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The Late Permian Carbon Isotope Anomaly in the Bellerophon Basin, Carnic and Dolomite Alps

By WILLIAM T. HOLSER & MORDECKAI MAGARITZ*)

With 3 figures and 2 tables

Carinthia
Carnia
South Tyrol
Cadore
Carbon isotopes
Oxygen isotopes
Sulfur isotopes
Permian–Triassic stratigraphy

Zusammenfassung

Die in den letzten Jahren an verschiedenen Stellen der Erde nachgewiesene positive Anomalie des marinen Kohlenstoff-Isotopen-Verhältnisses ($^{13}C/^{12}C$, ausgedrückt als $\delta^{13}C_{carb}$) wird in ersten Proben aus der Bellerophon Formation der Südalpen bestätigt. Das Reppwandprofil in den Karnischen Alpen zeigt die Kohlenstoff-Isotopen-Anomalie überaus klar und in einer vollständigen Kurve. Knapp über der Basis der Bellerophon Formation steigt $\delta^{13}C$ deutlich an. Die gleiche Tendenz fand sich im Zechsteinbecken von Norddeutschland an der Grenze Kupferschiefer/Zechsteinkalk, am Capitan/Ochoa-Kontakt im Delaware Becken von Texas und in anderen Gebieten, was auf ein synchrones Ereignis schließen läßt. Die Bellerophon-Formation kann daher mit der Paratirolites-Zone des Oberperms korreliert werden (Dorasham-Unterstufe). Der oberste Teil über der Anomalie könnte gleich alt sein wie das jüngste Perm im Transkaukasus.

Für die Zukunft bietet sich das Reppwandprofil wie kaum ein anderes an, eine Erklärung für die auffallende und offensichtlich weltweit verbreitete oberpermische Kohlenstoff-Isotopen-Anomalie im Sinne der „Global Event Stratigraphy" zu finden.

Summary

A uniquely large positive excursion of marine carbon isotope ratio in the Late Permian recently discovered in other localities worldwide, is confirmed in several sections in the Bellerophon Formation. The section at the Reppwand in the Carnic Alps is the most complete representation of this anomaly so far found. The sharp onset of positive $\delta^{13}C$, which occurs very close to the contact of the Gröden and the Bellerophon Formations, can consequently be precisely correlated with the Kupferschiefer-Zechsteinkalk boundary in the Zechstein Basin and with the Capitanian-Ochoan contact in the Delaware Basin. The main part of the Bellerophon Formation is correlated with the Paratirolites zone of the Dorashamian Substage of the Upper Permian, and the top part of the Bellerophon may be equivalent to very latest Permian as defined in the Transcaucasus. The Carnic Alps is a prime area for further study of the geochemistry, correlations, and origin of this anomaly.

*) Authors' addresses: WILLIAM T. HOLSER, Department of Geology, University of Oregon, Eugene, OR 97403, USA; MORDECKAI MAGARITZ, Isotopes Department, Weizmann Institute, Rehovot, Israel; and Department of Geology, University of Oregon, Eugene, OR 97403, USA.

1. Introduction

Carbon is one of the important elements whose geochemical cycle is controlled by surficial earth processes. The carbon record through time reflects the distribution of carbon between two major reservoirs: the organic carbon and the inorganic phases (mainly dissolved carbonate in the ocean). Owing to biological discrimination against the heavy isotopic (^{13}C), any shift in the ratio of the two reservoirs with time will be reflected in the carbon isotopic composition of carbonate precipitates representing that period. Carbon isotope variations are conventionally described as departures in parts per thousand from an arbitrary (PDB) standard:

$$\delta^{13}C_{carb} = \frac{(^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{PDB}}{(^{13}C/^{12}C)_{PDB}} \times 1000$$

The secular variations of carbon isotopes (VEIZER et al., 1980; SALTZMAN et al., 1982), together with similar evidence from the sulfur (CLAYPOOL et al., 1980) and strontium (BURKE et al., 1983) cycles indicate major changes in ocean chemistry through time (HOLSER, 1984). On a long time scale a predicted negative correlation between $\delta^{13}C$ and $\delta^{34}S$ variations is evident as a statistical tendency (VEIZER et al., 1980), but when looking in detail at periods of major changes in the isotopic record this correlation is not evident (HOLSER & MAGARITZ, 1984). Abrupt shifts in the carbon isotope record have been documented for various times. The most recent shift occurred at about 14.000 years B. P. in the deep-sea carbon reservoir (SHACKELTON & OPDYKE, 1976). Other shifts have been reported for the Miocene (WOODRUFF et al., 1981), the Cretaceous/Tertiary boundary (SMIT, 1982; PERCH-NIELSEN et al., 1982) and the Cenomanian/Turonian boundary (SCHOLLE & ARTHUR, 1980).

