The myth of the brackish Sarmatian Sea

Werner E. Piller[1] and Mathias Harzhauser[2]

[1]Institut für Erdwissenschaften, Bereich Geologie und Paläontologie, Universität Graz, Heinrichstrasse 26, A-8010 Graz, Austria; [2]Geologisch-Paläontologische Abteilung, Naturhistorisches Museum Wien, Burgring 7, A-1014 Wien, Austria

ABSTRACT

The biota of the 1.5 Ma period of the Middle Miocene Sarmatian of the Central Paratethys lack stenohaline components. This was the reason to interpret the Sarmatian stage as transitional between the marine Badenian and the lacustrine Pannonian stages. However, our new data indicate that brackish water conditions could not have prevailed. Sarmatian foraminifera, molluscs, serpulids, bryozoans, dasycladacean and corallinacean algae as well as diatoms clearly indicate normal marine conditions for the entire Sarmatian. During the Lower Sarmatian, however, a sea-level lowstand forced the development of many marginal marine environments. During the Late Sarmatian a highly productive carbonate factory of oolite shoals, mass-occurrences of thick-shelled molluscs and larger foraminifera, as well as marine cements clearly point to normal marine to hypersaline conditions. This trend is not restricted to the western margin of the Pannonian Basin System but can be observed in the entire Central and even Eastern Paratethys.

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Introduction

The ascent of the Alpine chain led to a partition of the Tethyan Ocean around the Eocene/Oligocene boundary. By this geodynamic process the Tethys disappeared as a palaeogeographical and palaeobiogeographical entity and two different palaeogeographical areas evolved – the (Neogene) Mediterranean and the Paratethys seas. This geographical separation also resulted in a biogeographical differentiation and even necessitated the establishment of different chronostratigraphic/geochronologic scales (Figs 1 and 2). Within the Paratethys a distinction between Western, Central and Eastern Paratethys was carried out, reflecting an internal differentiation. Related to this is a complex pattern of changing seaways and landbridges between the Paratethys and the Mediterranean as well as the western Indo-Pacific (e.g. Rögl, 1998, 1999). This also created a complex pattern of biogeographical relationships between these palaeobiogeographical units (Harzhauser et al., 2002).

Within the chronostratigraphic frame of the Paratethys the Sarmatian stage is of particular interest due to its specific development. The Sarmatian was established by Suess (1866) for the Central Paratethys and covers a time span of 1.4 Ma between 11.6 and ~13 Ma before present. Unfortunately and misleadingly, for the Eastern Paratethys a different definition for the Sarmatian is used, including a much longer time span. Herein we deal with the original definition of the Sarmatian (sensu Suess, 1866) and correlate this stage with the Volhynian and Lower Bessarabian stages of the Eastern Paratethys, being equivalent with the Upper Serravallian of the Mediterranean scale (Fig. 1).

In the Central Paratethys the Sarmatian is generally interpreted as transitional from the marine Badenian Sea towards the temperate-freshwater environments of Lake Pannon (Papp, 1954, 1956). This interpretation was mainly based on the absence of steno-haline biota such as radiolaria, planktic foraminifera, corals and echinoderms (comp. Steininger and Wessely, 2000), which disappeared at the Badenian/

Correspondence: Werner E. Piller, Institut für Erdwissenschaften, Bereich Geologie und Paläontologie, Universität Graz, Heinrichstrasse 26, A-8010 Graz, Austria. Tel.: +43 316 380 5582; fax: +43 316 380 9871; e-mail: werner.piller@uni-graz.at
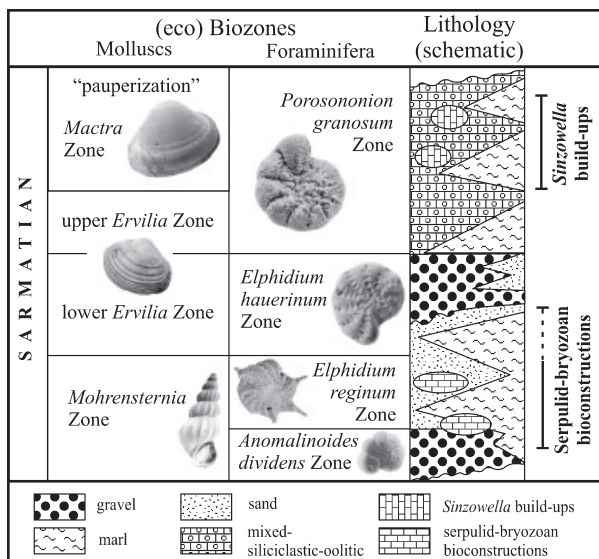
Time (Ma)	Epochs	MEDITERRANEAN AGES	CENTRAL PARATETHYS AGES	EASTERN PARATETHYS AGES
5.3				
	Late Miocene	MESSINIAN	PONTIAN	PONTIAN
		TORTONIAN	PANNONIAN	MAEOTIAN
10				
				KHERSONIAN
11.6				BESSARABIAN
	Middle Miocene	SERRAVALLIAN	SARMATIAN	VOLHYNIAN
13.59				KONKIAN
		LANGHIAN	BADENIAN	KARAGANIAN
15				TSHOKRAKIAN
16.4				TARKHANIAN

