 2

4: The central channels of spicula can be filled by pyrite. In the course of ongoing diagenesis under the same physico-chemical conditions of a reducing milieu, the spicules are completely replaced by pyrite. Sample RGS Spong 2

5: Badly preserved holothurian sclerites (*Theelia* sp.) have a patchy distribution. Sample Spong 1b

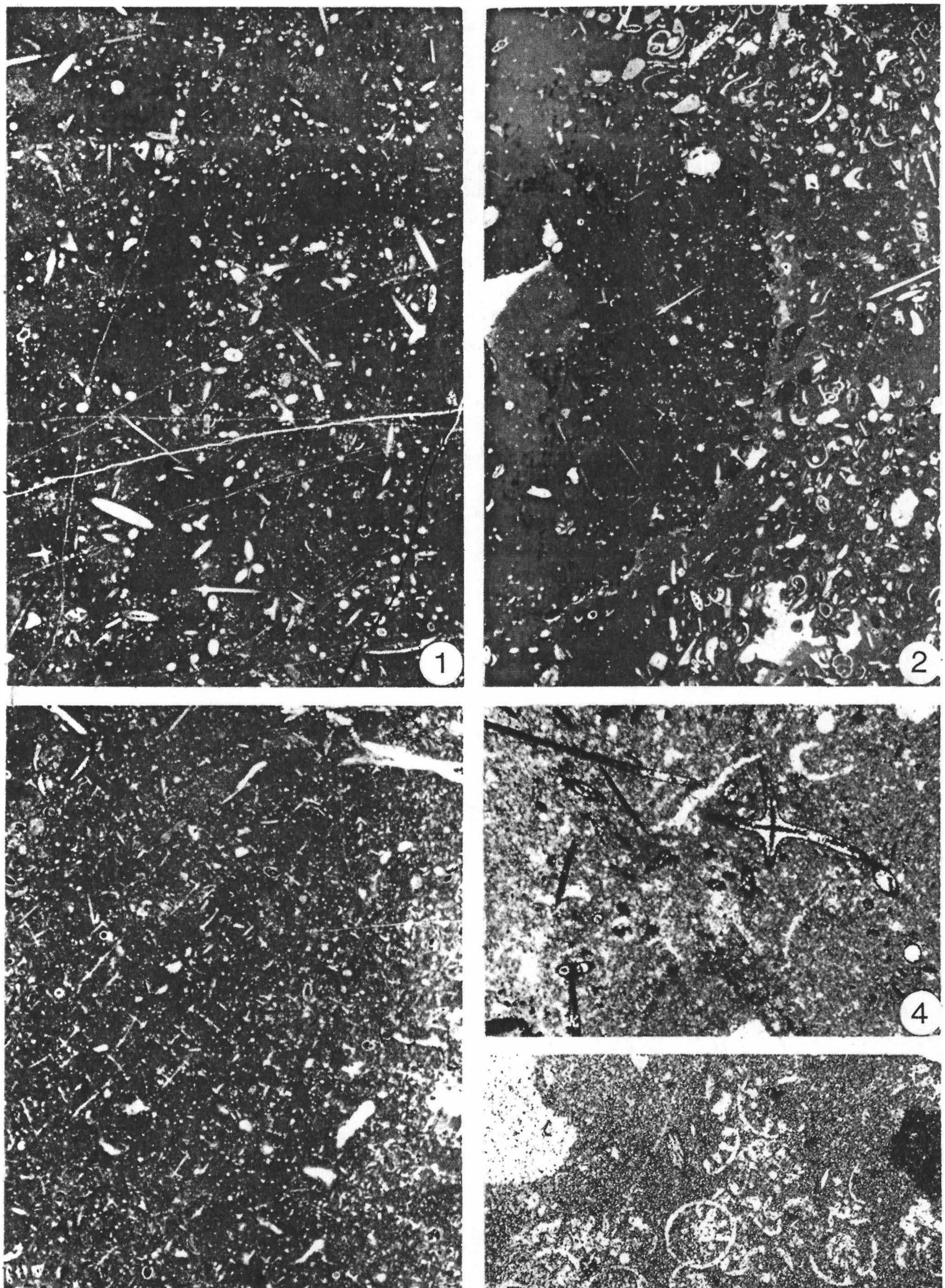
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Plate 6: Neptunian dykes of the Schnöll Fm.

