

Cool-water carbonates in a paleoequatorial shallow-water environment: The paradox of the Auernig cyclic sediments (Upper Pennsylvanian, Carnic Alps, Austria-Italy) and its implications

Elias Samankassou* Département de Géosciences, Géologie et Paléontologie, Université de Fribourg, Pérolles, CH-1700 Fribourg, Switzerland

ABSTRACT

Distinct parts of limestones within the upper Paleozoic Auernig Group of the Carnic Alps, Austria and Italy, are characteristic of cool-water carbonates. The Carnic Alps were between 5°N and 10°S paleolatitude during the late Carboniferous, a position confirmed by dasyclad algae and fossil plants. The floral association, occurrence of coal seams, and absence of evaporites indicate a humid tropical environment. The entire section lacks abiotic components of typical warm-water limestones: no ooids and no aggregates occur within the Auernig Group. Parts of the limestones show, surprisingly, a cool-water association of high-diversity bryozoans, brachiopods, crinoids, red algae, sponge spicules, and entomozoan ostracodes. The genesis of these limestones, atypical for a paleoequatorial setting, cannot be explained by changes in salinity, bathymetry, or terrigenous input. The water temperature, possibly linked with upwelling, nutrient supply, and paleoceanographic currents, is the most convincing cause of this unusual association. Paleoclimatological changes are interpreted as linked to contemporaneous glaciation-deglaciation cycles in Gondwana. This paper shows that cool-water carbonates in shallow-water environments are not necessarily nontropical, as generally interpreted. Future studies should consider water temperature, oceanic circulation, and availability of nutrients, supplementary to bathymetry, salinity, and latitude-related climate in interpretation of carbonate components.

Keywords: cool-water carbonates, cyclothem, paleoceanography, Pennsylvanian, Carnic Alps.

INTRODUCTION

Following the classical contributions of Chave (1967), Lees and Buller (1972), and Lees (1975), cool-water carbonates have received considerable attention. James (1997) gave a historical perspective, along with characteristics of cool-water carbonates, and proposed new terms for their description and classification. He suggested the term “photozoan association” for the shallow, warm-water biotic assemblage, and “heterozoan association” for the counterpart in cool-water environments.

Sediments of the heterozoan association, also called “nontropical carbonates” (e.g., Nelson, 1988), are not limited to high latitude. This study documents an example of carbonates of the heterozoan association in a low-latitude, shallow-water setting, and discusses its implications.

GEOLOGIC SETTING

Late Namurian to middle Westphalian basins formed by the Variscan orogenic movements in the Carnic Alps on the present Austrian-Italian border (Fig. 1) were filled with deltaic and shallow-marine sediments from the middle Carboniferous to the Early Permian. These sediments now compose the Pennsylvanian to Lower Permian Auernig Group, Rat-

tendorf Group (both consisting of cyclic deposits; Fig. 2), and Trogkofel Group (Fig. 1).

EVIDENCE OF PALEOEQUATORIAL POSITION

According to Schönlaub (1992), the Carnic Alps were located between 5°N and 10°S pa-

leolatitude during the late Carboniferous. This position fits with the reconstruction of Golonka et al. (1994), which shows the region at ~10°S paleolatitude (see subsequent discussion).

Fossil plant assemblages, recorded within the entire Auernig Group, consist of Equisophyta, Lycophyta, Filicophyta, and Pteridospermae. These forms, like most of their recent representatives, are characteristic of the tropical-humid realm (Fritz and Boersma, 1990).

The common occurrence of thin coal lenses and seams within thick prodeltaic conglomerates and sandstones indicates a rainy, high-precipitation environment (LePain et al., 1994). Furthermore, no indicators of arid conditions (e.g., evaporites) have been reported from the Auernig Group.

Together, these paleontological and sedimentological criteria clearly indicate an equatorial, warm, rainy environment during deposition of the Auernig Group.

