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The Permian-Triassic Boundary in the Gartnerkofel Region of the Carnic Alps (Austria). Introduction.

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With 7 Text-Figures, 1 Table, 1 Plate and 1 Microfiche (in pocket)

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Carinthia
Carnic Alps
Permian/Triassic Boundary
Mass Extinction
Event Stratigraphy

Contents

Zusammenfassung ... 5
Abstract ... 5
1. Historical Notes ... 6
2. The Gartnerkofel Project ... 7
3. Funding ... 8
4. Scientific Consortium ... 8
5. Drilling Logistics ... 8
6. Core Logging ... 12
7. Sampling of the Core and the Outcrop ... 12
8. Archive of Core and Data ... 13
References ... 13

Zusammenfassung

Das größte Massensterben in der Geschichte der Erde fand vor rund 250 Millionen Jahren an der Perm/Trias-Grenze statt. Für die Klärung dieses Geschehens bot sich die Gegend um das Naßfeld in den Karnischen Alpen im Süden Österreichs an, da hier die entsprechenden Gesteine in einer lückenlosen karbonatischen Schichtfolge zur Ablagerung kamen.

Zu diesem Zweck wurde auf der Nordseite des Gartnerkofels eine wissenschaftliche Bohrung abgeteuft, deren Ergebnisse in diesem Band mitgeteilt werden. Die Bohrung, zwischen Mitte September und Ende Oktober 1986 ausgeführt, lieferte bei 94 % Gewinn einen 331 m langen Kern.

Das umfangreiche Probenmaterial entstammt der Bohrung sowie Obertagsaufschlüssen aus der Umgebung, die für Vergleichs- und Kontrollzwecke ebenfalls untersucht wurden. 19 Spezialisten beschäftigten sich damit u.a. in Bezug auf Stratigraphie, Sedimentologie, Paläontologie, Palynologie, Mineralogie, Petrographie, Element- und Isotopen-Geochemie sowie Paläomagnetik.

Der vorliegende Band enthält die jeweiligen Fachergebnisse und bringt die davon abgeleiteten Schlußfolgerungen. Bohrkern und Basisdaten sind im Archiv der Geologischen Bundesanstalt aufbewahrt und stehen für weitere Untersuchungen zur Verfügung.

Abstract

The major mass extinction event near the Permian/Triassic (P/Tr) boundary was investigated by geological coring through the boundary near Gartnerkofel in the Carnic Alps of Austria, a site of dominantly carbonate sedimentation in the western end of the Tethys Sea.

Coring of GK-1 was accomplished in September and October, 1986, with 94 % recovery to a depth of 331 m.

The core material (and some parts of the nearby outcrop section on the Reppwand) was studied by a consortium of 19 specialists in stratigraphy, sedimentology, paleontology, palynology, mineralogy, petrography, elemental and isotope geochemistry, and paleomagnetics.

Their final reports and conclusions comprise the present volume. Core and data were archived in the Geologische Bundesanstalt, Vienna.

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1. Historical Notes

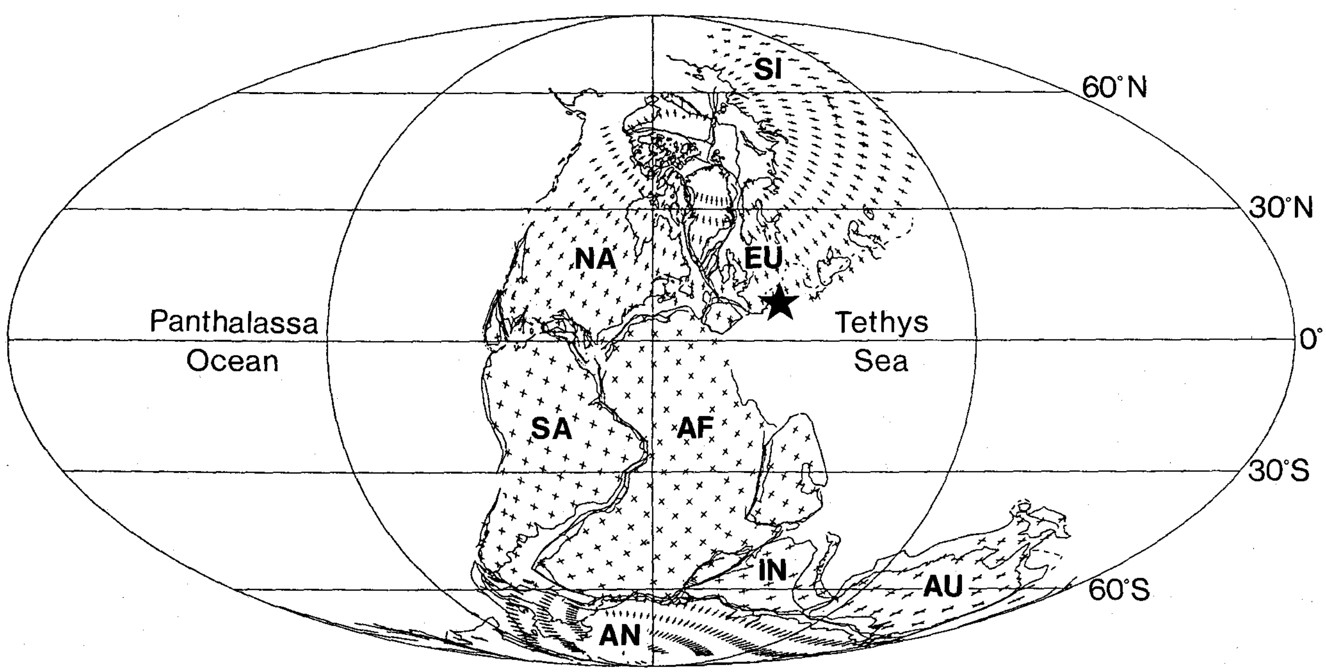
The boundary (at about 250 Ma) between the Paleozoic and Mesozoic Eras and the Permian and Triassic Periods is the culmination of the most dramatic extinction of biota in geological history. A large fraction of taxa of marine organisms became extinct in Late Permian time, and the earlier diversity was not re-established until well into the Triassic (D.M. RAUP & J.J. SEPKOSKI, 1982). The Permian–Triassic (P/Tr) transition was also associated with a wide range of other unusual events (W.T. HOLSER & M. MAGARITZ, 1987): a dramatic retreat of the seas from the newly aggregated Pangaean Continent, shifts in marine chemistry – salt content and isotopic ratios of carbon, sulfur and strontium, and changes in geophysical parameters including an increase of paleomagnetic reversals. Although many of these anomalies have been recognized for some years their relation to the mass extinction event has remained obscure. In the early 1980's the discovery at the Cretaceous/Tertiary (K/T) boundary (at 66.5 Ma) of a large and worldwide anomaly of rare metals (Ir, Co, Ni, etc.) in meteoritic ratios added a new paradigm – the impact of a large meteor – to the possible causes of mass extinctions (L.W. ALVAREZ et al., 1980). Then when D.M. RAUP & J.J. SEPKOSKI (1984) detected a common thread of periodicity among the extinction events, it seemed even more probable that not only the K/T but also the P/Tr events may have had a meteoritic cause. However, initial results of searches for an iridium anomaly at the P/Tr boundary were ambiguous or conflicting (F. ASARO et al., 1982; A.S. ALEKSEEV, 1983; Y.Y. SUN et al., 1984; D.-Y. XU et al., 1985; D.L. CLARK et al., 1986) and have remained so in recent publications (Z.F. CHAI et al., 1986; L. ZHOU, 1987; L. ZHOU & F.T. KYTE, 1988; D. BOCLET et al., 1988; C.J. ORTH, 1989).