1: The degree of fracturing of the rocks by neptunian dykes is sometimes very high. 2 generations of dykes can be identified. Note the high amount of calcite, that seals the former cavities. This calcite is not always geopetally arranged on the roofs, but also covers the floors (see also fig. 4). This means that the dykes were opened polyphasely. Sediment infill is here mostly micritic. Sample RGS 3

2: Example of a single-phase filling of dykes by a densely packed echinodermal sediment. Sample RGS 3

3: Thicker dykes are filled by a sediment rich in lithoclasts, whereas apophyses - in this case a 2nd generation of fracturing - are filled by a fine micritic sediment. The calcitic seam in the middle of this dyke reveals further stretching of the rock. Note enrichment of pyrite in the dykes. Sample RGS Spong 4b

4, 5: Examples of a well-layered, partly cross-bedded filling of dykes. Arrangement of cements in Fig. 4 reveals polyphase opening. Fig. 4: Sample RGS 4; fig. 5: Sample RGS 1

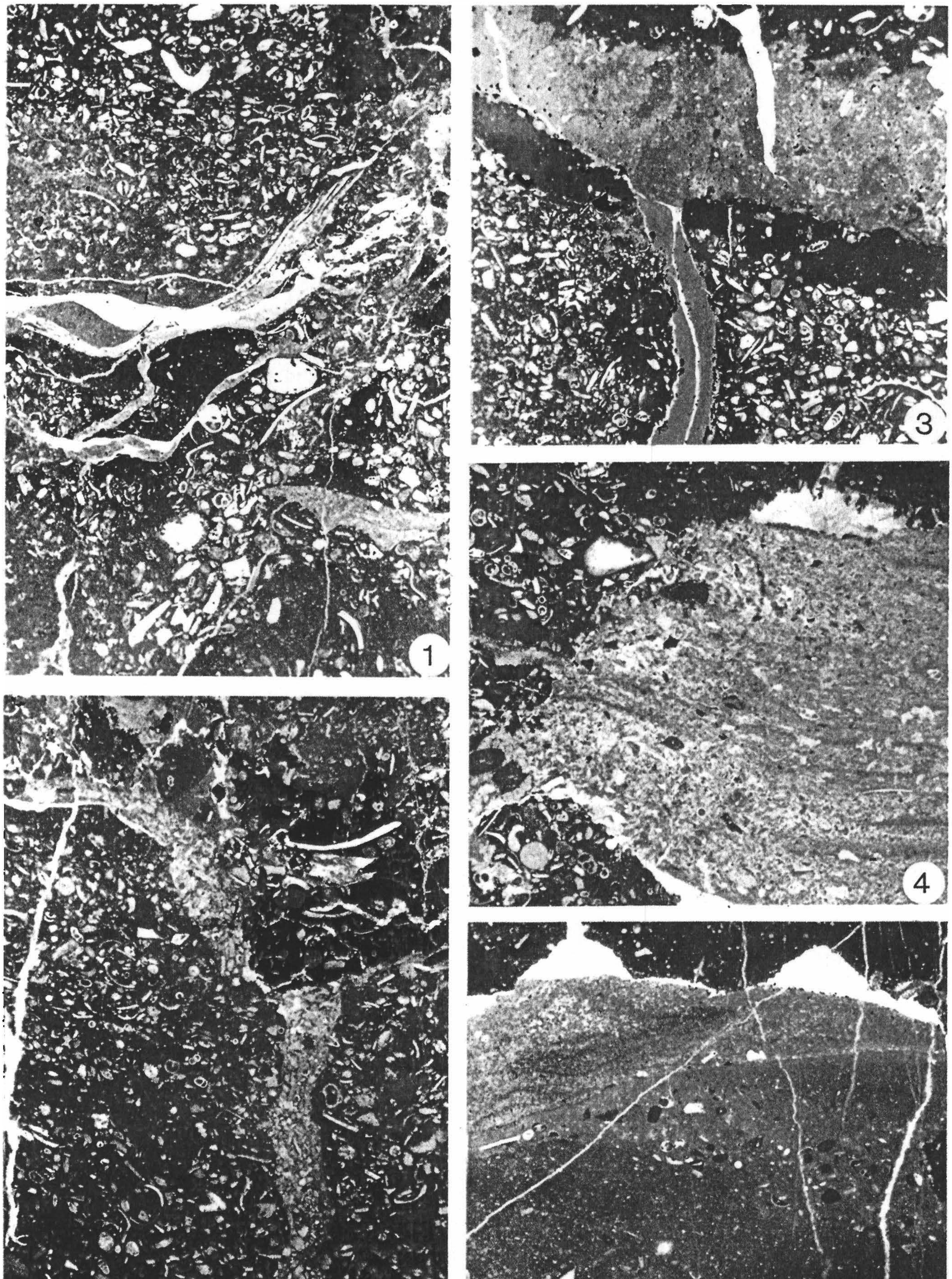
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Plate 7: Microfacies of the Enzesfeld Limestone