EVIDENCE OF COOL-WATER COMPONENTS

Abiotic Components of Limestones

Among the nonskeletal components, ooids and aggregates are the most important and characteristic grains of warm, shallow-water

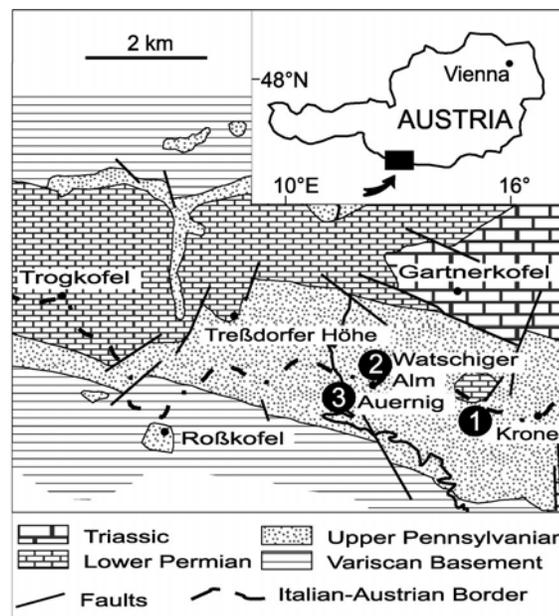


Figure 1. Location of study area. Numbers 1–3 indicate sections measured and analyzed.

*E-mail: elias.samankassou@unifr.ch.

Stratigraphy		Units of the study area	
Permian	Sakmarian	RATTENDORF GROUP	Upper Pseudoschwagerina Limestone
	Asselian		Grenzland Formation
Pennsylvanian			Lower Pseudoschwagerina Limestone
	Gzhelian	AUERNIG GROUP	Garnizza Formation
			Auernig Formation
			Corona Formation
			Pizzul Formation
Kasimovian	Meledis Formation		

Figure 2. Stratigraphic position of Auernig Group. Interval studied (shown by bold line) is Kasimovian-Gzhelian in age.

carbonates in the tropical realm (Lees and Buller, 1972). According to my investigations (Samankassou, 1997a), no ooids occur within the Auernig Group (Fig. 3). Ooids and aggregates have never been reported in previous papers, although the limestones of the Auernig Group are shallow marine (Venturini, 1990; Krainer, 1992). This circumstance is in contrast to the overlying Rattendorf Group, where ooids are frequent, particularly in the lower part of the Lower Pseudoschwagerina Limestone cyclothem and most of the Grenzland Formation and Upper Pseudoschwagerina Limestone (Samankassou, 1997a, 1997b).

Widespread early marine cementation characterizes dasycladalean algal mounds (Fig. 4A; Samankassou, 1998). In comparison, mounds overlying nodular limestones are very poorly cemented (Fig. 5). Silicification, a feature common in many high-latitude upper Paleozoic cool-water carbonates (Beauchamp, 1994), is characteristic of the nodular bedded limestone.

Biotic Components of Limestones

The dasycladalean algae *Anthracooporella* and *Epimastopora*, as well as large foraminifers, fusulinids, are common in Auernig cyclothem (Fig. 4B). *Anthracooporella* frequently built mounds (Samankassou, 1998). The Auernig mounds are usually overlain by limestones lacking dasyclads, but containing diverse brachiopods, numerous, very diverse bryozoan taxa (Kodsi, 1967), small foraminifers, ostracodes (including entomozoans), red algae, crinoids, and sponge spicules (Fig. 5). Silicification of the biota is common (Fohrer, 1997). In contrast to the Rattendorf Group, oncoids are very rare in the Auernig Group. Phylloid algae occur essentially worldwide at all paleolatitudes.