Fig. 1 Middle–Late Miocene stratigraphic correlation between the Mediterranean and Paratethys areas.

Fig. 2 Biostratigraphy of the Sarmatian of the Central Parathethys and lithologic characteristics along its western margin.
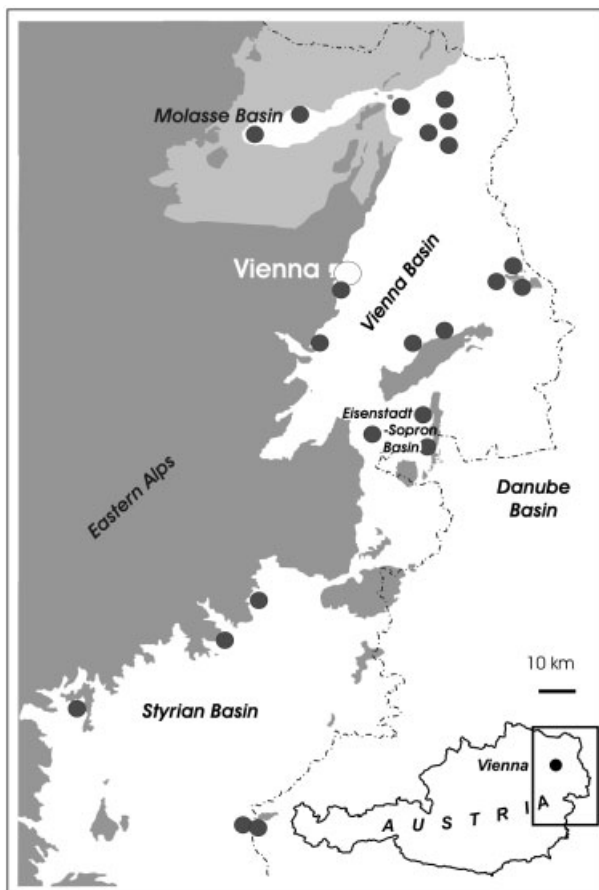

Fig. 3 Western margin of the Sarmatian Sea (white areas approximate former Sarmatian water cover, grey areas are land) and distribution of studied localities in Eastern Austria.

Sarmatian boundary. Based on the occurrence of specific mollusc faunas, Papp (1956) reconstructed a decrease in salinity from around 30‰ at the Badenian/Sarmatian boundary to 16‰ at the Sarmatian/Pannonian boundary. Relying on foraminifera, Brestenska (1974) suggested a salinity between 25 and 18‰ for the Early Sarmatian and 18 and 16‰ for the Late Sarmatian. More recently, Friebe (1994), referring to a variety of organism groups, stated 'A reduced salinity, even for the central basin, has to be taken for granted'. In contrast, Pisera (1996), dealing with 'reefs', suggested a water chemistry 'highly supersaturated in respect to calcium carbonate and probably also with high alkalinity' and proposed locally even hypersaline conditions (Pisera, 1996, p. 103). This interpretation, however, was widely ignored and to date the brackish character of the Sarmatian is still taken as common scientific knowledge (e.g. Rögl and Steininger, 1984; Rögl, 1996; Kovac et al., 1999).