The most dramatic change in $\delta^{13}C$ values is a rise of 5 ‰ or more that occurred in the last stage of the Permian. Its onset has been documented from three localities in the Zechstein Basin of northwestern Europe

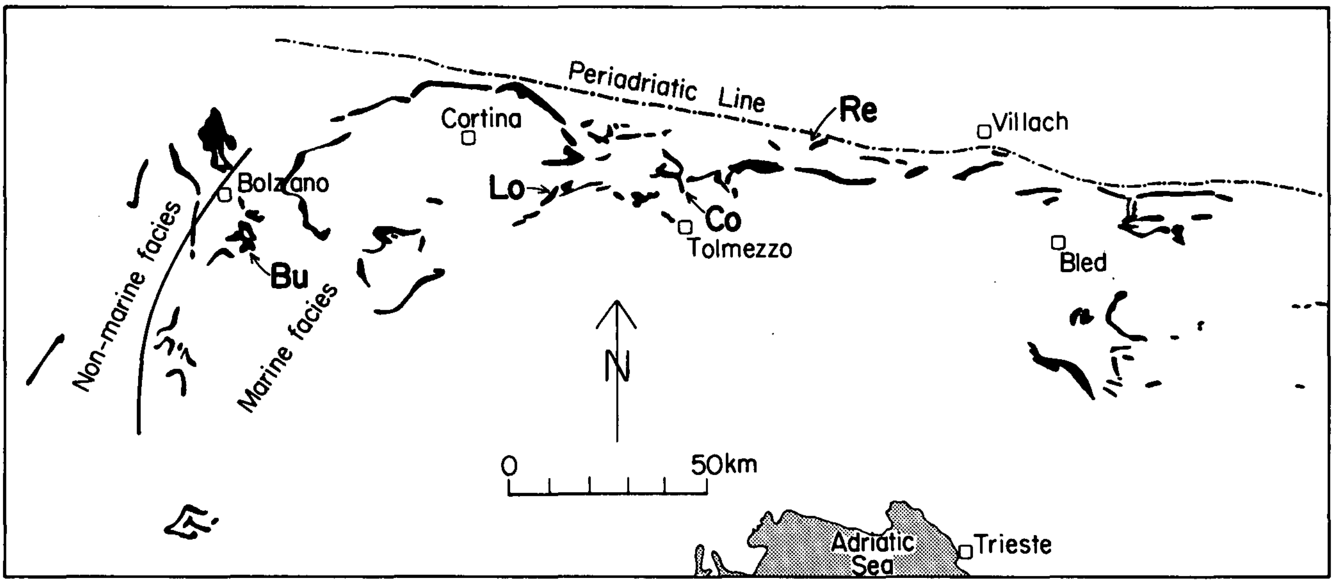

Figure 1: Outcrops of Upper Permian in the Bellerophon Basin in the Dolomite and Carnic Alps, after BUGGISCH (1978). Sections analyzed for stable isotopes are indicated: Bu = Butterloch; Co = Comeglians; Lo = Lozzo; Re = Reppwand. From the westernmost extent of marine facies (shown as a dashed line near Bolzano) the evaporite/limestone section increases rapidly eastward to a maximum thickness of evaporite content at Lozzo; farther east evaporites decrease until the section at the Reppwand is completely marine.