During this same period our own involvement with the P/Tr interval had begun with studies of the extraordinary high levels of ^{13}C in marine carbonates of the Upper Permian (M. MAGARITZ et al., 1983; W.T. HOLSER et al., 1986). Shifts of the marine carbon isotope ratio are related to major worldwide reorganizations of the exogenic carbon cycle: specifically, if a larger fraction of carbon is stored as organic carbon, with low ^{13}C, then the residual marine bicarbonate has higher ^{13}C, which is directly sampled by marine carbonate sediments. Carbon isotope profiles near the P/Tr boundary in the Southern Alps sampled in 1982 suggested that $\delta^{13}C$ dropped smoothly but rather sharply somewhere near the P/Tr boundary (W.T. HOLSER & M. MAGARITZ, 1985) – an indication confirmed by more detailed later sampling (M. MAGARITZ et al., 1988; A. BAUD et al. 1989). This drop signalled a major change in the carbon system, and a study of the rate and complexity of the drop might contribute to a better understanding of the biotic extinction event. Such understanding would be enhanced by a close correlation of carbon isotope shifts both with the paleontology/stratigraphy of the boundary section, and with any other geochemical anomalies found in this interval.

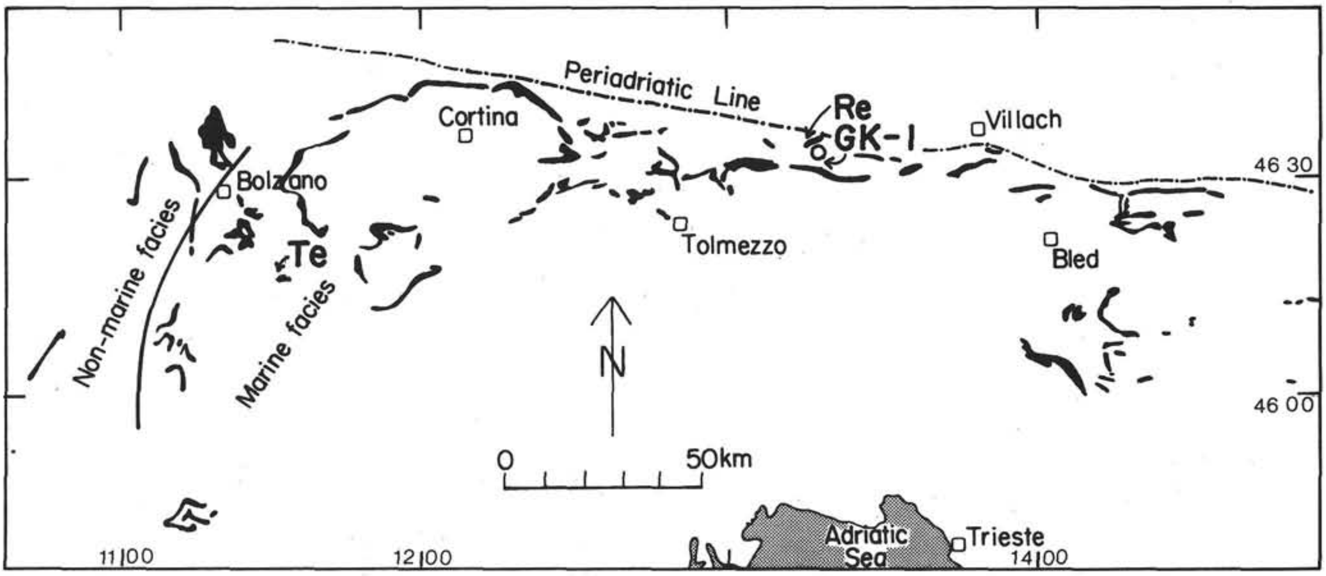
The most complete stratigraphic sections through the marine Upper Permian–Lower Triassic interval, that would be most suited to such studies, lie along the shores of the Tethys Sea, opening eastward from the Southern Alps and presently exposed in the Alpine-Caucasian-Himalayan belt (Text-Fig. 1).

The overall plan of investigation involved two parts:

1) A survey of carbon isotope profiles throughout the Tethyan region, from the Alps to China; and
2) A comprehensive study of one locality in which the carbon isotope profile would be integrated with parallel investigations of paleontology, microfacies, mineralogy, geochemistry and paleomagnetism.