1, 2: MF-Type 4: Echinoderm-Foram-Biomicrite with Gastropodes (Wacke- to Packstone). The Enzesfeld limestone is characterized by a very high foram content. In contrast to the omnipresent *Involutina liassica*, other species as *Semiinvoluta violae, S. bicarinata, Ophthalmidium leischneri* and lagenids are clearly rarer. In Fig. 2 an angular clast of Oberrhätkalk reveals the erosion of the underlying formation. Fig. 1: Sample Lien HG I.1.; fig. 3: Sample Lien HG I.4.

3: Relict of a pelagic crinoid. Bright semi-valves embedded in the dark matrix correspond to *Schizosphaerella punctulata*. Sample Lien HG I.2.

4: Relict of a radiolaria, incorporated in a Fe/Mn-oxide crust. Sample Lien HG I.2.

5, 6: The calcareous Dinophyceen cyst *Schizosphaerella punctulata* (bright semi-valves) is a common constituent of the matrix of the Enzesfeld limestone. At higher magnifications, characteristic pores (fig. 6: arrows) are visible. Sample Lien HG I.2.

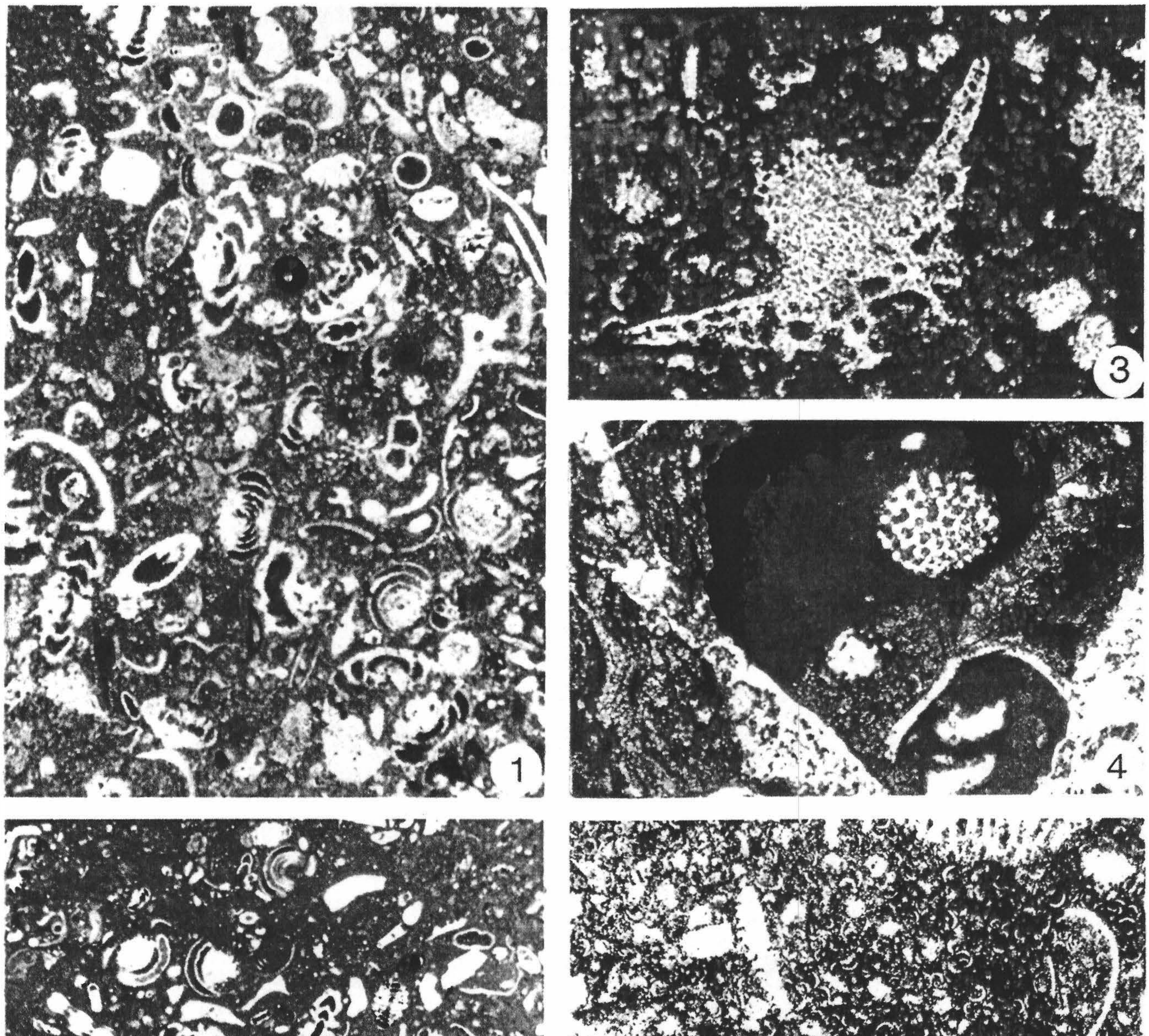
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Plate 8: Hardgrounds and crusts of the Enzesfeld Limestone, Microfacies of the Adnet Fm., Basal Unit