In this paper we provide new palaeontological and microfacial data for the environmental reconstruction of the Sarmatian of the Central Parathethys, which complement recently produced geochemical results (Latal et al., 2004) and clearly demonstrate that the conventional brackish water interpretation has to be rejected.

Study area, stratigraphy and data set

The study area focuses on the Austrian parts of the Pannonian Basin System, the Vienna and Styrian basins and subbasins, as well as on parts of the Molasse zone (Fig. 3). In the course of this study nearly all currently available outcrops in Eastern Austria were (re)visited and sections were logged in detail. Molluscs, foraminifera, serpulids, bryozoans and calcareous algae were reinvestigated taxonomically and palaeoecologically and carbonates were studied microfacially and geochemically.

The biostratigraphy of the Sarmatian represents an ecostratigraphy based on benthic foraminifera and on molluscs. Both groups, generally, allow a threefold subdivision (foraminifera: *Elphidium reginum*, *E. hauerinum*, *Porosononion granosum*-zones; molluscs: *Mohrensternia*-, *Ervilia*-, *Mactra*-zones) (Fig. 2) which

do not fully correlate. The existence of a basal foraminiferal zone – *Anomalinoides dividens*-zone – is widely ignored. This zone is represented in basinal settings only due to the sealevel lowstand at the Badenian/Sarmatian boundary (Harzhauser and Piller, 2004).

Results

Biota

The Lower Sarmatian *Mohrensternia*-zone is generally dominated by fine-siliciclastic sedimentation. Carbonate rocks are represented by reworked Badenian limestones and only rarely by autochthonous build-ups dominated by serpulids and (in the uppermost parts) bryozoans (Fig. 2). Associated with the serpulid mass-occurrences are acetabulariid green algae (also typical in the Eastern Paratethys, e.g. Génot *et al.*, 2002). The fine-siliciclastic sediments were mainly deposited on tidal flats or in estuaries and are rich in low-diversity molluscan faunas. Sections in the Molasse Basin (Hollabrunn/Lower Austria) (Fig. 3), for example, represent a small and shallow embayment presumably dominated by tidal conditions settled by large populations of solenid bivalves. The narrow lough was probably strongly influenced by the waters of the surrounding drainage systems, leading to polyhaline conditions. The occurrence of turritellids and naticids [*Turritella eryna sarmatica* Papp, *Euspira helicina sarmatica* (Papp)], however, exclude a drop in salinity far from polyhaline. A similar situation may be reconstructed for the fauna of Waldhof/Graz (Styrian Basin). Here the water of the Stallhofen Bay was affected by the drainage systems from the Alps, whereas to the east the small-sized depression was protected from the open Sarmatian Sea by the Sausal Swell, allowing the establishment of very low energy water conditions. The gastropod genus *Mohrensternia* (Fig. 4) flourished in these hyposaline coastal environments (Kowalke and Harzhauser, 2004). In contrast, in sections reflecting open water conditions, diatomites with marine diatoms occur (e.g. section Petronell: Harzhauser and Piller, 2004; Walbersdorf: Rögl and Müller, 1976).
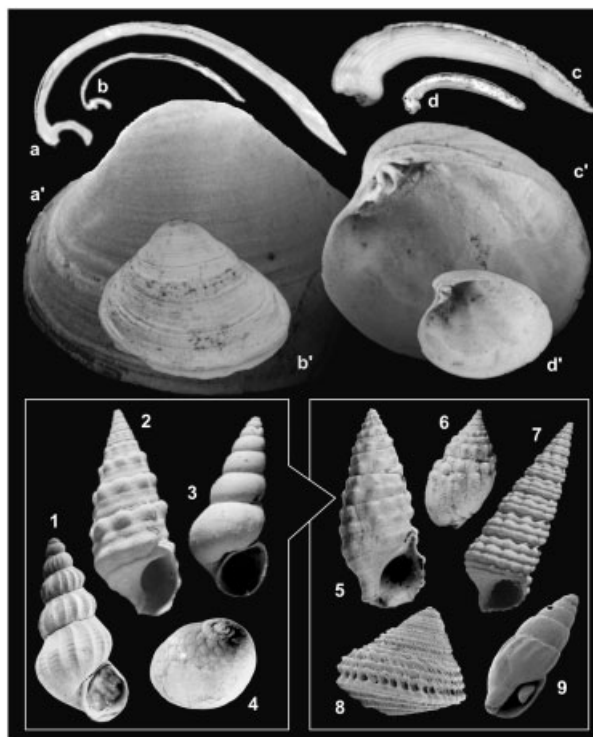