Text-Fig. 1.
Reconstruction of the supercontinent Pangaea in the Late Permian after A.L. LOTTES & D.B. ROWLEY (1990).
Added letters indicate: AF = Africa; AN = Antarctica; AU = Australia; EU = Europe; IN = India; NA = North America; SA = South America; SI = Siberia.
Star indicates approximate position of core Gartnerkofel-1 in the Naßfeld area of the Carnic Alps of southern Austria.



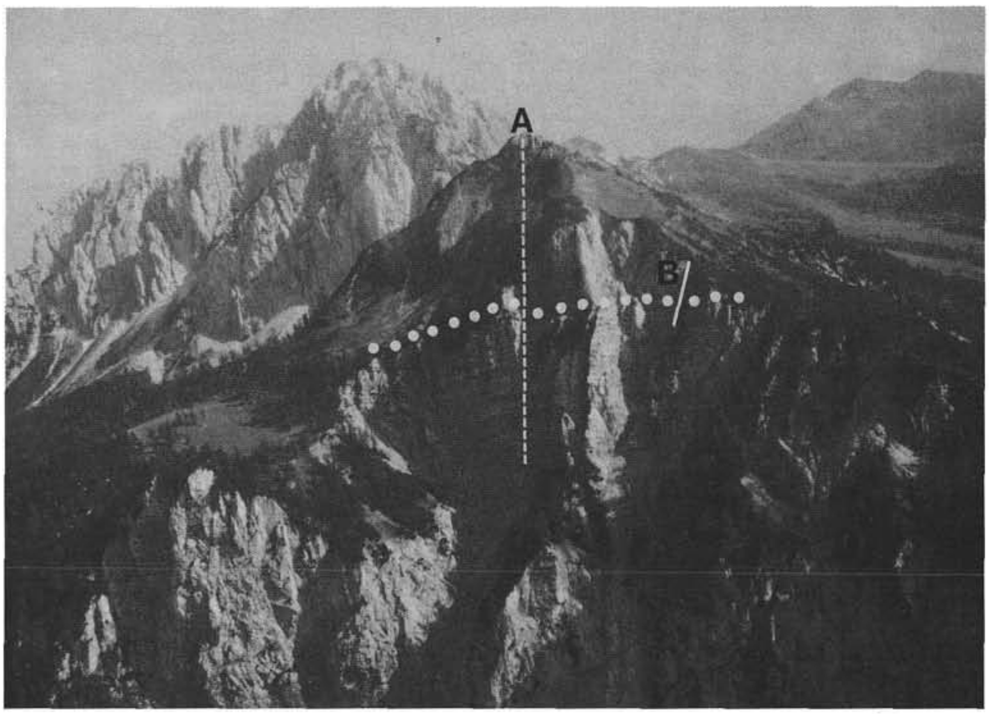
Text-Fig. 2.
Location of the Gartnerkofel-1 (GK-1) core hole and the Reppwand outcrop section (Re) in relation to the surface distribution of P/Tr rocks in the Southern Alps (Te = Tesero).

For the first part the results have been published by M. MAGARITZ et al. (1988) and by A. BAUD et al. (1989). For the second part preliminary reports have been presented by W.T. HOLSER & H.P. SCHÖNLAUB (1987, 1988) and published by W.T. HOLSER et al. (1989); this volume comprises a final and complete report.

2. The Gartnerkofel Project

The Southern Alps (Dolomite Alps of Italy, Carnic Alps of Austria and Julian Alps of Yugoslavia) expose a belt of Permian-Triassic sediments that vary in facies from non-marine sandstones west of Bolzano, Italy, through near-shore evaporites and limestones near the longitude of Cortina, Italy, to shelf carbonates west of Villach, Austria and Bled, Yugoslavia (Text-Fig. 2; R. ASSERETO et al., 1973; W. BUGGISCH, 1978). The area lies in the western bight of the Tethys Sea ("1" in Text-Fig. 1). A prominent carbonate cliff section at the Reppwand ("Re" in Text-Fig. 2), on the north slope of the Gartnerkofel in the Carnic Alps (Text-Fig. 3), was sufficiently far east of the shoreline to be fully marine, and a preliminary study of the outcrop sequence and its carbon isotope profile had indicated that the boundary section was rather complete (W.T. HOLSER & M. MAGARITZ, 1985). This area was selected for our comprehensive study. The geology is well known from the studies of F. KAHLER & S. PREY (1963) and H.P. SCHÖNLAUB (1987).

In order to obtain the best possible reference section free of outcrop alteration, we proposed continuous coring of the boundary section. In the event, this deci-



Text-Fig. 3.
Aerial photograph from the north of the Reppwand cliff with the Gartnerkofel (2195 m) in the background.
A = Drill site on Kammleiten (1998 m); B = Top of the outcrop section.
Dotted line indicates the boundary between the well bedded Permian Bellerophon Formation below and the more indistinctly bedded Triassic Werfen Formation above.
Photo: G. FLAJS, Aachen.

Text-Fig. 4.
View from the northwest of the Gartnerkofel section with Reppwand cliff on the left.

sion to sample the section by coring, was particularly important for preservation of the thin interbeds of marl and their clay minerals and sulfides. A survey of possible drill sites in the Reppwand area, by SCHÖNLAUB and HOLSER, fixed on the Kammleiten, a hill at 1998 m elevation on the north slope of the Gartnerkofel, a few hundred meters south of the Reppwand cliff outcrop (Text-Figs. 3,4). At the top of Kammleiten, the hard Muschelkalk Conglomerate provided a substantial foundation for the drill rig. It was proposed to drill through the Muschelkalk Conglomerate (few tens of meters), through the underlying Triassic Werfen Formation, the P/Tr boundary, and as deep as possible into the Permian Bellerophon Formation (Text-Fig. 5). The entire hole was to be cored.