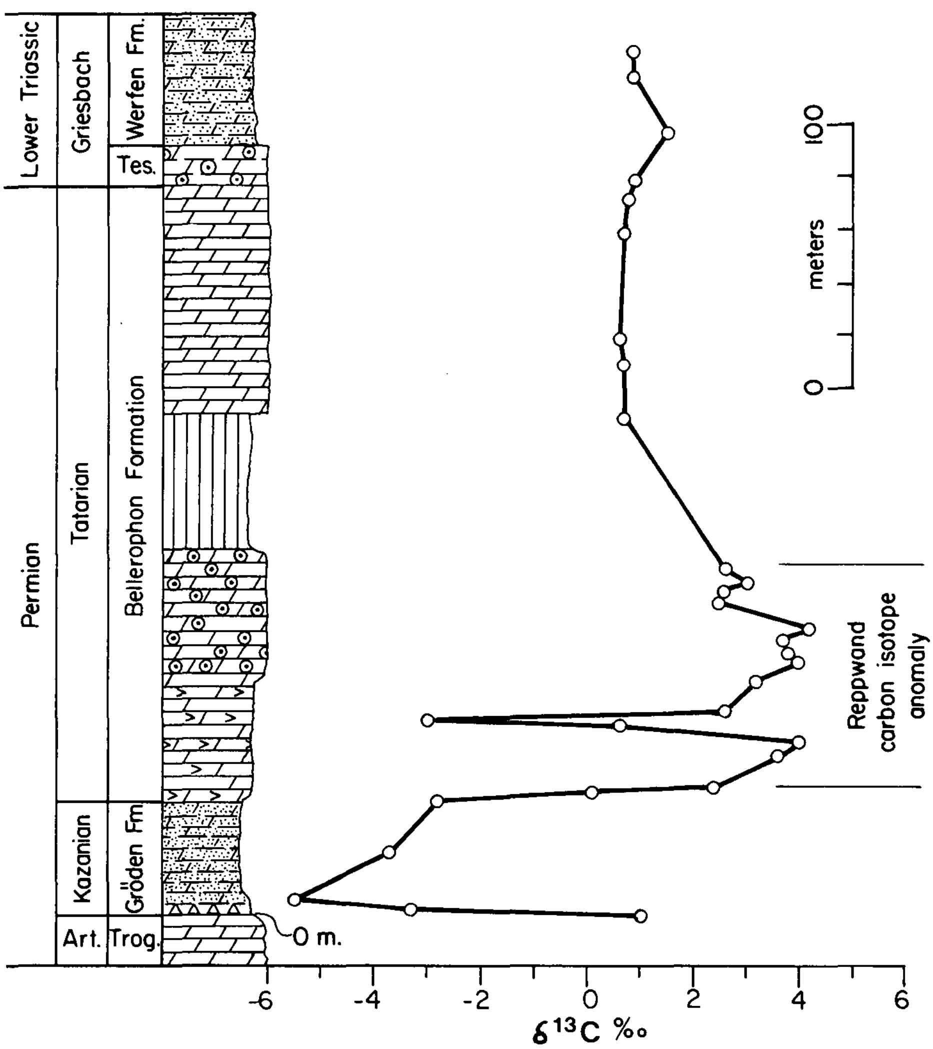

Figure 2: Carbon isotope profile at the Reppwand, Carnic Alps. Details are given in Table 1.

(MAGARITZ & SCHULZE, 1980; MAGARITZ et al., 1981; MAGARITZ & TURNER, 1982), from three cores in the Delaware Basin of west Texas (MAGARITZ et al., 1983) and from southeast China (CHEN et al., 1984). However, none of these sections showed both the rise to enriched $\delta^{13}C$ values and the return to normal values around 0 ‰. In this paper we report on a section from the Carnic Alps that is so far unique in recording the entire carbon isotope anomaly.

Although the processes causing the carbon isotope anomaly are not yet entirely clear, they must reflect a major transformation of carbon from the dissolved bicarbonate reservoir into the reservoir of buried organic carbon, and *vice versa*, to account for increase and decrease in ^{13}C content. Because the record shows a very short time (a few thousand years) for the shift, both in the Pleistocene and in the Permian (MAGARITZ et al., 1983), one has to conclude that a very fast process is involved. The relations of deep-sea to surface reservoirs in the Permian ocean and their relative isolation and stability over time are virtually unknown, and are probably important for the understanding of the Permian carbon cycles. A second constraint is the sulfur isotopic record. If the organic carbon had been deposited in a marine environment it would probably have been associated with anoxic sea-floor conditions. Under such conditions large quantities of sulfur are also usually deposited (BERNER & RAISWELL, 1983), which would have also shifted the $\delta^{34}S$ value upward (GOLDHABER & KAPLAN, 1974). On the other hand, if carbon was removed in a terrestrial environment where sulfur is generally scarce (BERNER & RAISWELL, 1983), no change would be expected in the $\delta^{34}S$ composition. Since the $\delta^{34}S$ is low and constant in the Late Permian

Table 1: Stable Isotope Analyses in a Section of Permian and Triassic Rocks at the Reppwand, Carnic Alps, Austria. Measured and sampled by W. T. HOLSER, July 12th, 1982 (with assistance of H. JAEGER, G. PERETSMAN and H. P. SCHÖNLAUB).