Dasyclads and large foraminifers confirm the shallow-water environment and the equa-

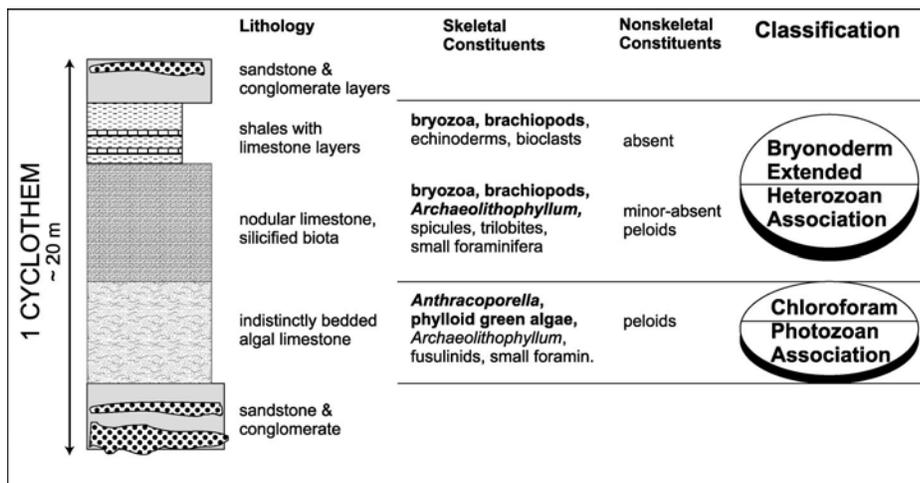


Figure 3. Example of typical Auernig cyclothem. Limestones with cool-water characteristics, including typical heterozoan association, overlie limestones exhibiting photozoan association. Nonskeletal constituents are consistent with respective classification. Vertical sequence is not to scale.

torial position. In contrast, the biotic assemblage of the commonly cross-bedded, nodular limestones that overlie the mounds are characteristic of the cool-water heterozoan association (sensu James, 1997).

Components of the Auernig limestones record contrasting signatures: (1) the lack of abiotic components is not compatible with the paleogeographic position, contrary to the younger rocks of the Rattendorf Group, and (2) the mound limestones contain a photozoan association and are overlain, without any unconformity, by limestones containing a typical heterozoan association (Fig. 3).

These patterns differ from all case studies known to date. Some Mississippian deposits, comparable by their contrasting grain compositions (e.g., Wright, 1994; Brandley and Krause, 1997), differ from those of the present study in that abiotic grains, ooids, and evaporites accompany the photozoan association.

INTERPRETATION AND DISCUSSION OF POSSIBLE CAUSES

The rapid change in biotic association within a single cyclothem is conspicuous (Fig. 3). Paleogeography, salinity, biotic turnover, ba-

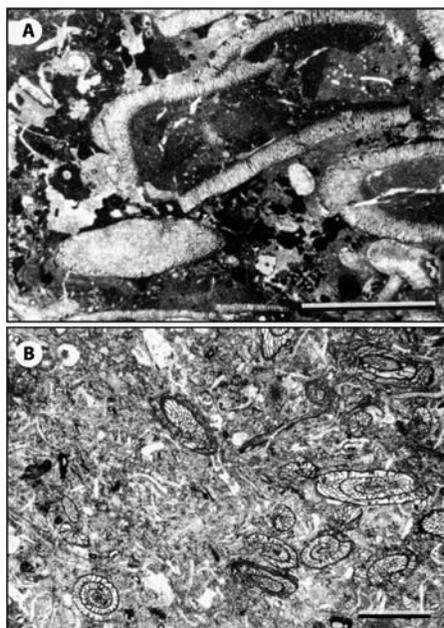


Figure 4. Interval of photozoan association. A: Dasyclad *Anthracooporella* boundstone with peloidal fillings. B: Fusulinid foraminifer packstone including algal fragments and smaller foraminifers (lower right). Scale bars represent 5 mm.