As a supplement to the complete core, a limited part of the section through the P/Tr boundary was described and sampled from the Reppwand cliffs (Text-Fig. 3), about 500 m northwest of the drill site on Kammleiten. This section, labelled in some records as "Reppwand B", had a much better exposure of the P/Tr boundary and of the overlying Werfen Formation, than did the section northeast of the drill site that we had previously sampled in 1982 (W.T. HOLSER & M. MAGARITZ, 1985). Accessibility, however, is limited and due to rock-fall dangerous.

3. Funding

HOLSER and SCHÖNLAUB, acting jointly as Co-Principal Investigators, applied in 1985 for funding by the Fonds zur Förderung der Wissenschaftlichen Forschung (FWF) and the National Science Foundation (NSF), under the Austria-USA Cooperative Science Program. Grants were finally approved to begin 1 July, 1986, for a period of 24 months; they were subsequently extended for an additional year. The bulk of the expenses, including the drilling contract, storage and sampling of the core, and technical support of the Austrian members of the Scientific Consortium (see below) was covered by Grant No P 5991 E from FWF in the total amount of AS 2.172.069.–. HOLSER's travel and communications expense was covered by Grant INT-8521025 from NSF for $ 8962, his technical support was dependent in part on NSF Grants EAR-8400222 and EAR-8707061. Analytical work of two other members of the Scientific Consortium was supported by the Weizmann Institute (MAGARITZ) and NASA and the U.S. Department of Energy (ORTH). This international support made this project possible, and is gratefully acknowledged.

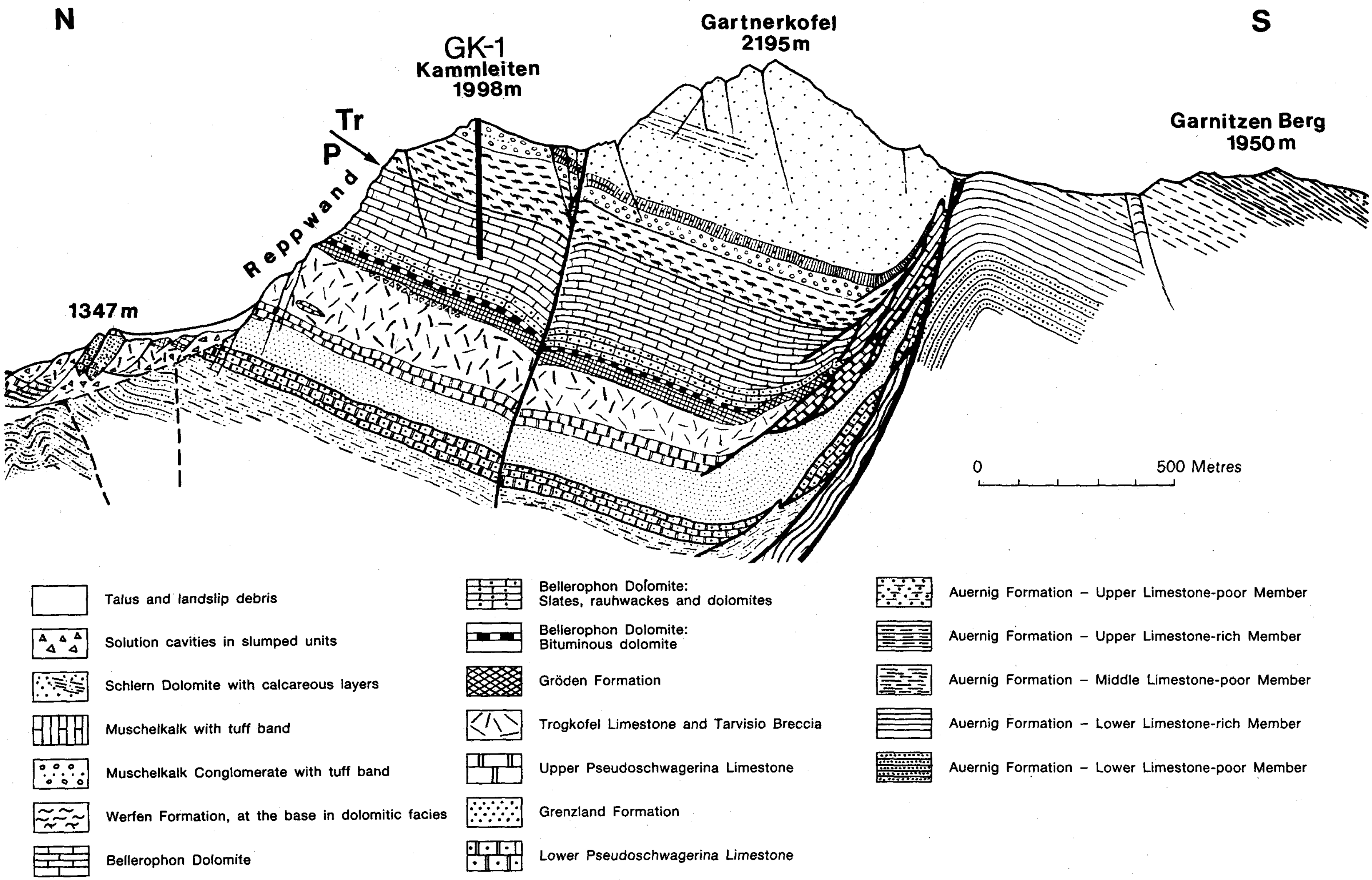
4. Scientific Consortium

The cross-disciplinary nature of the investigation of the Gartnerkofel core was critically dependent on the collaboration of a team of specialists who were recruited for the project. They are listed in Table 1, with their affiliations and the fields in which they contributed. Some of the members of the Consortium are pictured in Text-Fig. 6.

5. Drilling Logistics

The drilling was contracted to Vöest-Alpine, Eisenerz, and the project is indebted to the administration and personnel of Vöest-Alpine, in particular Dipl. Ing. KLOBASSA, Franz MITTER, Max HABERFELNER and Franz KORNER for the successful completion of the project.