	Cumulative thickness [m]	Sample no.	$\delta^{13}C$ [1 PDB]*)	$\delta^{18}O$ [1 PDB]*)
Lower Triassic, Griesbachian, Werfen Formation				
Siltstone and dolostone, light red to brown.	331.5			
Dolostone and limestone, gray to gray-green, weathers pale brown, thick-bedded, massive, in thin-section medium-crystalline dolomite (25–100 %) and de-dolomite, faunal fragments; 41 m.	326,5	82313	+0.9	−8.3
	316.5	82312	+0.9	−8.0
	295.5	82309	+1.5	−6.5
	290.5			
Dolostone and limestone, mostly oolitic, gray-green, massive to faintly layered – *Tresoro Horizon* (e.g., ASSERETO et al., 1973, 15 m).	279.5	82307	+0.9	−6.6
	275.5			
Upper Permian, Tatarian, Bellerophon Formation (BUGGISCH, 1976, p. 682)				
Dolostone, gray-green to greenish brown, thick-bedded to massive, but finely laminated crystalline dolomite in thin section; 87 m.	271.5	82304	+0.8	−6.5
	258.5	82302	+0.7	−8.2
	219.5	82298	+0.6	−7.7
	189.0	82295	+0.7	−7.1
	188.5			
Covered; 50 m.				
	138.5			
Dolostone, brown in alternating prominent and recessive beds 0.1 to 1 m thick, in thin section much finely crystalline dolomite replacing oolitic or pelletal limestone; some coarsely crystalline dolomite breccia; 50 m.	131.5	82294	+2.6	−2.9
	126.5	82293	+3.0	−1.4
	123.5	82292	+2.6	−3.8
	119.5	82291	+2.5	−1.5
	109.5	82289	+4.2	−2.5
	105.5	82288	+3.7	−2.8
	100.5	82287	+3.8	−2.7
	96.5	82286	+4.0	−3.7
	89.5	82285	+3.2	−3.3
	88.5			
Dolostone, gray to purple, alternating beds of fine splintery dolostone and coarse porous evaporite breccia (Rauhwacke); in thin section finely crystalline dolomite, some sandy near base; 45 m.	77.5	82284	+2.6	−2.7
	74.5	82283	−3.0	−2.8
	72.9	82282	+0.6	−6.9
	65.9	82281	+4.0	−2.5
	60.9	82280	+3.6	−4.0
	49.9	82279	+2.4	−3.0
	47.5	82278	+0.1	−2.4
	45.7	82286	−2.8	−4.3
Permian, Artinskian to Tatarian, Gröden Formation	43.7			
(BUGGISCH, 1976, p. 673; 1978)				
Siltstone, dolomitic, alternating red and gray-green to violet beds, becoming less red upward, dolomitic section rich in stilolites; 42 m.	23.5	82275	−3.7	−2.9
	6.0	82271	−5.5	−4.5
Permian, Artinskian, Tarvis Breccia (BUGGISCH, 1976, p. 669; 1978, p. 174)				
Dolostone breccia, some fragments bituminous, pockets of coarsely crystalline ferroan dolomite; 2 m.	2.0	82272	−3.3	−3.3
	0.0			
Permian, Sakmarian, Trogkofel Limestone (BUGGISCH, 1976, p. 666; 1980)				
Dolostone, cliff-forming, biofragments and breccia replaced by fine grained dolomite, some coarse dolomite cement.		82270	+1.0	−4.6

*) Stable isotope ratios on dolomite, by the method of MAGARITZ & KAFRI (1981).

(CLAYPOOL et al., 1980), the removal of C_{org} is inferred in terrestrial sites, perhaps in an accumulation from luxuriant forests that accompanied the waning Early Permian glaciation (HOLSER & MAGARITZ, 1984).

2. Sampling in the Bellerophon Basin

The site of our sampling is the Bellerophon Basin in the Carnic and Dolomite Alps (fig. 1). This region exposes an important section of Permian and Triassic rocks that were deposited on the northern shelf of the western Tethys Sea, completely independent of the contemporary Zechstein Basin (which had its inlet far to the north on the Boreal Ocean). As shown in figure 1, they crop out from a western shoreline near Bolzano, Italy, eastward across deepening shelf through the Dolomites of Italy, the Carnic Alps of Austria, and the Julian Alps of Yugoslavia (ASSERETO et al., 1973; BUGGISCH et al., 1976). East–west cross-sections are figurred by ASSERETO et al. (1973, fig. 4) and by BOSSELINI & HARDIE (1973, fig. 2). The latest Permian deposition is the Bellerophon Formation, which gives its name to the basin. In 1982 we sampled 8 sections in this basin for isotopic study. The most complete and interesting section was found at the Reppwand, in the Carnic Alps, and three other sections so far analyzed to the west provide supplementary information.