1, 2: Crusts of Fe/Mn-oxides indicate times of very low or non-sedimentation. These crusts may be massive (fig. 1) or finely laminated (fig. 2). On these crusts growing of serpulid worms (fig. 1: gen. et spec. indet, fig. 2: ? *Spirorbis* sp.) is rather common. Borings penetrating down from these crusts into the underlying rocks, indicate hardground formation (fig. 1: arrows). Fig. 1: SampleRGS Brand 13; Fig. 2: Lien HG I.5.

3, 4: MF-Type 5: Bioturbated Ostracod-Echinoderm-Mollusc-Biomicrite (Wackestone). The bioturbated sediment also contains relicts of pelagic crinoids (fig. 3: C) and nodules, that can be assigned as hardground nodules, if they are coated by Fe/Mn-oxides, bored or settled by organisms. Fig. 3, 4: Sample RGS HG III.3.

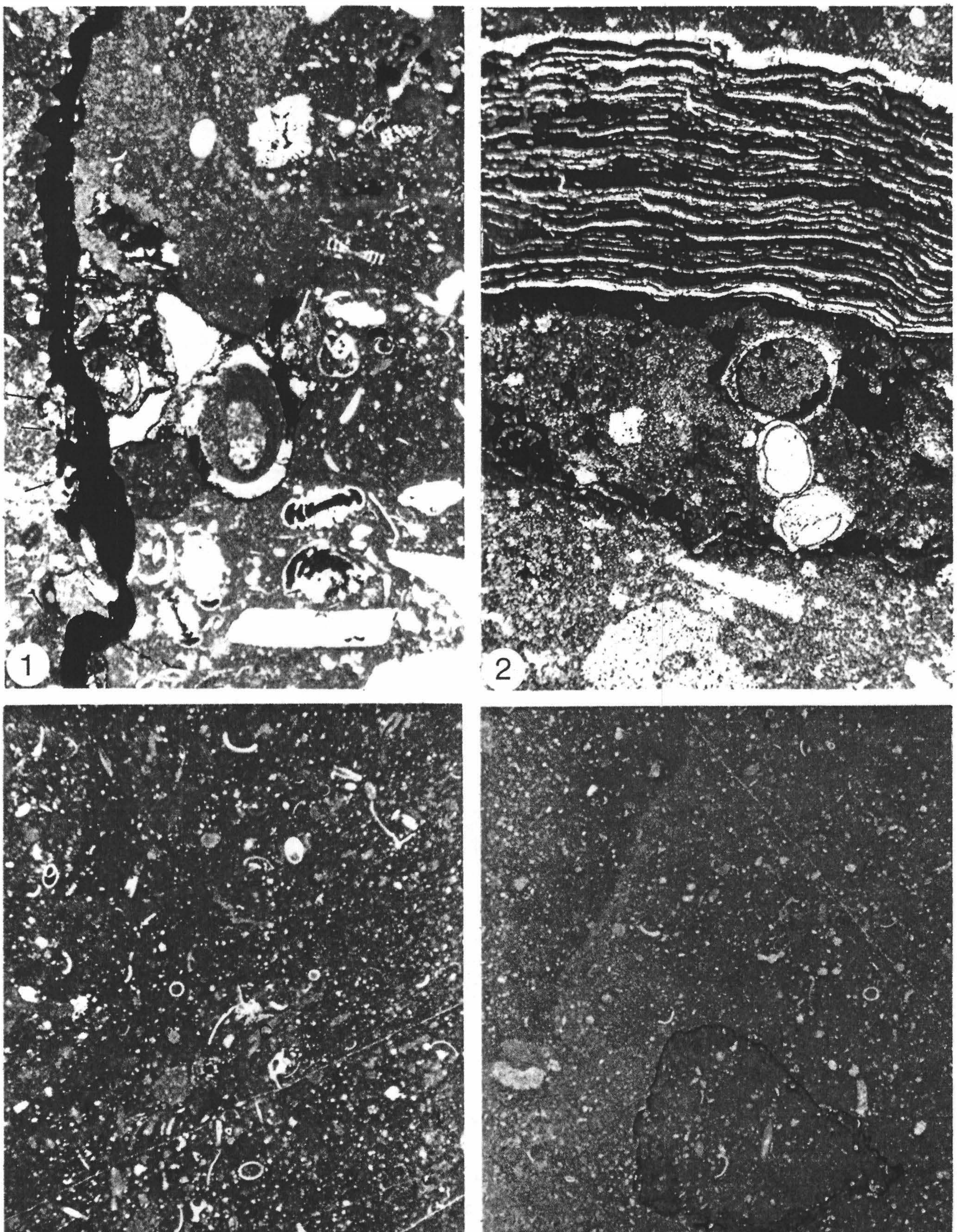
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Plate 9: Bioturbation structures