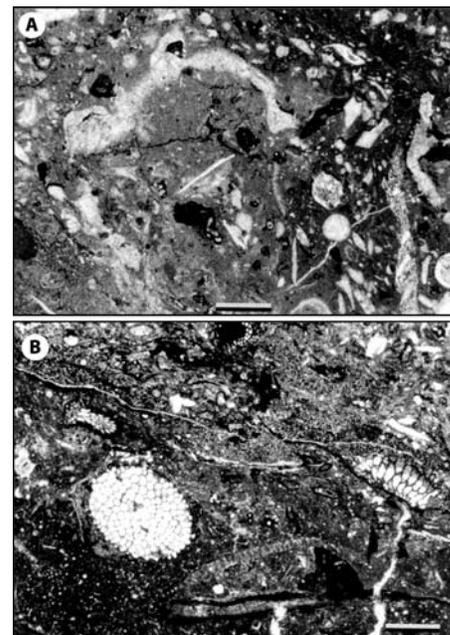


Figure 5. Interval of heterozoan association. A: Bryozoan-spicule wackestone. B: Bryozoan wackestone; problematic *Tubiphytes* (dark) is present throughout most of interval. Note compactional structures (e.g., stylolites). Scale bars represent 2 mm.

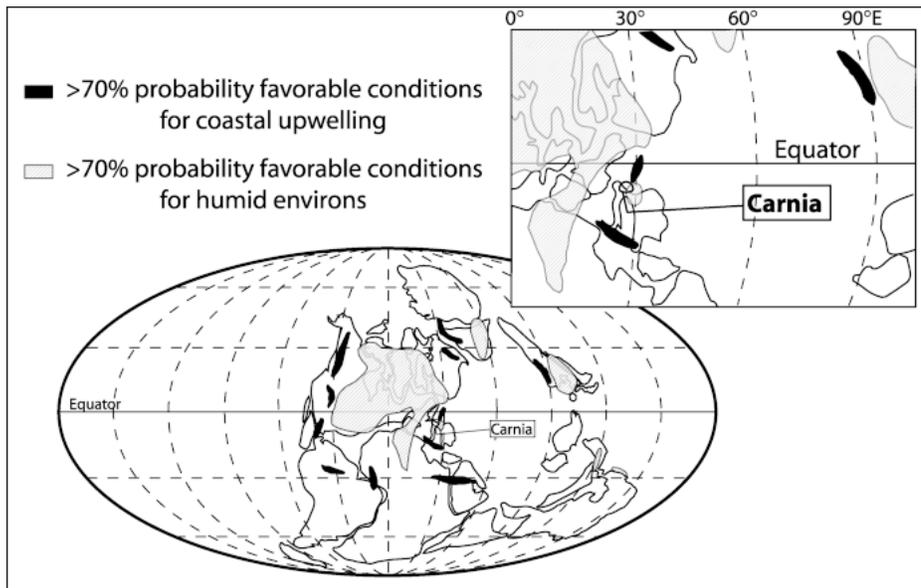


Figure 6. Carnic Alps were located close to area of high probability for upwelling and humid environs during late Carboniferous, an argument supportive of low-latitude occurrence of heterozoan association. Modified from Golonka et al. (1994).

thymetry, nutrient availability, temperature, and paleocurrents are potential causes for this change.

Paleogeography

High-paleolatitude positions could produce cool-water carbonates (e.g., Beauchamp, 1994; Stemmerik, 1997). The paleoequatorial position of the Carnic Alps is unequivocal, however. A shift during a unique cyclothem from equatorial to higher latitude is not realistic within such a short depositional interval (see subsequent discussion). This conclusion is valid for the entire Auernig Group.

Salinity

When salinity is lower than normal marine, a foramol association can persist in warm-water environments (Lees and Buller, 1972; Carannante et al., 1988). Fully marine biota occur in both parts of the Auernig cyclothem: dasycladalean-bearing limestones yield foraminifers, brachiopods, and calcareous sponges, whereas the overlying limestones yield bryozoans, brachiopods, red algae, and sponge spicules. Thus, a major change in salinity could not be the cause of the biotic difference.

