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Origin and Depositional Environments of the Evaporite and Carbonate Complex (Upper Permian) from the Central Part of the Dinarides (Southern Croatia and Western Bosnia)

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Key words: Evaporites, Gypsum, Anhydrite, Early-diagenetic dolomites, Terrestrial breccias, Coastal Sabkha and Playa environments, Upper Permian, Dalmatia, Lika, Bosnia, Dinarides

Ključne riječi: Evaporiti, gips, anhidrit, ranodijagenetski dolomiti, terestičke breče, okoliši obalne sabkhe i plaje, gornji perm, Dalmacija, Lika, Bosna, Dinaridi

The Upper Permian sediments from central part of the Dinarides contain three main facies: 1.- carbonates; 2.- evaporites with early-diagenetical dolomites and 3.- clastic rocks (siltstones and sandstones) and one special rock type - carbonate cavity breccias. The carbonate facies include lagoonal and intertidal limestone, evaporite facies contain gypsum (originated by hydration of anhydrites), early-diagenetical dolomites and anhydrites deposited in coastal sabkha environment. The clastic rocks were deposited either fore-shore or playa to salt-lake playa environments. The carbonate cavity breccias are interpretated as a terrestrial features, i.e. secondary surface products of physical and chemical weathering of tectonically disrupted carbonate-evaporite sediments. The Upper Permian evaporites and carbonates of the central Dinarides are sediments deposited in evaporitic conditions arround the edges of an epeiric marine basin which existed in conditions of a general regressive tendency and permanent coastal seawards progradation. The Upper Permian evaporites of central Dinarides are comparable with evaporites from the Bellerophon Formation from the Southern Alps, Italy.

Gornjopermski sedimenti središnjeg dijela Dinarida sadrže tri glavna facijesa: 1.- karbonate; 2.- evaporite s ranodijagenetskim dolomitima i 3.-klastične stijene (siltit i pješčenjak) te jedan poseban tip stijena - šupljikave karbonatne breče. Karbonatni facijes uključuje lagunarne i plimske vapnence, a evaporitni facijes se sastoji od gipsa (nastalog hidratacijom anhidrita), ranodijagenetskih dolomita i anhidrita taloženih u okolišima obalnih sabkhi

Klastične stijene su taložene ili u okolišima prednjeg žala i/ili u okolišima plaja do slanih jezera. Šupljikave karbonatne breče su interpretirane kao terestičke tvorevine, tj. kao sekundarni površinski produkti fizičkog i kemijskog trošenja tektonski razdrobljenih karbonatno-evaporitnih sedimenata. Gornjopermski evaporiti i karbonati središnjeg dijela Dinarida su sedimenti taloženi u evaporizacijskim uvjetima duž rubnog dijela epikontinentalnog morskog bazena koji je postojao u uvjetima opće regresivne tendencije i stalne progradacije obale u smjeru mora. Po svojim sedimentacijskim značajkama ti se evaporiti mogu usporediti s evaporitima "Belerofon formacije" u gornjem permu Južnih Alpa, Italije.

1. INTRODUCTION

The"Permo-Triasic"evaporites and accompanying sediments from the central part of the Dinarides (central and northern Dalmatia, and the neighbouring region between Lika and SW Bosnia - Fig. 1) have been a subject of extensive geological investigations. The purpose of the investigations was to determine the age of evaporites and accompanying sediments, superposition and tectonic relationships with the surrounding rocks, mineralogy, petrology and chemical composition, and also to define their depositional conditions and environments.

This paper deals only with the results of petrological and sedimentological investigations of carbonates and evaporites together with the interpretation of their origin, depositional environments and conditions. It is also a natural extention of the article written by ŠUŠNJARA et al.(1992) in this vol. and as such is a part of the presentation of syntesis of the above mentioned extensive geological investigations.

2. GEOLOGICAL SETTING AND OUTLINE OF STRATIGRAPHY

The age of the evaporites and accompanying sediments from the central part of the Dinarides (central and northern Dalmatia, Lika and SW Bosnia) has been a subject of some dispute: namely these sediments have ages ascribed in range from the Permian (KATZER, 1921; 1925) to the Malmian into the Early Cretaceous (ŠUŠNJAR et al., 1965; ŠUŠNJAR, 1981). Although the prevailing view was that the "Permo-Triassic" and Lower Triassic are the likely ages but there was no real paleontological evidence to support this argument. PODUPSKY (1963, 1973) regards that the deposition of evaporites occurred in the Permian in an epicontinental environment, and that they do not belong to the marine lagoonal depositional cycle. HERAK (1973, 1983) together with the presented arguments in favour of the Permian or "Permo-Triassic" age of the evaporites from Dalmatia and Lika, reflects to the possibility of their deposition in shallow marine environments, although he does not exclude the possibility that the evaporite complex contains also units of different age associated with separated types diapiric movements.