1: The mottled bright-dark appearence of the rocks of the Schnöll-Fm. is due to a high degree of bioturbation. By the bifurcating character of the burrows, they are correlated to the ichnogenus *Chondrites*. Sample RGS 2

2: A different type of bioturbation structures is found in the Enzesfeld Limestone. These burrows exhibit polyphase formation as shown by different degree of lithification (arrow). From a main cavity 1 or 2 further burrows extend down into the sediment. Sample Lien HG I.5.

3: Two generations of burrows (1st generation: darker, big burrows, 2nd one smaller, bright ones) are to be indicated in this example of the Enzesfeld Limestone. Sample RGS Brand 14.

4: Especially in the Schnöll-Fm the burrows exhibit signs of quick lithification, as indicated by stylolitization of their outlines. A nodular appearence of the rocks develops. Sample Spong 1b, x 10.

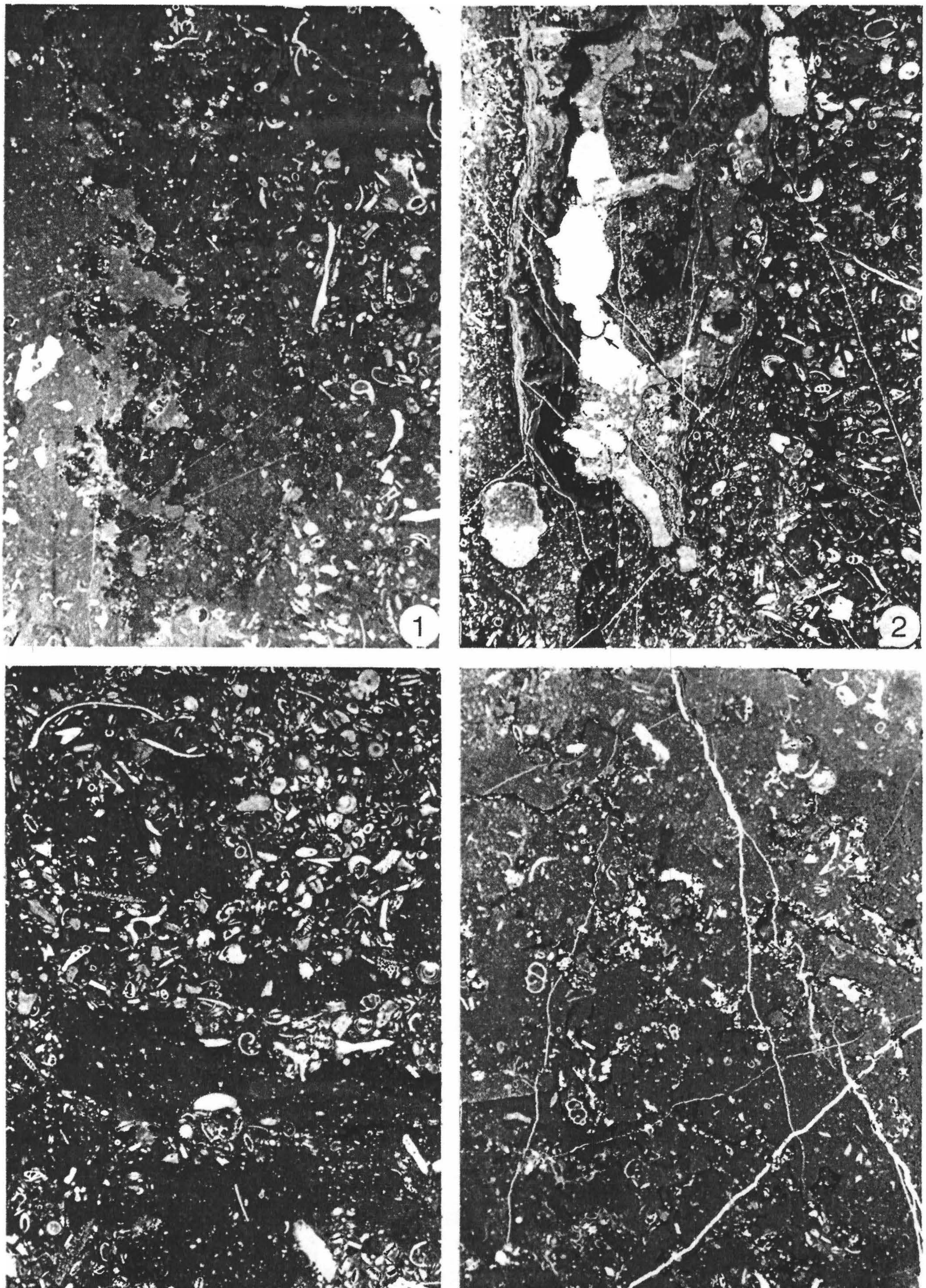
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Plate 10: Gartenau-Quarry (Stop 1.2)