Biotic Turnover

Biotic evolution within this time interval, without intrinsic causes, is not a realistic explanation. The duration of one cyclothem is assumed to be ~40 k.y. (Massari and Venturini, 1990); Krainer (1992) proposed 100 k.y. per cyclothem. Both values are significantly shorter than one fusulinid zone (1 m.y. average; Ross and Ross, 1995). A phylogenetically driven cause for the documented biotic

change within one cyclothem is therefore not consistent with the time involved.

Bathymetry

On the same shelf, photozoans could occur in shallow positions, with heterozoans dominating deeper water locations (Beauchamp, 1994; Brandley and Krause, 1997; James, 1997). There are no sedimentary indications of deep-water deposits in the Auernig Group. The red alga *Archaeolithophyllum*, common in part of the heterozoan association of the Auernig Group, is indicative of shallow water (Toomey et al., 1977; Beauchamp, 1994). Except for entomozoans, the ostracode assemblages of the nodular limestones containing heterozoans include shallow-water forms, e.g., Kirkbyidae and Bairdiidae (Fohrer, 1997). Furthermore, fusulinid and benthic smaller foraminifers are indicative of shallow-water conditions. Upper Paleozoic cyclothem of the Carnic Alps do not show any lateral variations in water depths (Samankassou, 1997a). A bathymetric-controlled change can therefore be excluded as the main cause for the biotic variations. Furthermore, the environment of deposition of the Lower Pseudoschwagerina Limestone was deeper than that for the Auernig Group: there, algal mounds fell below the lower limit of the photic zone and were drowned (Samankassou, 1999): Nevertheless, there are no indications of cool-water rocks within these sequences. This finding contradicts an interpretation of a bathymetrically driven change in biota in the Auernig Group.

Terrigenous Clastic Supply

Input of terrigenous clastic sediments could affect carbonate-producing biota (Chave,

1967). Nelson (1988) assumed that reduced terrigenous input favored formation of cool-water carbonate because of the lower rate of metabolism in cool-water environments: (1) siliciclastics influence the photosynthetic activity by arresting production; (2) they also bring nutrients. There is no major difference in the terrigenous content of the two parts of the cyclothem. Therefore, terrigenous clastic input obviously had no major influence on the variation of the biotic associations within the Auernig cyclothem.

Nutrients

Nutrient excess could lead to a heterozoan association, together with fleshy and green algae (Hallock and Schlager, 1986). The question of nutrients could not be definitively answered by the present data. It is nevertheless known that elevated nutrient supply is often linked with upwelling, low temperature, and reduced salinity (Birkeland, 1997). Therefore, if temperature changes are assumed, nutrients must be considered. The abundance of algae below the nodular limestones may be a valuable indicator of higher nutrient levels.

Temperature

Water-temperature change is the remaining possibility and the only convincing cause of the biotic changes. Glaciation and deglaciation processes of Gondwana at this time (Frakes et al., 1992) seem to have influenced the character of limestones (e.g., through temporal upwelling of cooler water) and imply a paleoceanographic-driven temperature change.

Paleoceanography

Water circulation, particularly upwelling, can affect the biotic association of carbonates through oxygen, nutrients, and temperature (Lees and Buller, 1972; James, 1996). Upwelling can thus lead to a dominance of heterozoan association in tropical latitudes (e.g., Simone and Carannante, 1988). Therefore, a change in paleoceanography is a convincing explanation for the anomalous associations observed in the Auernig carbonates. A possible model involves the following: (1) a supply of cool, nutrient-rich water, favored by upwelling, to the shallow-water shelves and (2) the establishment of a heterozoan association in an unconventional bathymetric-latitude position. This scenario seems more pronounced in a distinct part of the cyclothem (above algal mounds), probably coupled with the time-correlative intervals showing the greatest deglaciation of Gondwana.