Fig. 4 (A) The drastic increase in shell thickness and size of the bivalve genera *Sarmatimactra* (a, b) and *Venerupis* (c, d) from the Early to the Late Sarmatian seems to be linked to high carbonate saturation coinciding with a stabilization of the water chemistry. (B) Euryhaline gastropod taxa of the Early Sarmatian communities are replaced by assemblages adapted to marine and hypersaline conditions. A higher complexity of the trophic nets, typical for stable and derived communities, is expressed by the boom of the carnivorous guild; e.g. *Duplicata* (6) and *Mitrella* (9). The potamidid *Potamides disjunctus* (7) is closely related to the Recent *Potamides conicus*, which is a common species in modern saline lakes (Plaziat, 1993). [a–a′: *Sarmatimactra vitaliana* (d'Orbigny), b–b′: *S. eichwaldi* (Laskarev), c–c′: *Venerupis gregarius ponderosus* (d'Orbigny), d–d′: *V. gregarius gregarius* (Goldfuss), 1: *Mohrensternia banatica* Jekelius, 2: *Granulolabium bicinctum* (Brocchi), 3: *Hydrobia frauenfeldi* (Hoernes), 4: *Agapilia picta* (Ferussac), 5: *Cerithium rubiginosum* Eichwald, 6: *Duplicata duplicata* (Sowerby), 7: *Potamides disjunctus* (Sowerby), 8: *Gibbula buchi* (Dubois), 9: *Mitrella agenta* Harzhauser & Kowalke].

During the *Ervilia*-zone, sedimentation switched from siliciclastic to carbonate dominated (Fig. 2). Together with this change a drastic increase in shell thickness of bivalves occurred (e.g. *Venerupis, Sarmatimactra*; Fig. 4). Most Upper Sarmatian 'gastropod-sediments' were formed by marine to hypersaline cerithiids (*Cerithium rubiginosum* Eichwald). In addition, marine molluscan taxa appeared (*Gibbula buchi, Jujubinus turricula, Mitrella agenta*) (Fig. 4), unknown from any earlier Sarmatian deposits.

Correspondingly, foraminiferan – coralline algal – microbial build-ups experience their optimum during the

Mactra-zone (Fig. 2), forming bioconstructions of up to 20 m width in the Eisenstadt-Sopron Basin as well as in the NW Styrian Basin. Foraminifera are exclusively represented by sessile nubeculariids (*Sinzowella*). There is also a distinct shift in polychaete predominance from Early Sarmatian *Hydroides pectinata* prevalence in *Mohrensternia* and *Ervilia*-zones towards *Janua heliciformis* dominance in the Late Sarmatian *Mactra*-zone.