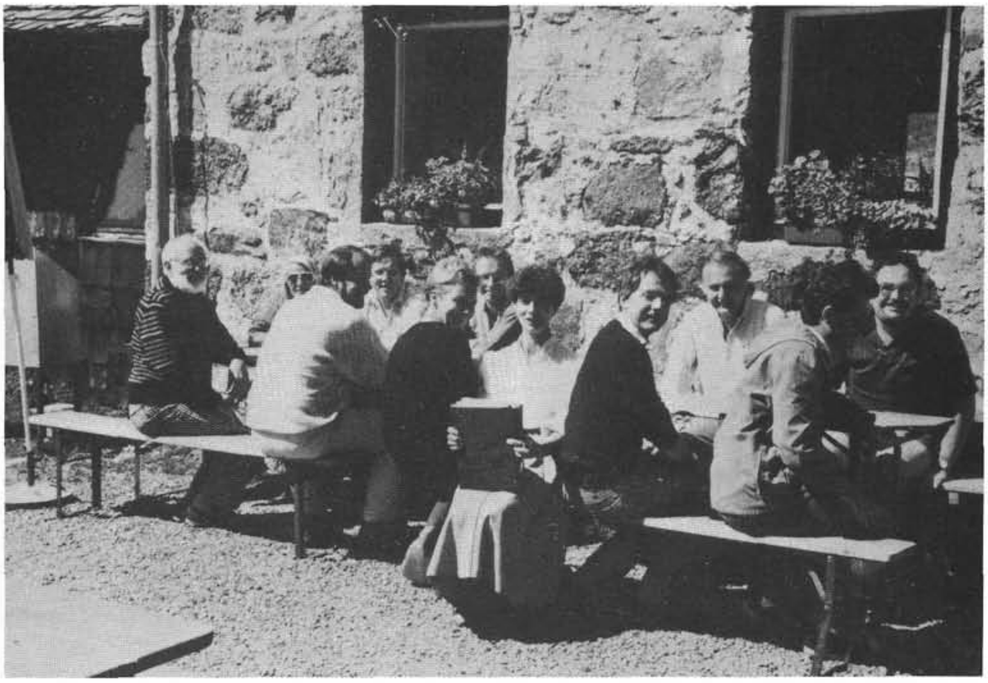
The selected drill site on the Kammleiten was located 380 m steeply above and 1.3 km beyond the end of the nearest road at Watschiger Alm, which is in turn 1,5 km northeast of the highway at Nassfeldpass. It was necessary to break the drilling equipment into more than 50 packages for transport by helicopter



Text-Fig. 5.
N–S geological cross section of the Gartnerkofel area (modified from F. KAHLER & S. PREY 1963) showing the section penetrated by the core hole.

▲ a)

b) ▼



Text-Fig. 6.
Some members of the scientific consortium.
a) During summer 1987.
From left to right: KLAUS BOECKELMANN, HERMANN MAURITSCH, RUPERT SCHMÖLLER, HANS P. SCHÖNLAUB, BILL HOLSER.
b) Late autumn 1987.
At the house front from left to right: Mrs. FENNINGER, ALOIS FENNINGER, KLAUS BOECKELMANN, PETER KLEIN, MORDECKAI MAGARITZ.
Seated from left to right: BILL HOLSER, R. STETTER (a student), HERMI DOLLINGER (the host), WOLFGANG ZEISSL, JOHANNES OBENHOLZNER.

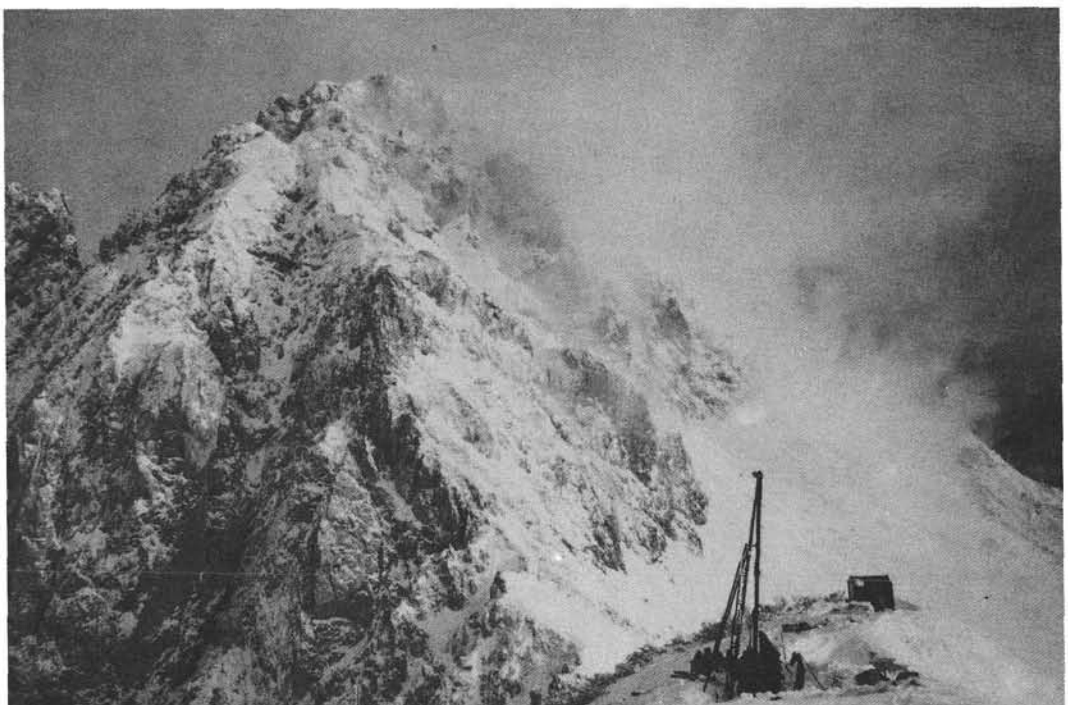
from the roadhead. The helicopter could not get access to the area until 9 September, 1986, after the main tourist season, and after grazing farm stock had been driven away from the area and into the valley. The lift was successfully completed in one day on 11 September (Pl. 1, Fig. 3), and the drill rig was assembled and ready for spudding on 13 September. The helicopter returned on 28 October 1986 to remove the disassembled drill rig and the 100 boxes of core resulting from the drilling program. In the intervening weeks, daily access to the drill site, for the drilling crew and the geologists, was on foot.