With the support of numerous palinological evidence ŠUŠNJARA et al.(1992) have succeeded to precisely determine that the evaporite complex with accompanying sediments from central Dalmatia belongs to the lower part of the Late Permian and in the wide region of Srb in Lika to the middle stage of the Late Permian.

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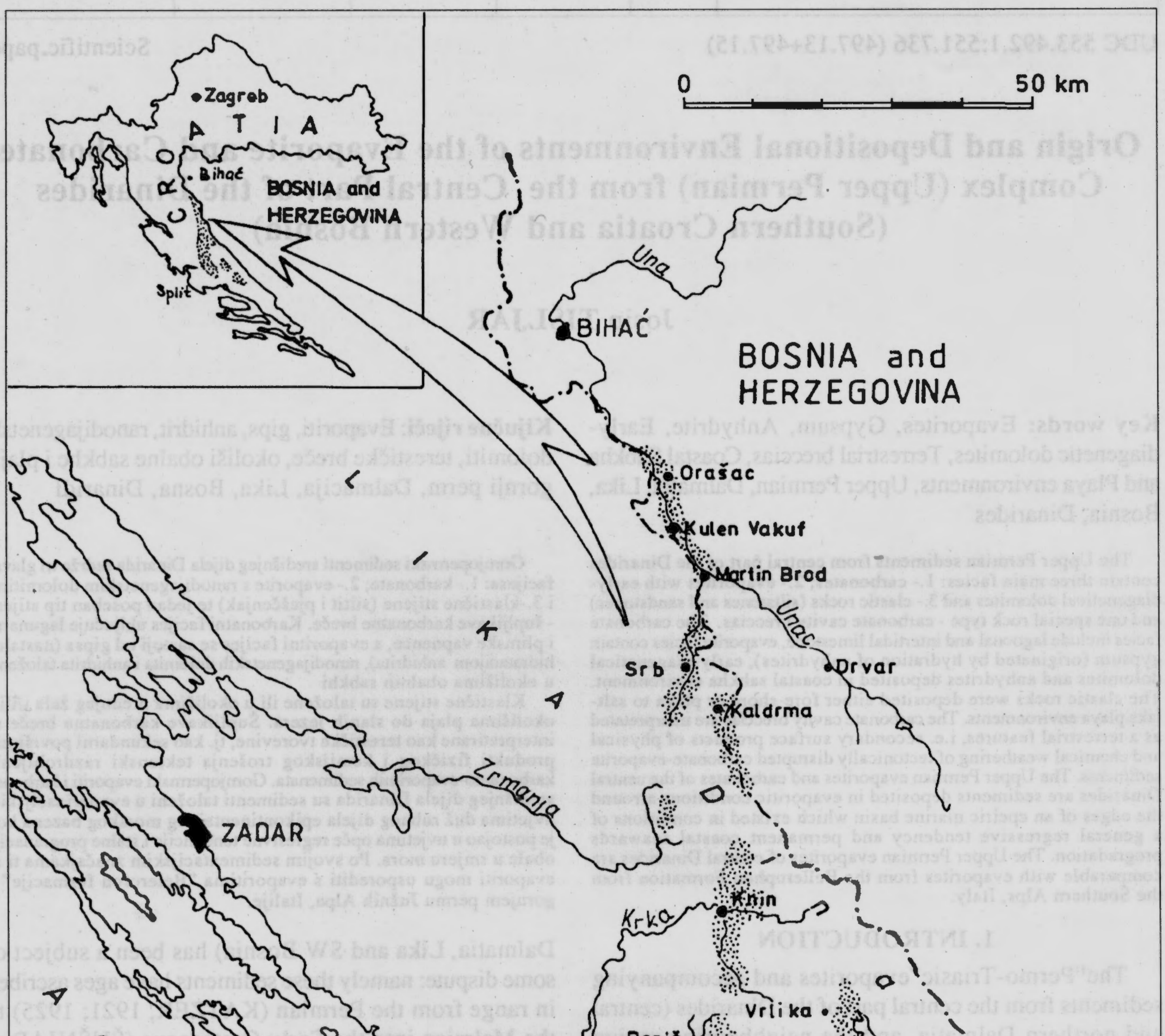


Fig. 1: Map showing the location of the studied area of the Upper Permian evaporite complex from the central part of the Dinarides.

Slika 1: Karta područja istraživanja gornjopermskog evaporitnog kompleksa središnjeg dijela Dinarida.