The Reppwand section is completely undeformed, with the gentle dip characteristic of the Alps south of the tectonic Periadriatic Line (KAHLER, 1963; SCHÖNLAUB, 1979). It exposes Upper Permian and Lower Triassic limestones and siltstones of dominantly marine aspect (figs. 2, 3). The petrography and geochemistry of the Reppwand section have been described in detail for the Trogkofel Limestone (BUGGISCH et al., 1976; BUGGISCH, 1980), for the Gröden Formation (BUGGISCH et al., 1976; BUGGISCH, 1978), and for the Bellerophon Formation (BUGGISCH et al., 1976); no comparable description of the overlying Werfen Formation has been published. The carbonate rocks in the section are mostly dolomite of early diagenetic origin, which best preserves the carbon isotope record (MAGARITZ, 1984). The section sampled was at the eastern end of the Reppwand cliff, 3 km east of Nassfeld, starting at the top of the Trogkofel Limestone, continuing through the Gröden and Bellerophon, and into the Lower Triassic Mazzin Formation on the slopes above (table 1; fig. 2).

To the west in the Dolomite Alps the sea of the Bellerophon Basin transgressed on a shoreline with the deposition of a rather thick section of $CaSO_4$ evaporites overlying the Gröden clastics (fig. 1; ASSERETO et al., 1974). BOSELLINI & HARDIE (1973) described in detail the geology and petrology of the section at Passo di Valles (between Butterloch and Lozzo in fig. 1) and concluded that it represented a rhythmic sequence of sabkha evaporites. Although the sections in the Dolomite Alps are nearer to the shoreline than the Reppwand, and consequently may be more influenced by terrestrial geochemistry, they do provide an opportunity to confirm the basin-wide extent of the carbon isotope anomaly, and to compare changes in $\delta^{13}C_{carb}$ with any changes in $\delta^{34}S_{sft}$.

Samples have been analyzed from three of the sections sampled in the Dolomite Alps (table 2). The section at Comeglians (fig. 1; Co) is exposed in and above

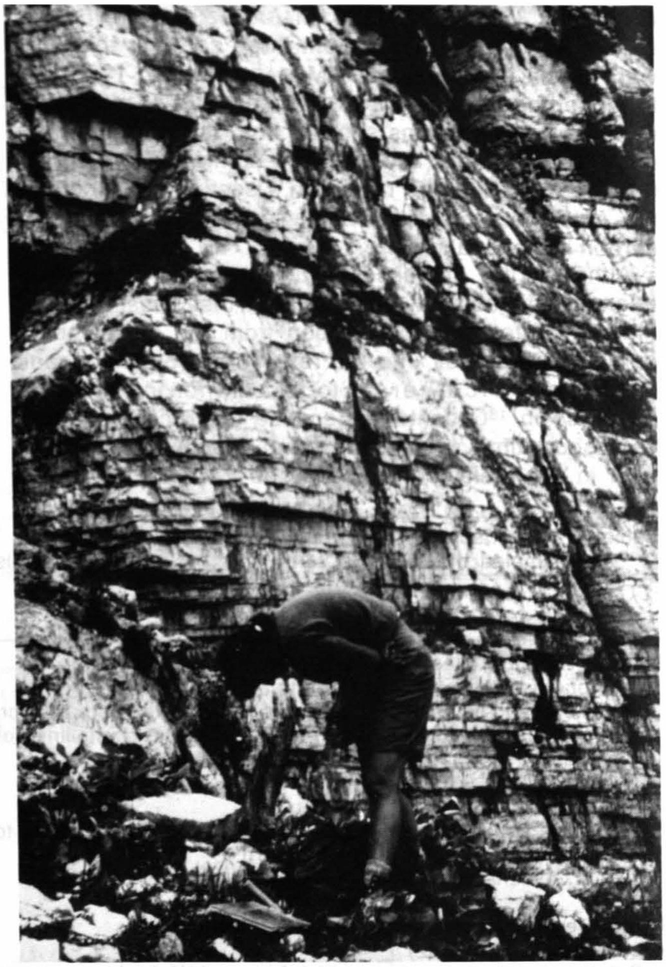

Figure 3: Dolomitic limestones near the base of the Bellerophon Formation at the Reppwand, Carnic Alps.

a gypsum quarry northwest of the town and was chosen for analysis because it is the easternmost exposure of a substantial evaporite section. It is highly deformed, with vertical banding in the gypsum; the few dark limestone beds form boudinage. The section at Lozzo (fig. 1: Lo) is the thickest exposure of evaporite. It begins in gypsum just above Highway 51 at the south edge of the town, and continues westward up a canyon through two sections of banded gypsum and into Triassic limestones and marls above. The section at Butterloch (fig. 1: Bu) was chosen as a well-studied section that was far west but still substantially marine. The section lies about 2 km northeast of Redagno, starting in the Val Gardena (= Gröden) sandstones in the bottom of the Butterloch ravine, and continuing up the eastern cliffs through marl and gypsum beds of the Bellerophon Formation. The section is clearly figured in ASSERETO et al. (1973, fig. 5).