In several outcrops of the Vienna and Styrian Basins (e.g. Waltra, Löffelbach), mass occurrences of the larger foraminiferal species *Spirolina austriaca* d'Orbigny are well documented (Fig. 5A). Besides these larger
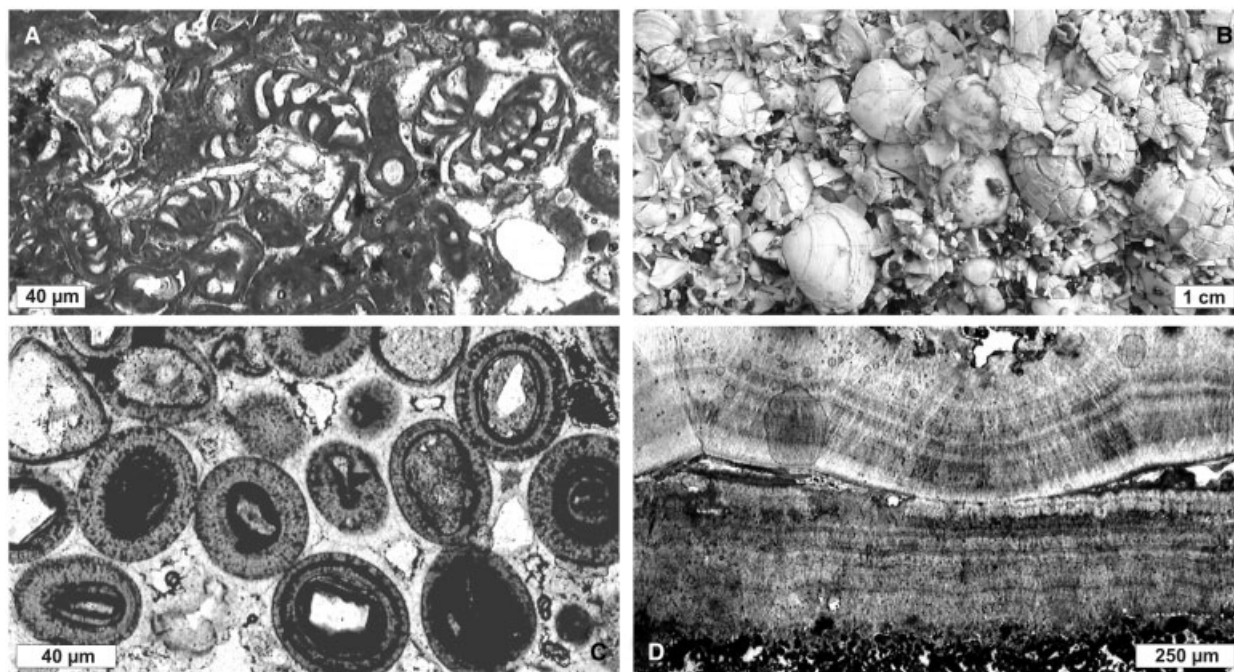
Fig. 5 Typical elements of Upper Sarmatian sediments. (A) Mass-occurrences of the peneroplid foraminifer *Spirolina austriaca* (locality Waltra/Styria, thin-section, SA 11/01). (B) Mass-occurrences of thick-shelled molluscs (locality Nexing/Lower Austria). (C) Oolite grainstones with multilayered radial ooids (locality Wolfsthal/Lower Austria, thin-section WA-B5/01). (D) Radial-fibrous (botryoidal) cement (locality St Margarethen/Burgenland, thin-section Hu 20/01).

foraminifera, masses of thick-shelled miliolids also occur in most sections.

Carbonate sediments

As mentioned above, in lower Sarmatian sections carbonates are rare in the studied areas, except for bryozoan–serpulid–algal–microbial bioconstructions and serpulid (*Hydroides*) mass occurrences, which co-occur with dasycladacean algae. In the upper *Ervilia* zone, however, massive carbonate sedimentation starts (Fig. 2) culminating in more than 20 m thick oolites and in nubeculariid–coralline algal–microbial bioconstructions. The ooid grains are multilayered and of radial type (Fig. 5C) and occur in thick cross-bedded sequences with intercalated microbial carbonates. Laterally, these oolites are represented by cross-bedded mass occurrences of molluscan shells (e.g. Nexing; Fig. 5B) in which reworked oolite-limestone clasts occur. In most of the carbonates the allochems, particularly the molluscan shells, show micritic envelopes. The oolites and shell beds are cemented by an isopachous, fibrous (probably former aragonite or Mg-calcite) cement.

In some outcrops, particularly in St Margarethen-railway cut, thick crusts of radial-fibrous (botryoidal) cement occur (Fig. 5D).

Discussion

For the Lower Sarmatian in Austria, mostly marginal marine outcrops are available. This is due to a sea-level lowstand at the turn of the Badenian/Sarmatian (Harzhauser and Piller, 2004). In terms of sequence stratigraphy this corresponds with the base of TB 2.6 of Haq *et al.* (1988) and with Ser-3 sequence boundary of Hardenbol *et al.* (1998). Therefore, the occurrence of gastropods pointing to reduced salinity is no surprise. Considering the entire molluscan fauna, however, clearly reveals a full range of normal marine gastropods (turritellids, naticids) (Fig. 4). In more basin-central sections the reduced marine character disappears for the Lower Sarmatian and full marine conditions are indicated by marine diatomites as well as by serpulid mass-occurrences dominated by the genus *Hydroides*. Extant species of this genus are highly sensitive to changes in salinity and

carbonate alkalinity. They have their optimum at 30‰, ranging between 20 and 35‰, although abundance decreases with changes in both directions. Also an increase of K^+ and KCl reduces their abundance (Pechenik and Qian, 1998; Qiu and Qian, 1998).