Two independent lines of evidence support the model proposed: (1) According to Golonka et al. (1994), the paleolocation of the Carnic Alps was close to an area of predicted coastal upwelling (Fig. 6); (2) Beauchamp and Kells (1999) reported the occurrence of biotic

associations of heterozoans in interglacial intervals, supposed to be warmer, in Pennsylvanian-Permian cyclothems from the Canadian Arctic. There, the cool-water carbonates have been tentatively interpreted as evidence for a massive influx of cold meltwater into the global circulation system during the earliest phases of climatic warming, a scenario inferred for the Auernig Group example.

A scenario supportive of this study's interpretation has been described from the Ordovician, where cool-water currents related to Gondwana's glaciation are supposed to have affected the margins of Laurentia (Patzkowsky and Holland, 1993; Lavoie and Asselin, 1998; Pope and Read, 1997). However, the temporal interval between biotic changes in the Auernig cyclothems is very short compared to such intervals described from the Ordovician. Furthermore, the paleogeography is not well defined in these examples (Brookfield, 1988).

The present-day situation, in which carbonates having cool-water characteristics predominate on the eastern sides of modern ocean basins, even in low latitudes (Whalen, 1995), supports the suggested scenario.

IMPLICATIONS

Multiple factors influence the composition of carbonate rocks. The heterozoan association should therefore not automatically be used as an indicator for high-latitude settings. Future studies should consider water temperature, oceanic circulation, and availability of nutrients in addition to factors currently used, such as bathymetry, salinity, and latitude-related climate, in interpretation of carbonate components, particularly when dealing with the heterozoan association. As carbonate rocks are reexamined, this example calls for caution in interpretation of components typical of cool-water carbonates.

CONCLUSIONS

Distinct parts of limestones within the Auernig cyclothems of the Carnic Alps, Austria, are characteristic of cool-water carbonates. The Carnic Alps were equatorial during the late Carboniferous, on the basis of the fossil microfloral and macrofloral associations of dasyclad algae and plants. Plant associations and coal seams within the sequence indicate overall tropical environments with high precipitation.

The entire section lacks abiotic components typical of warm-water limestones: no ooids and no aggregates occur within the Auernig Group. Parts of the limestones show a cool-water association of bryozoans, brachiopods, crinoids, red algae (e.g., *Archaeolithophyllum*), entomozoan ostracodes, and sponge spicules. Water-temperature changes, linked with nutrient supply and coastal upwellings, are the most convincing causes for this unusual association. Paleooceanographic changes linked to contemporaneous glaciation and de-

glaciation phenomena of Gondwana are inferred. Cool-water carbonates in shallow-water environments are therefore not necessarily non-tropical, as generally interpreted.

ACKNOWLEDGMENTS

I thank the former Pangea Group in Erlangen, Germany (E. Flügel, B. Fohrer, and H. Forke), and J. Golonka, who furnished a file used in Figure 6. R.R. West and journal reviewers N.P. James, I.P. Montañez, L. Pomar, and J.F. Read made constructive suggestions for improvements to earlier drafts of the paper. The financial support of the German Research Foundation (DFG Project FI 42/72) and the Swiss National Science Foundation (Project 20-56491.99) is gratefully acknowledged.