3. Analytical Methods

An aliquot of ground powder was analyzed by standard X-ray diffraction procedure. Weight percent dolomite/(dolomite + calcite) was calculated using the area under the respective peaks (Cu-$K_\alpha 2\theta$ = 30.8° and 29.5°) and the WEBER & SMITH (1961) formula.

The carbon and oxygen isotopes in carbonate minerals were measured using the conventional phosphoric acid method. For the samples containing >50 % dolomite we used the procedure described in MAGARITZ & KAFRI (1981), measuring only the dolomitic component. The CO_2 gas was analyzed in a Varian M250 mass spectrometer and the results are given using the "δ" notation. Reproducibility of duplicate samples is better than 0.15 ‰. The $\delta^{18}O$ values of the dolomites were corrected by −0.84 ‰ (SHARMA & CLAYTON, 1965).

Sulfur isotope ratios were measured on sulfate, after precipitation as $BaSO_4$ (CLAYPOOL et al., 1980) and thermal decomposition to SO_2 (HOLT & ENGELKEMEIR, 1970; BAILEY & SMITH, 1972). The resulting SO_2 was analyzed on a Micromass 602 mass spectrometer with a reproducibility of ±0.15 ‰.

4. Results

4.1. Carbon and Oxygen Isotopes

The results for the Reppwand section are listed in table 1. As shown in fig. 2, the carbon isotope anomaly lies entirely within the Bellerophon Formation. High values of $\delta^{13}C$ between +2.5 and over 4.0 ‰ extend, with one interruption, through 80 m of section. The steep rise to these high values takes place in the Bellerophon Formation, but within a few meters of its base. The end of the anomalous high lies within a 50-m covered interval, although $\delta^{13}C$ had begun to decline as far as +2.5 ‰ in the preceeding 20 m. "Normal" values of $\delta^{13}C$ between 0 and +1 ‰ continue smoothly through the era boundary.

The positive high is interrupted by a sharp excursion to $\delta^{13}C$ = −3 ‰ (fig. 2). Similar negative excursions have previously been noted in two other localities: the western side of the Delaware Basin, Texas (MAGARITZ et al., 1983), and the Zechstein Basin (MAGARITZ et al., 1981; MAGARITZ & TURNER, 1982). But they are not found in other complete sections, and it is not yet clear whether these occurrences represent a local phenomenon (e. g., fresh-water inflow), or some kind of a marine signal. Detailed study of additional sections may help to resolve this question.

The Bellerophon Formation of the Italian Dolomites and the Austrian Carnic Alps is generally correlated with the Zechstein (KOZUR, 1981, p. 419; ANDERSON, 1981; WATERHOUSE, 1976, p. 83), mainly on the basis of brachiopods (ASSERETO et al., 1973, p. 187), and palynomorphs (KOZUR, 1977, p. 112), although the biostratigraphy has never been studied in systematic detail (FLÜGEL, 1981). This general relation is sharpened by isotope correlation of the onset marker that matches the Kupferschiefer-Zechsteinkalk transition of the Zechstein Basin with this rise just above the Gröden-Bellerophon boundary at the Reppwand (fig. 1). Where the underlying Gröden Formation is marine it is generally correlated as Wordian to Capitanian on the basis of fusulinids (KAHLER, 1974). This is confirmed by carbon isotope correlation of the onset marker with the section in the Delaware Basin, west Texas, where it occurs at the top of the Capitanian Stage, just below the contact of the Bell Canyon Formation (Delaware Mountain Series) and the overlying Castile Formation (Ochoan Series) (HOLSER et al., 1984).

Of the seven other sections that we sampled in the Bellerophon Basin, samples from those at Butterloch, Lozzo and Comeglians (all Italy) have so far been analyzed (table 2). In each of these sections, all of which lie shoreward of the Reppwand, and all of which include evaporite facies, the high of $\delta^{13}C$ is represented, but in none of them is both the onset and the termination of the anomaly present as it is at the Reppwand. In addition, a very detailed study of carbon isotopes in Triassic limestones from 30 localities throughout the Dolomite Alps by CARL NELSON of Rice University (pers. commun., September 1983) has found uniformly low values in all the lower members of the Triassic; he did not analyze any Permian limestones.