3. SEDIMENTOLOGICAL CHARACTERISTICS, ORIGIN AND SEDIMENTARY ENVIRONMENTS OF THE UPPER PERMIAN EVAPORITE COMPLEX

The Permian sequences in Central and Northern Dalmatia, Lika and Western Bosnia (Fig. 1) contain three main types of facies: 1.- carbonate rocks (mainly limestones), 2.- evaporites (gypsum and anhydrite) and early-diagenetic dolomites and, 3.- clastic rocks, i.e. siltstones, sandstones, and very rarely conglomerates (see Figs. 1, 2 and 3 in the atricle by ŠUŠNJARA et al., 1992, p. 96-99). Special facies type are carbonate cavity breccias or the so-called "rauhwacks" ("porous carbonate breccias" - ŠUŠNJARA et al.,(1992). The superposing succession of the three main facies types and facies of carbonate cavity breccia equally developed on all locations and is often indistinct due to soil and vegetation covering and intensive tectonic disruptance of the sequences. In general, however, ŠUŠNJARA et al. (1992) state that evaporites are the oldest facies and are succeeded by clastic and/or carbonate facies and carbonate cavity breccias. Under the general name "evaporites" here is encircled evaporite facies, i.e. gypsum with no macroscopically visible dolomite and with dolomite laminas and vuggy dolomicrites (seciton 3.2).

Outcrops with accurately determined direct synsedimentary contacts of carbonate and clastic rocks were not observed due to soil cover and tectonical disturbances; this does not necessarily mean that these contacts and relationships do not exist. The relationship between evaporites and carbonate cavity breccias is more complex. Although the breccias regularly occur immediately above evaporites, and rarely in association with carbonate rocks, their stratigraphic position is dubious since they are a weathering product of tectonically disrupted and leached rocks of the evaporite and/or carbonate facies , and they also occur during the course of different chronostratigraphic units (section 3.3).

3.1 PETROGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE CARBONATE FACIES

The Upper Permian carbonate facies consists of stratified, and in places horizontally laminated, dark-gray and black kerogenous mudstones, pellets-bearing and/or ostracods-bearing wackestones, and crystalline (microsparite) limestones rich in organic matter and pyrite. Often they are more or less intensively late-diagenetically dolomitized or recrystallized. Rarely this facies contains dolomites resulting from late-diagenetically dolomitization of wackestones and mudstones. Sporadically are found dark-gray kerogenous cryptocrystalline limestones, mudstones, and pelletoidal wackestones and packstones, rarely pelletoidal grainstones, which contain calcite pseudomorphs after anhydrite, or kerogenous ostracods-bearing mudstones/ wackestones with large, discoidal gypsum crystals (Fig. 2) or with molds of gypsum crystals which are now occupied by secondary minerals: opal, chalcedony and/or quartz. The gypsum was formed initially by displacive growth

Fig. 2: Thin-section photomicrograph of kerogeneous ostracoda wackestone with large, discoidal gypsum crystals formed initially by displacive growth in a intertidal-supratidal sabkha environment. Carbonate facies from Elezovac; width of photograph = 7,5 mm (crossed nicols).

Slika 2: Kerogenski ostrakodni vekston s krupnim, diskoidalnim kristalima gipsa nastalim rastom u mulju plimskog do natplimskog sabkha okoliša. Karbonatni facijes područja Elezovac; širina slike = 7,5 mm (ukriženi nikoli).

in carbonate mud in the lateral marginal intertidal-supratidal zone of lagoon which gradually passes into sabkha, i. e during the early phase of the regressive sabkha cycle ("gypsum mush" - SELLEY, 1988).

Limestones of the carbonate facies occurring in association with evaporites belong to sediments deposited in restricted shallow, hypersaline lagoons or in very shallow subtidal to intertidal environments of the regressive cycle. Here together with fine carbonate sediment, quite a large quantity of finegrained organic matter was accumulated. A part of the limestone from this facies was probably deposited as a contemporary lateral or younger facies together with coastal sabkha and playa deposits in a generally regressive cycle on the margin of an epeiric sea (Fig. 3). In part they could have been deposited even after the coastal and terrestrial sabkhas ceased to exist, mainly laterally, in somewhat deeper, i.e. distant areas of an epeiric sea or a marine basin with a permanent narrowing tendency - a regression cycle (Fig. 3). The lagoons and shallow bays that existed there, due to the continuous fall of seawater, and its somewhat greater depth could not have been transformed into sabkhas, during the progradation of the coast or relative sea-level fall (Fig. 3).

3. 2 DEPOSITIONAL ENVIRONMENTS AND ORIGIN OF EVAPORITE FACIES

In numerous outcrops, drill cores and gypsum guarries it has been observed that no significant quantities or macroscopically visible dolomite layers or laminae occur in the lower portions of the evaporite facies. While in the higher sequences of the evaporite facies the dolomite beds occur frequently, and also evaporite beds alternated with dolomite beds (Fig. 4), or tectonic dolomite-evaporite breccias which are not of synsedimentary origin (Fig. 5). These breccias originate by intensive tectonical crushing of the dolomite-anhydrite thin layer alternation.