1: Overview of Gartenau-Quarry, Leube Cement Co. From left to right various developments of Malmian-Valanginian Aptychus Limestones (Oberalm/Schrambach/Lower Roßfeld Fm.) and coarse clastic Upper Roßfeld Fm. on the right. July 1997.

2: Strongly tectonized Schrambach Fm. (left) grades via pink Anzenbach layers into Lower Roßfeld Fm.

3: Lower Roßfeld Fm., left pinkish Anzenbach Member, right on top coarse clastic sediments of Upper Roßfeld Fm.

4: Basal marls of Upper Roßfeld Fm. (Late Valanginian/Early Hauterivian) and hanging "Wildflysch"

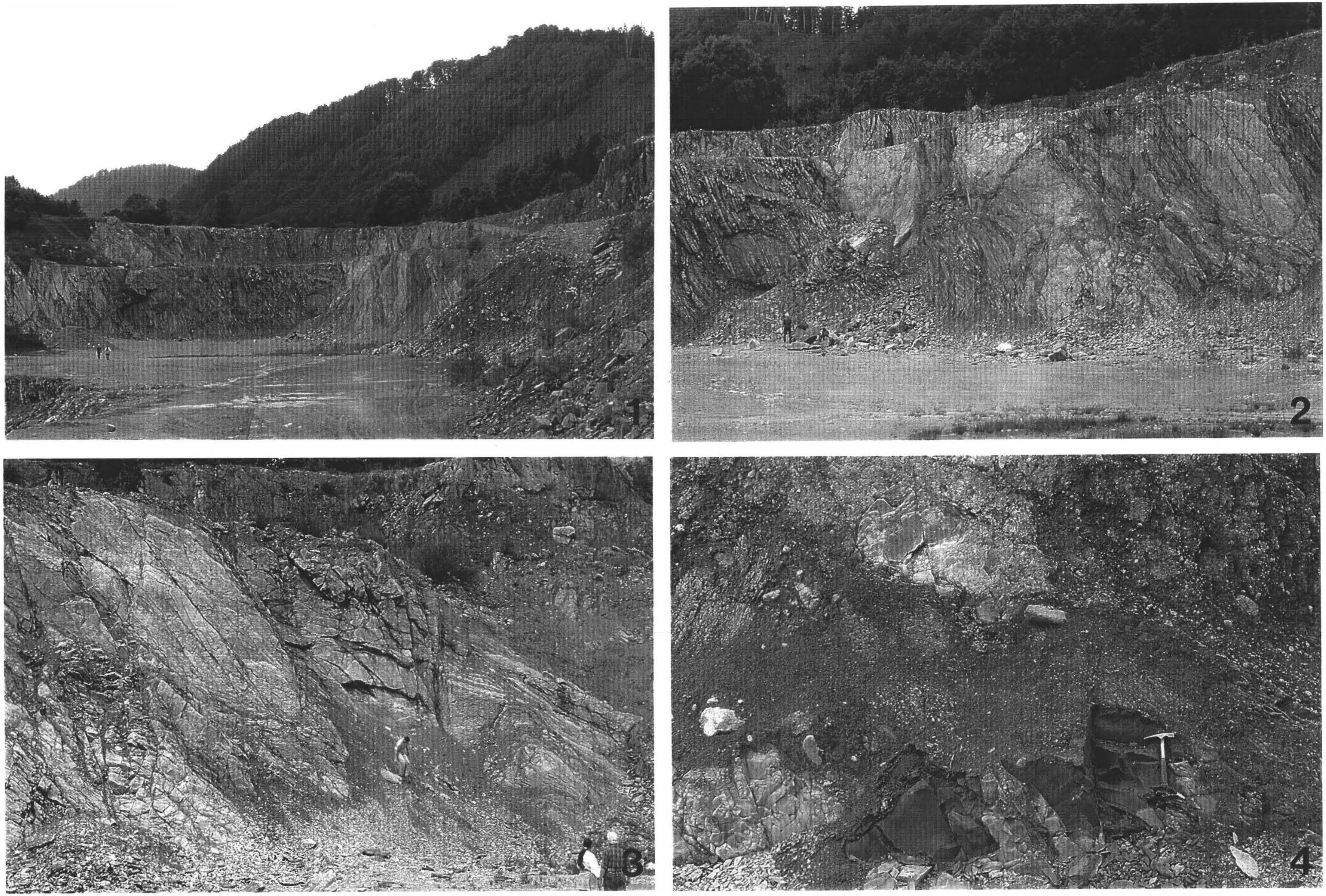
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Plate 11: Gartenau-Quarry (Stop 1.2)