4.2. Sulfur Isotopes

We have checked the level of $\delta^{34}S$ in four samples of gypsum from Butterloch and Comeglians, for comparison with previous determinations of Permian marine evaporites. Three of these have $\delta^{34}S$ = +10.0, very close to the mean of previous Late Permian marine evaporite sulfates from throughout the world (CLAYPOOL et al., 1980; SALTZMAN et al., 1982); a single value of $\delta^{34}S$ = +13.6 is within the range of variation previously reported for rocks of this age. In particular these data confirm the previous determinations of PAK (1978), and CORTECCI et al. (1981), for samples from both the Gröden and Bellerophon Formations throughout the Dolomite Alps. Together these data display a relatively uniform and normal sulfur isotope level for the Bellerophon Basin, and furthermore support a marine origin for the Bellerophon Formation even near its western shore.

5. Discussion

The analyses of the Reppwand section comprise a comprehensive profile of carbon isotopes that includes both the onset and termination of the positive anomaly. The other sections so far analyzed in the Dolomite Alps confirm that the anomaly can be detected throughout the Bellerophon Basin, even within evaporite facies.

These determinations in the Bellerophon Basin verify the worldwide nature of the Late Permian carbon isotope anomaly, previously found in the western USA, Greenland, the Zechstein Basin, and China, as listed in Section 1. In a separate paper (HOLSER et al., 1984) we discuss in some detail the implications of this anomaly for stratigraphic correlations in the Late Permian, The following points are of specific interest with respect to correlations of the Bellerophon Formation with other Permian sections.

In the Bellerophon Basin the termination marker of the carbon isotope anomaly lies within the Bellerophon Formation (tables 1,2) – most clearly in the Reppwand section (fig. 2); the overlying Mazzin Member of lowermost Triassic age is everywhere normal. The termination marker thus lies below the Permian-Triassic boundary as defined somewhat arbitrarily at the base of the Tesero Horizon (ASSERETO et al., 1973, p. 182) in the Dolomite Alps. Correlation of the Bellerophon Formation with critical sections of Late Permian age is somewhat indefinite, as they depend on brachiopods and a sparse conodont fauna – and neither of these has been studied systematically in this formation. ASSERETO et al. (1973, p. 188) conclude that the Bellerophon is older than the *Paratirolites* zone, the final ammonoid zone of the Dorashamian stage, but the isotope correlation

Table 2: Stable Isotope Analyses in Permian-Triassic Sections of the Dolomite Alps, Italy.

Description	Sample no.	$^{13}C_{carb}$ (PDB)	$^{18}O_{carb}$ (PDB)	$^{34}S_{sft}$ (CDT)
Butterloch Section (Bu in fig. 1)				
Bellerophon Formation				
Dolomite, gray, thick-bedded, with nodules of gypsum, at 124 m.	82119	+4.3	− 4.9	+10.0
*Gypsum, massive, in 0.2-m beds with gray dolomite, at 121 m.	82118	+2.4	− 7.5	+13.6
Dolomite, gray, blocky, with some large gypsum nodules, at 119 m.	82117	+2.4	− 6.1	
Dolomite, gray, oolitic, top of 1.6-m bed at 113 m.	82112	+1.8	− 4.0	
As above, base of bed, base of formation.	82111	+2.0	− 3.0	
Val Gardena Sandstone				
Dolomite, light gray, blocky, in 0.2-m bed among gray sandstones, at 65 m.	82110	+1.3	− 4.1	
Dolomitic nodules, in red sandstone, at 56 m.	82109	−2.5	− 4.2	
*Limestone, black, thin-bedded, with white gypsum, in red to yellow sandstone, at 20 m.	82106	+0.9	− 6.9	
Base of section at stream bed.				
Lozzo Section (Lo in fig. 1)				
Werfen Formation (?)				
Limestone, dark gray, hard, massive, marly, at 350 m.	82201	−1.8	− 9.1	
Limestone, gray, wavy-bedded, oolitic, at 342 m.	82203	−2.3	− 9.0	
Bellerophon Formation (?)				
Limestone, slightly dolomitic and shaly, dark gray, platy, at 337 m.	82205	−2.9	− 8.9	
Limestone, dark gray, on 0.1 m beds with shaly partings, fossiliferous, at 320 m.	82209	+3.2	− 8.5	
Gypsum, dark gray, with brownish-gray boudinage of dolomite, highly deformed, at 128 m.	82193	+ 3.5	−10.2	
*As above, at 111 m.	82191	+1.4	− 4.4	
Dolomite, black, boudinage in gypsum, at 59 m	82138	+3.8	− 5.0	
*Gypsum, medium gray, in 2-mm laminae with limestone boudinage, at 40 m.	82136	+0.8	−10.2	
As above, at 38 m.	82137	+2.9	− 4.1	
Dolomite breccia, dark gray, at 5 m.	82133	+3.9	− 3.9	
*Gypsum, as in 82136, at 3 m.	82132	+1.1	− 9.9	
Reference point (0 m) at bridge Highway 51 bis				
*Gypsum, interbedded white and black, 2-mm laminae, somewhat deformed, at about −100 m.	82126	+0.8	− 9.1	
Comeglians Section (Co in fig. 1)				
Bellerophon Formation				
*Gypsum, white, laminated, highly deformed, with breccias and boudinage of black dolomite, at 54 m on 3rd quarry bench.	82245	+0.7	−11.3	
*Dolomite nodule in gypsum, as above, at 40 m on 2nd bench. Whole rock analysis.	82243	+3.0	− 9.1	+10.0
*Sample as above, black nodular portion.	82243	+4.0	− 4.5	
Sample as above, dolomite of white portion.	82243	+3.3	− 7.3	
Dolomite, large boudinage in gypsum, at 21 m on 1st bench.	82240	+3.1	− 7.5	
*Gypsum, laminated, white with minor black dolomite, at 18 m.	82239	−0.1	− 9.4	+10.0
Base of section at quarry buildings.				