The carbonate sequences of the *Ervilia* and *Mactra* zones reflect shallow-water, high-energy conditions of a highly productive carbonate factory of subtropical climate. The formation of thick oolite sequences as well as the mass occurrences of thick-shelled shell beds require at least normal saline, subtropical conditions. The same environmental conditions are clearly necessary for the peneroplid, larger foraminifer *Spirolina austriaca* and other porcelaneous foraminifers. Also the isopachous, fibrous and the botryoidal cements, originally most probably aragonite or Mg-calcite, clearly point to marine waters supersaturated with respect to calcium carbonate. The same indication comes from the mass occurrences of cerithiid gastropods, which usually thrive in normal marine to hypersaline waters (Harzhauser and Kowalke, 2002). Studies of stable carbon and oxygen isotope

compositions of gastropod shells from different environments show a wide range of oxygen values from $-5.1‰$ for freshwater taxa (e.g. *Lymnaea*), to mean values of $-2.1‰$ (*Potamides disjunctus*) and $-2.6‰$ (*Granulolabium bicinctum*) for taxa living mainly under normal marine conditions, to values up to $1.7‰$ for the salinity tolerant taxon *Potamides hartbergensis*, which nevertheless has carbon values showing a marine environment (Latal *et al.*, 2004). To translate these oxygen isotope values into salinity values the Sarmatian Central Paratethys can best be compared with the modern Mediterranean Sea due to its general climatic and hydrographic setting. Application of the data and equation provided by Pierre (1999) produces for *Potamides hartbergensis* a salinity range of about $11‰$ between normal marine to hypersaline individuals. Additionally, the disappearance of the serpulid *Hydroides* in the Upper Sarmatian beds may suggest a rise in salinity and titration alkalinity. The complete lack of stenohaline biota in the Sarmatian may have been induced by the changing seawater composition at the end of the Badenian. This change was either a reduction in salinity (Rögl, 1998) or caused by hypoxic events (Schmid *et al.*, 2001), which may be reinforced by the sea-level drop at the Badenian/Sarmatian boundary. This drop – together with tectonic activities – probably interrupted seaways into the Mediterranean/Indo-Pacific (Rögl, 1996) and prohibited re-immigration of these biotas. Several representatives of stenohaline organisms, however, are present even in the Lower Sarmatian (e.g. calcareous nannoplankton: Stradner and Fuchs, 1979; Chira, 1999). The fully marine to hypersaline conditions in the Late Sarmatian seem to be related with an opening of a seaway (into the Mediterranean Sea), which is clearly indicated by the sudden appearance of certain molluscs (*Gibbula buchi, Jujubinus turricula, Mitrella agenta*). Other stenohaline biota, such as corals and echinoids, were obviously unable to re-enter the Paratethys.

Conclusions

The observed biota (foraminifera, diatoms, gastropods, bivalves, serpulids, bryozoans, dasycladacean and coral-linacean algae) clearly point to marine waters for the entire Sarmatian along the western margin of the Pannonian Basin System.

For the Lower Sarmatian in the studied area this marine environment is represented by predominantly marginal marine settings, mainly tidal flats. Careful study of these associations as well as more basinal sections clearly document their normal-marine character.

For the Upper Sarmatian the formation of pure oolithic carbonate sediments, the thick-shelled molluscan fauna, the occurrence of larger foraminifera as well as various kinds of marine cements and stable oxygen isotope values for gastropod shells favour not only normal marine but also hypersaline conditions.

These data clearly underline that it is necessary to reject the more than 100-year-old interpretation of the Sarmatian Sea as a brackish basin passing gradually into a terrestrial superlake. Hence, the Sarmatian is subdivided at least into a short Early Sarmatian part with normal marine, in marginal areas probably mixohaline, conditions and a longer Late Sarmatian part of normal marine to occasional hypersaline conditions.

The above-depicted scenario for the Sarmatian is not restricted to the western margin of the Pannonian Basin System because similar features are known from Poland, Slovakia, the Ukraine and Rumania as well as from the far Eastern Paratethys, clearly suggesting that our data reflect a regional and not local trend during this time period (Belokrys, 1967; Iljina *et al.*, 1976; Pisera, 1996).

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