1: Strongly tectonized Aptychus Limestone (Schrambach Fm.)

2: Hauterivian - ? Barremian "Wildflysch", Upper Roßfeld Fm.

3: Plum cake marls ("Rosinenmergel") of Upper Roßfeld Fm., Hauterivian

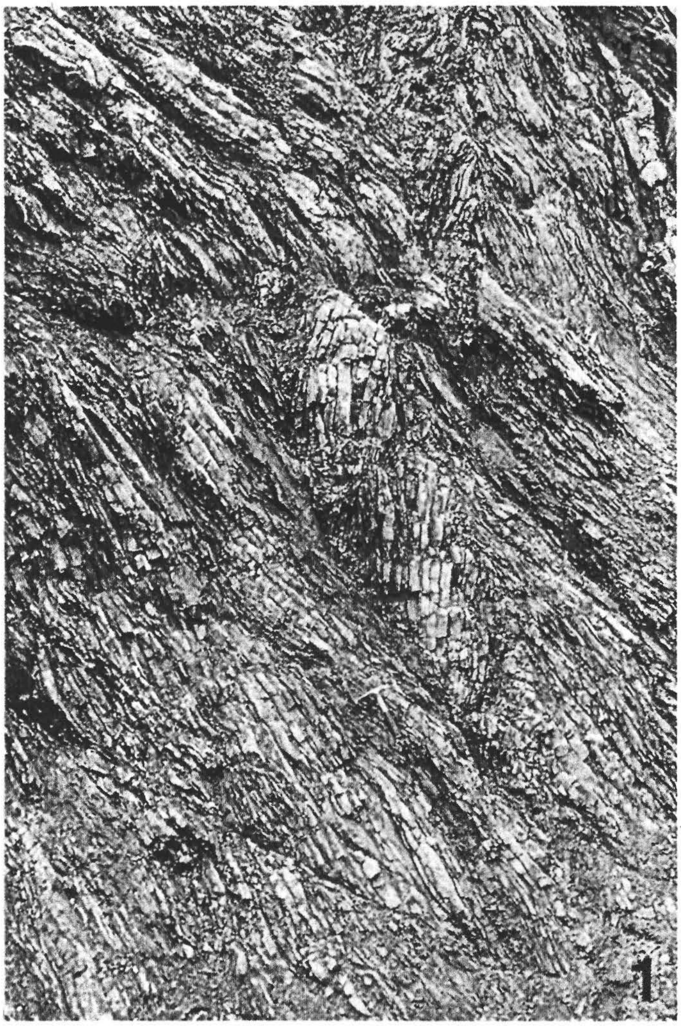
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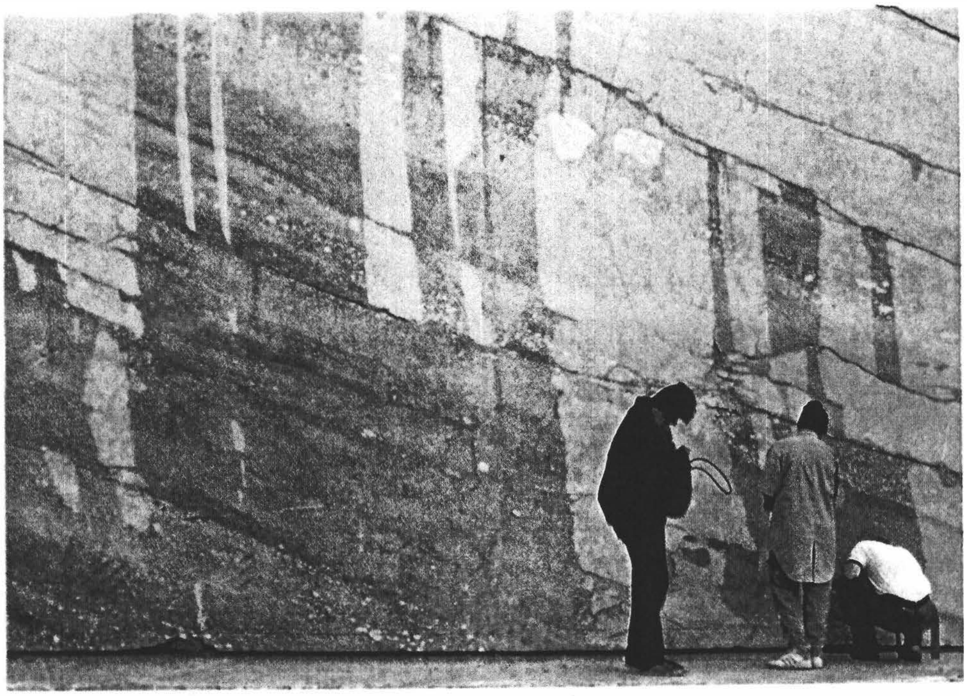
Plate 12: Untersberger Marmor, Kiefer Quarry, Fürstenbrunn (Stop 1.3)