The core began with an HQ bit giving a 64-mm core in a 96-mm hole (Pl.1, Fig. 4). At 220.50 m the bit was switched to NQ giving a 48-mm core in a 76-mm hole. The average core recovery was 93.75 % of a total of 330 m but the actual recovery was highly variable owing to excessive fracturing in the hard dolomitic limestone that comprised most of the section. Average drilling rate was about 10 m/day, the deviation from the vertical was not more than 6 m at the bottom of the drill hole.

Drill cuttings were flushed out by circulating water. The water supply was lifted 230 m by two stages of pumps from springs in the Kühweger Alm, east of the drill site. The water supply eventually limited the drilling operation. As the season advanced, the spring flow decreased so that it was necessary to limit the drilling time each day. Ultimately the remaining water supply was frozen out by a snow storm on October 24 (Text-Fig. 7) and drilling was stopped on October 25 at a total depth of 331.00 m.

Table 1.
Scientific consortium of the Gartnerkofel Project.

Dr. KLAUS BOECKELMANN	Institut für Geologie und Paläontologie, Technische Universität, Berlin, FRG	Core logging, core sampling, sedimentology, microfacies, diagenesis
Prof. Dr. ALOIS FENNINGER	Geologisch-Paläontologisches Institut, Karl-Franzens-Universität Graz, Austria	Clay and carbonate mineralogy
Prof. WILLIAM T. HOLSER	Department of Geological Sciences, University of Oregon, USA	Co-principal Investigator, planning, core logging, isotope geochemistry, ore microscopy, geochemical interpretations, editor
Dr. CATHERINE JENNY-DESHUSSES	Musée géologique cantonal, Lausanne, Switzerland	Foraminifera
Dr. PETER KLEIN	Geologische Bundesanstalt, Wien, Austria	Core sampling, analytical chemistry
Dr. MARTIN KRALIK	Geotechnisches Institut, BVFA Arsenal, Wien, Austria	Strontium isotopes
Prof. MORDECKAI MAGARITZ	Environmental Sciences and Energy Research Department, The Weizmann Institute, Rehovot, Israel	Carbon and oxygen isotopes, diagenesis, geochemical interpretations
Prof. Dipl.-Ing. Dr. HERMANN MAURITSCH, Dr. WOLFGANG ZEISSL	Institut für Geophysik, Montanuniversität Leoben, Austria	Paleomagnetism
Dr. JOHANNES H. OBENHOLZNER	Institut für Geowissenschaften, Montanuniversität Leoben, Austria	Volcanic rocks
Dr. CHARLES J. ORTH, Dr. MOSES ATTREP Jr., Dr. L.R. QUINTANA	Isotope and Nuclear Chemistry Division, Los Alamos National Laboratory, Los Alamos, USA	Neutron activation analysis
Dr. EDWIN PAK	Institut für Radiumforschung und Kernphysik, Universität Wien, Austria	Sulfur isotopes
Prof. Dr. RUPERT SCHMÖLLER	Institut für Geophysik, Montanuniversität Leoben, Austria	Geophysical logging
Univ.-Doz. Dr. HANS PETER SCHÖNLAUB	Geologische Bundesanstalt, Wien, Austria	Co-principal Investigator, planning, site geology, stratigraphy, drilling supervision, core logging, core sampling, conodont paleontology, editor
Doz. Dr. JOSEF-MICHAEL SCHRAMM	Institut für Geowissenschaften, Universität Salzburg, Austria	Clay mineralogy, thermal overprint
Dr. KARL STATTEGGER	Institut für Geologie und Paläontologie, Karl-Franzens Universität Graz, Austria	Heavy minerals, statistics
Dr. REINHARD ZETTER	Institut für Paläobotanik, Universität, Wien, Austria	Palynology



Text-Fig. 7.
Drill site and Gartnerkofel after snow fall in late October 1986.

6. Core Logging

The core was logged, as it came from the barrel, by one or two of the site geologists: BOECKELMANN, HOLSER and SCHÖNLAUB. The character of the core was described on a scale varying mostly from a centimeter to tens of centimeters, by eye and hand lens. Particular attention was paid to the following characteristics:

1) Color.
2) Grain size.
3) Acid test for the occurrence of calcite in the predominantly dolomitized limestone.
4) Dark marl or clay interbeds, varying from mm-scale stylolites to dm-scale marls.
5) Pyrite, or goethite/hematite alteration of pyrite.
6) Oolitic texture.
7) Microfossils.
8) Laminar bedding, tempestites, or other sedimentological features.
9) Breccia, slickensides or other evidence of late deformation.
10) Veins or cavity fillings indicating late movement of solutions.

This core log is reproduced (in German language) as a microfiche in the pocket of this report. No attempt has been made to correct it for supplementary observations during the sampling of the core (see below), or for later observations by microscopy, X-ray diffraction, or chemical analysis. In particular, the interbeds described in the core log may not correspond exactly in depth or thickness with either the core sample list (P. KLEIN, this volume, Table 2), where samples of recognized marly interbeds are marked by a suffix "S", or the chemical analyses, where the occurrence of clay is signalled by high levels of "insoluble residue" (P.KLEIN, this volume, Tables 2–7), or aluminum as analyzed by INAA, (M. ATTREP et al., this volume).

7. Sampling of the Core and the Outcrop

The core boxes were first trucked to Leoben, where samples were taken for paleomagnetic studies. The original 68- or 44-mm core was cross-cut by a 25-mm diamond core drill at intervals of about 1 m, or at closer intervals of about 0,1 m near the P/Tr boundary. The paleomagnetic samples were designated by depth. A total of 594 samples were taken from the core, supplemented by 218 samples cut by a portable drill from a 48-m section of the Reppwand ("B") outcrop. Together these two sets of mini-cores yielded more than 1550 specimens for rock magnetic and paleomagnetic measurements (W. ZEISSL & H.J. MAURITSCH, this volume).