REFERENCES CITED

- Beauchamp, B., 1994, Permian climatic cooling in the Canadian Arctic, in Klein, G.D., ed., Paleoclimate, tectonics, and sedimentation during accretion, zenith, and breakup of a supercontinent: Geological Society of America Special Paper 288, p. 229–246.
- Beauchamp, B., and Kells, M.P., 1999, Climatic significance of Carboniferous-Permian cyclothems in the Sverdrup Basin, Canadian Arctic [abs.]: XIV International Congress on the Carboniferous-Permian, August 17–21, 1999, Calgary, Canada, p. 10.
- Birkeland, C., 1997, Geographic differences in ecological processes on coral reefs, in Birkeland, C., ed., Life and death of coral reefs: London, Chapman and Hall, p. 273–287.
- Bradley, R.T., and Krause, F.F., 1997, Upwelling, thermoclines and wave-sweeping on an equatorial carbonate ramp: Lower Carboniferous strata of western Canada, in James, N.P., and Clarke, J.A.D., eds., Cool-water carbonates: SEPM (Society for Sedimentary Geology) Special Publication 56, p. 365–390.
- Brookfield, M.E., 1988, A mid-Ordovician temperate carbonate shelf—The Black River and Trenton Limestone Groups of southern Ontario, Canada: Sedimentary Geology, v. 60, p. 137–154.
- Carannante, G., Esteban, M., Milliman, J.D., and Simone, L., 1988, Carbonate lithofacies as paleolatitude indicators: Problems and limitations: Sedimentary Geology, v. 60, p. 333–346.
- Chave, K.E., 1967, Recent carbonate sediments—An unconventional view: Journal of Geological Education, v. 15, p. 200–204.
- Fohrer, B., 1997, Ostracoden aus dem Oberkarbon und Unterperm der Karnischen Alpen (Österreich): Systematik, Biostratigraphie und Palökologie: Jahrbuch des Geologischen Bundesanstalt (Vienna), v. 140, p. 99–191.
- Frakes, L.A., Francis, J.E., and Syktus, J.I., 1992, Climate modes of the Phanerozoic. The history of the Earth's climate over the past 600 million years: Cambridge, Cambridge University Press, 274 p.
- Fritz, A., and Boersma, M., 1990, Die steinkohlenzeitliche Pflanzenwelt Kärntens in ihrer fossilen Überlieferung, in Fritz, A., et al., eds., Steinkohlenzeitliche Pflanzenfossilien aus Kärnten, Volume Carinthia II (180–100): Klagenfurt, Austria, Verlag des Naturwissenschaftlichen Vereins für Kärnten, p. 11–13.
- Golonka, J., Ross, M.I., and Scotese, C.R., 1994, Phanerozoic paleogeographic and paleoclimatic modeling maps, in Embry, A.F., et al., eds., Pangea: Global environments and resources: Canadian Society of Petroleum Geologists Memoir 17, p. 1–47.
- Hallock, P., and Schlager, W., 1986, Nutrient excess and the demise of coral reefs and carbonate platforms: Palaios, v. 1, p. 389–398.
- James, N.P., 1996, Reading oceanographic change from neritic carbonates: The cool-water carbonate problem [abs.], in SEPM/IAS Research Conference: Carbonates and global change: An interdisciplinary approach: Wildhaus, Switzerland, p. 74.
- James, N.P., 1997, The cool-water carbonate depositional realm, in James, N.P., and Clarke, J.A.D., eds., Cool-water carbonates: SEPM (Society for Sedimentary Geology) Special Publication 56, p. 1–20.
- Kodsi, M.G., 1967, Die Fauna der Bank s des Auernig (Oberkarbon; Karnische Alpen, Österreich). 1. Teil: Festschrift Lonsdale 1839: Carinthia II, p. 59–81.
- Krainer, K., 1992, Fazies, Sedimentationsprozesse und Paläogeographie im Karbon der Ost- und Südalpen: Jahrbuch der Geologischen Bundesanstalt (Vienna), v. 135, p. 99–193.
- Lavoie, D., and Asselin, E., 1998, Upper Ordovician facies in the Lac Saint-Jean outlier, Québec (eastern Canada): Palaeoenvironmental significance for Late Ordovician oceanography: Sedimentology, v. 45, p. 817–832.
- Lees, A., 1975, Possible influence of salinity and temperature on modern shelf carbonate sedimentation: Marine Geology, v. 19, p. 159–198.