1: Quarry wall shows dipping of slope. Various generations of mud- and grain-flows, slumping-structures, "knollenkalk", olistolites. Exposure 1993.

2: Channeling on top of a bioturbated initial "knollenkalk" layer. Poor sorting of clasts.

3: Detail of Fig. 2.

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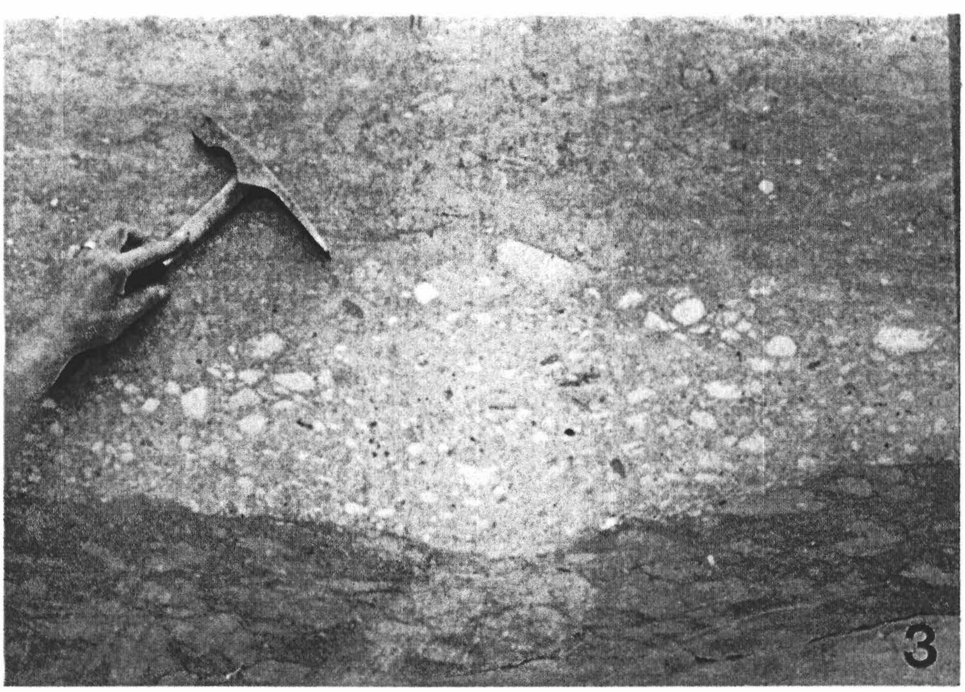
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