The GK-1 core was then moved to the laboratory of the Geologische Bundesanstalt in Wien, where the main sampling was accomplished by BOECKELMANN, KLEIN and SCHÖNLAUB. In the first round, 300 samples were taken from the Werfen and Bellerophon Formations at intervals that varied from a few tenths of a meter near the P/Tr boundary to several meters at more distant levels. These samples were numbered serially, from no. 1 at 57.53 m, the top of the Werfen Formation, to no. 300 at 329.04 m, in the Bellerophon Formation at the bottom of the core (P. KLEIN, this volume, Table 2).

The samples were of two kinds: those mainly carbonate rock, and those with visible dark shale or marl. For the carbonate samples the core was sliced vertically to obtain a 3–5 cm billet for making a large-area thin section for studies of microfacies (K. BOECKELMANN, this volume), paleontology (H.P. SCHÖNLAUB, C. JENNY-DESHUSSES, this volume), and diagenesis (K. BOECKELMANN and M. MAGARITZ, this volume). The back of each billet, thus exactly correlative with the thin section, was ground to powder in an agate mortar to pass a 50 micron mesh, and split to furnish replicate samples for mineralogy (A. FENNINGER and K. STATTEGGER, this volume; J.-M. SCHRAMM, this volume), analysis for main and trace elements (P. KLEIN, this volume; M. ATTREP et al., this volume), carbon and oxygen isotopes (M. MAGARITZ & W.T. HOLSER, this volume). Each of the marly interbeds was taken whole to be ground, without the preparation of a thin section, and these powders were similarly distributed for analysis, but also particularly for INAA determinations of common and trace elements (M. ATTREP et al., this volume) and palynology by R. ZETTER (yet without any positive recoveries).

Part of the first 57 m of the core, in the Middle Triassic Muschelkalk Conglomerate, was separately sampled for studies of volcanic rocks (J.H. OBENHOLZNER, this volume).

Subsequently (13 October, 1987) the initial 300 samples of the core were supplemented by a set of 35 samples at about 10 cm spacing from the interval 225.5 to 230.6 m, across the lower anomaly in iridium and carbon isotopes (W.T. HOLSER et al.1989, P.KLEIN, this volume, M. MAGARITZ & W.T. HOLSER, this volume). This set of samples was designated with alphabetical suffixes to the next-above, numbered sample, e.g., sample 190A was at 220.5–220.53 m, just below sample 190 of the first set (Tables 3, 6 of P. KLEIN, this volume). Two other sets of similar closely-spaced samples were taken (8 June, 1988) in the intervals 251.00–254.28 m (19 samples between the original sampling nos. 223–226, across the middle carbon isotope anomaly: M. MAGARITZ and W.T. HOLSER, this volume, P. KLEIN, this volume, Table 4) and 313.50–314.85 m (14 samples between the original sampling nos. 282–284, across a sharply declining carbon isotope record: M. MAGARITZ & W.T. HOLSER, this volume). These samples were designated only by their depth (P. KLEIN, this volume, Tables 4,7). All of these supplementary sets were given distribution similar to the original set of carbonate samples.

When most of the chemical and mineralogical sampling and studies were complete (11 November, 1987), 22 large samples of carbonate rock – 0.8 to 2.8 kg each – were taken from the interval 180.4 to 234.9 m, and dissolved to recover conodonts. A second set of 22 large samples was finally taken (14 February, 1990) from the intervals 170.55 to 190.00 m and 226.14 to 228.85 m to recover additional conodonts.

The outcrop section at Reppwand B, 500 m northwest of the drillsite, was originally sampled through a stratigraphic thickness of 42 m (H.P. SCHÖNLAUB, this volume, Table 2, see also Pl.1, Fig. 2). H.P. SCHÖNLAUB and K. BOECKELMANN took samples at spacings from a few cm to 1.5 m; these samples were numbered serially upward from 1 to 67, and were marked on the outcrop. A zero reference level for the stratigraphic position of this sample set was later established at the base of the Tesero Horizon (Bellerophon/Werfen boundary). The relation was recorded to the correlative small-core sampling of the outcrop section for paleomagnetic measurements (see above). HOLSER sampled critical clay-rich horizons, numbered 86450 through 86463, and in known relation to samples 11 through 37, respectively. Subsequently (6 June, 1988) SCHÖNLAUB extended the sampling upward for 22.5 more meters, sample nos. 68 through 90. Most of these sample sets were analyzed for microfacies, carbon and oxygen isotopes, and in the critical boundary section by INAA and RNAA. SCHÖNLAUB conducted two campaigns of sampling for conodont studies, recovering and processing 44 samples of 748 to 2750 g weight from the core, tied to the original studied section between sample nos. 88 and 211, and 90 samples from the outcrop (H.P. SCHÖNLAUB, this volume). Correlations were established with the Gartnerkofel-1 core by the profiles of microfacies (K. BOECKELMANN, this volume), and carbon isotopes (MAGARITZ & W.T. HOLSER, this volume); results for iridium analyses (M. ATTREP et al., this volume) and conodont speciation (H.P. SCHÖNLAUB, this volume) were consistent with that correlation.

8. Archive of Core and Data

In view of the unique character and probable future importance of the core and the data obtained from it, a permanent archive was established at the Geologische Bundesanstalt, Rasumofskygasse 23, A-1031 Wien. The archive stores the remains of the core, ground samples, thin sections, notebooks, data sheets, photographs and a slide series. The archive is open for study and sampling to any qualified investigator.