- Lees, A., and Buller, A.T., 1972, Modern temperate-water and warm-water shelf carbonate sediments contrasted: Marine Geology, v. 13, p. M67–M73.
- LePain, D.L., Crowder, R.K., and Wallace, W.K., 1994, Early Carboniferous transgression on a passive continental margin: Deposition of the Kekikuk Conglomerate, northeastern Brooks Range, Alaska: American Association of Petroleum Geologists Bulletin, v. 78, p. 679–699.
- Massari, F., and Venturini, C., 1990, The significance of the Auernig Group cyclicity, in Venturini, C., ed., Field workshop on Carboniferous to Permian sequence of the Pramollo-Nassfeld Basin (Carnic Alps): Bologna, Italy, p. 81–89.
- Nelson, C.S., 1988, An introductory perspective on non-tropical shelf carbonates: Sedimentary Geology, v. 60, p. 3–12.
- Patzkowsky, M.E., and Holland, S.M., 1993, Biotic response to a Middle Ordovician paleoceanographic event in eastern North America: Geology, v. 21, p. 619–622.
- Pope, M.C., and Read, F.J., 1997, High-resolution stratigraphy of the Lexington Limestone (late Middle Ordovician), Kentucky, U.S.A.: A cool-water carbonate-clastic ramp in a tectonically active foreland basin, in James, N.P., and Clarke, J.A.D., eds., Cool-water carbonates: SEPM (Society for Sedimentary Geology) Special Publication 56, p. 411–429.
- Ross, C.A., and Ross, J.R.P., 1995, Foraminiferal zonation of late Paleozoic depositional sequences: Marine Micropaleontology, v. 26, p. 469–478.
- Samankassou, E., 1997a, Muster und Kontrollfaktoren der zyklischen Sedimentation im Jungpaläozoikum (Oberkarbon-Unterperm) der Karnischen Alpen, Österreich: Eine integrierte Untersuchung [Ph.D. thesis]: Erlangen, Germany, University of Erlangen-Nürnberg, 397 p.
- Samankassou, E., 1997b, Palaeontological response to sea-level change: Distribution of fauna and flora in cyclothems from the Lower Pseudoschwagerina Limestone (Latest Carboniferous, Carnic Alps, Austria): Geobios, v. 30, p. 785–796.
- Samankassou, E., 1998, Skeletal framework mounds of dasycladalean alga *Anthracooprella*, upper Paleozoic, Carnic Alps, Austria: Palaios, v. 13, p. 297–300.
- Samankassou, E., 1999, Drowning of algal mounds: Records from the Upper Carboniferous Lower Pseudoschwagerina Limestone, Carnic Alps, Austria: Sedimentary Geology, v. 127, p. 209–220.
- Schönlaub, H.P., 1992, Stratigraphy, biogeography and paleoclimatology of the Alpine Paleozoic and its implications for plate movements: Vienna, Jahrbuch der Geologischen Bundesanstalt, v. 135, p. 381–418.
- Simone, L., and Carannante, G., 1988, The fate of foramol ("temperate-type") carbonate platforms: Sedimentary Geology, v. 60, p. 347–354.
- Stemmerik, L., 1997, Permian (Artinskian-Kazanian) cool-water carbonates in North Greenland, Svalbard and the western Barents Sea, in James, N.P., and Clarke, J.A.D., eds., Cool-water carbonates: SEPM (Society for Sedimentary Geology) Special Publication 56, p. 349–364.
- Toomey, D.F., Wilson, J.L., and Rezak, R., 1977, Evolution of Yucca Mound complex, Late Pennsylvanian phylloid algal buildup, Sacramento Mountains, New Mexico: American Association of Petroleum Geologists Bulletin, v. 61, p. 2115–2133.
- Venturini, C., editor, 1990, Field workshop on Carboniferous to Permian sequence of the Pramollo-Nassfeld Basin (Carnic Alps) Guidebook: Bologna, Italy, 159 p.
- Whalen, M.T., 1995, Barred basins: A model for eastern-ocean-basin carbonate platforms: Geology, v. 23, p. 625–628.
- Wright, P.V., 1994, Early Carboniferous carbonate systems: An alternative to the Cainozoic paradigm: Sedimentary Geology, v. 93, p. 1–5.

Manuscript received February 6, 2002
 Revised manuscript received March 29, 2002
 Manuscript accepted April 2, 2002

Printed in USA