*) Nominal field descriptions – analysis indicated only minor carbonate content, hence the $\delta^{13}C$ and $\delta^{18}O$ analyses should probably given less weight than the other samples.

with southern China places the Bellerophon of the Reppwand within the Paratirolites zone (HOLSER & MAGARITZ, 1984). Most of the paleontology on which ASSERETO based his conclusions was from the western part of the basin in the Italian Dolomites, and the top beds of the Bellerophon may not be of the same age everywhere (ASSERETO et al., 1973, p. 180).

KOZUR (1977, p. 105) reviews evidence that the type Dorashamian (the final stage of the Permian) of the Transcaucasus is in part younger than the Changxing Limestone of southern China, and CHEN (1984) found the termination of the carbon isotope anomaly very close to the top of the Changxing. Consequently, the part of the Bellerophon lying above the anomaly and below the Permian-Triassic boundary may be equivalent to the uppermost type Dorashamian. Alternatively, the Permian-Triassic boundary, assumed to coincide with the base of the Tesero oolitic horizon in the Reppwand section (ASSERETO et al., 1973), may actually lie somewhat lower.

Although the sources of the Late Permian carbon isotope anomaly must lie elsewhere in the world, as alluded to in Section 1 (HOLSER & MAGARITZ, 1984), further investigation of the Reppwand section has the potential of contributing to our understanding of the origins of the anomaly. This section has the most complete representation of the anomaly thus far discovered (HOLSER et al., 1984). As such, it would be a good site for more detailed investigations, of which the following are some important examples:

(a) Carbon isotope determinations on a finer sampling scale, and including the section that was covered in the initial sampling (fig. 2);
(b) A search for short-term negative excursions in carbon and oxygen isotopes, which are not yet well understood but thought to represent fresh-water inflows into the basin (MAGARITZ et al., 1983);
(c) Analyses of $^{87}Sr/^{86}Sr$ to correlate with the dramatic positive swing so far known only sketchily near the Permian-Triassic boundary (BURKE et al., 1982; KOVACH, 1980);
and
(d) Paleomagnetic measurements to detect short-term returns to normal polarity within the long Kaiman reversed polarity interval – such normal intervals have already been detected in the Zechstein of the North Sea (TURNER & VAUGHAN, 1977 – in the same core as the carbon anomaly), and in the Bellerophon of South Tyrol (DACHROTH, 1976).

Many of the further investigations of the Permian/Triassic of the Carnic Alps would be greatly facilitated by the acquisition of a continuous core that would permit closely controlled sampling of a section undisturbed by surface alteration.

6. Conclusions

A large positive anomaly of marine carbon isotopes in the Late Permian previously known in the western USA, northwestern Europe, and southern China, is confirmed at several localities throughout the Bellerophon Basin, and fully developed in the Reppwand section. The anomaly, whose precise origin through some massive deposition of organic carbon is not yet completely understood, nevertheless permits sharp correlations of the Bellerophon with other Late Permian sections worldwide.

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