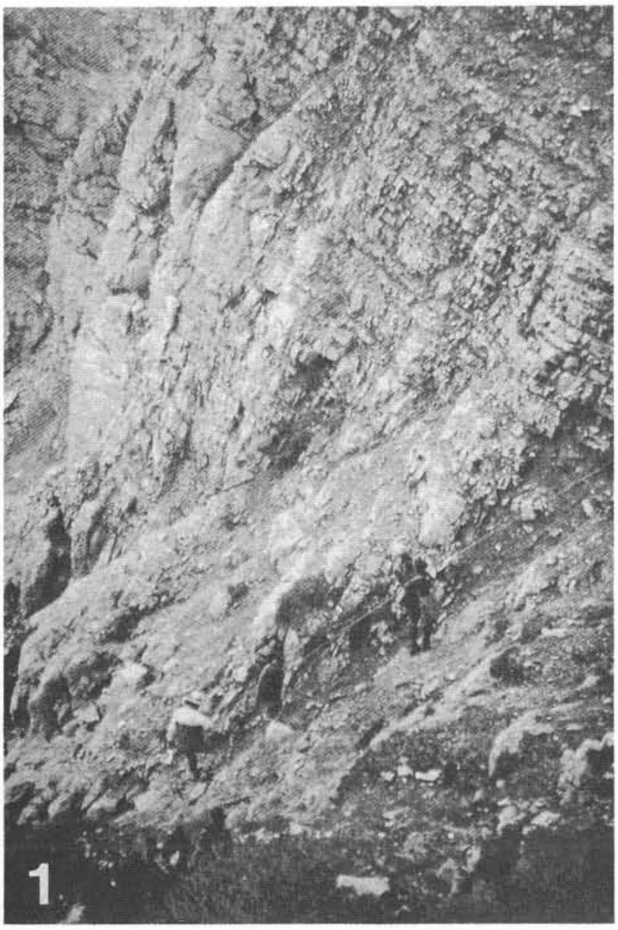
Plate 1

Fig. 1: Reppwand outcrop section with geophysicists sampling in the Werfen Formation.

Fig. 2: HOLSER at the P/Tr boundary on the Reppwand outcrop section.

Fig. 3: Helicopter landing a load on the drill site.

Fig. 4: Part of the 64 mm-diameter core showing the marly interbeds at depths 186.82 to 186.84 m and 186.93 to 186.95 m in the core box immediately after recovery on October 4th, 1986.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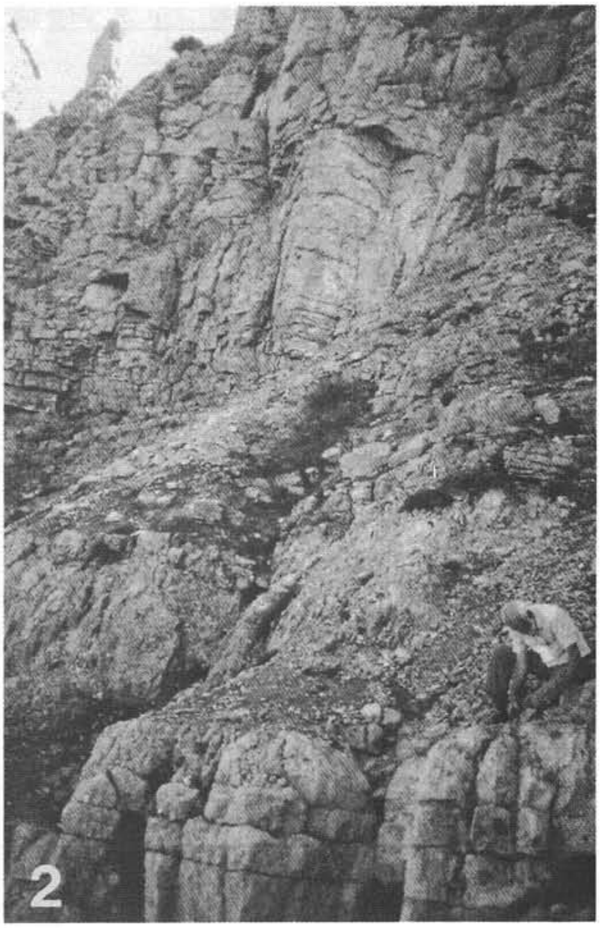
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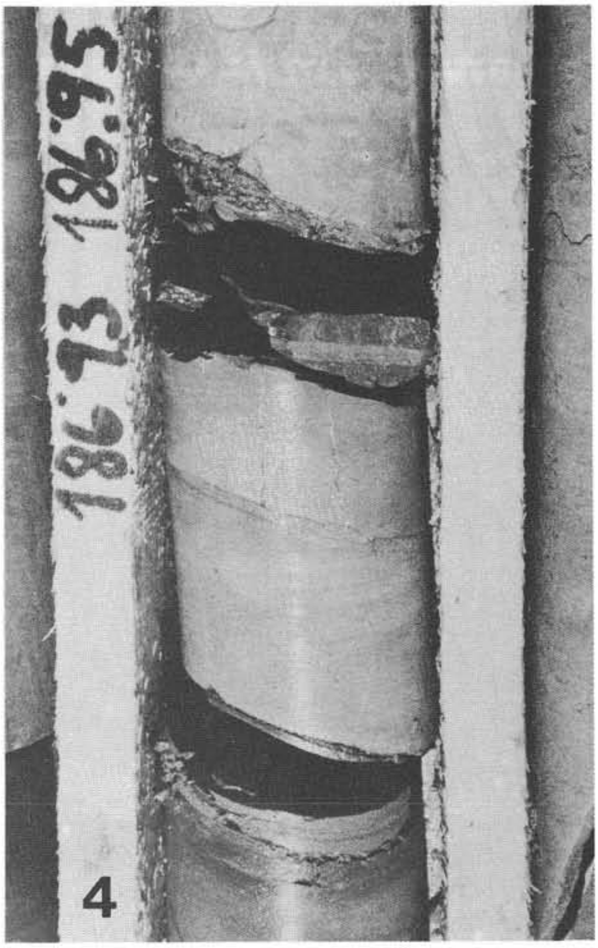
186.93 186.95
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