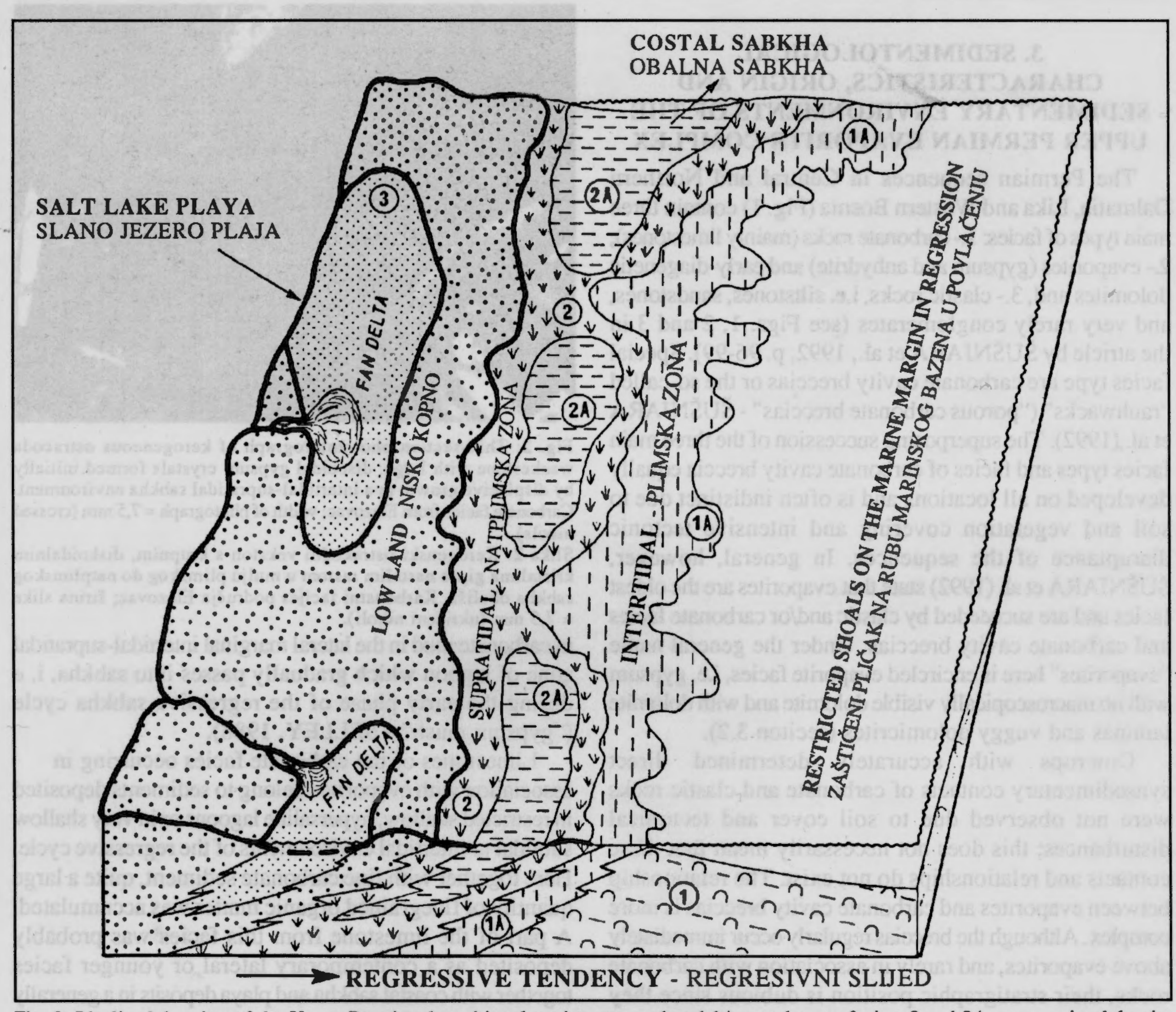


Fig. 3: Idealized drawing of the Upper Permian depositional environments: 1 and 1A = carbonate facies; 2 and 2A = evaporite-dolomite facies and 3 = clastic facies. In some places may be clastic facies in 1A and 2, too, and fan delta into the marine restricted shoals (not showing on the fig.).

Slika 3: Shematizirani prikaz okoliša taloženja gornjopermskog karbonatno-evaporitnog kompleksa: 1 i 1A = karbonatni facijes; 2 i 2A = evaporitno-dolomitni facijes i 3 = klastični facijes. Mjestimično 1A i 2 može biti i klastični facijes, a deltne lepeze su mogle biti formirane i u morskom zaštićenom plićaku (nije prikazano na slici).

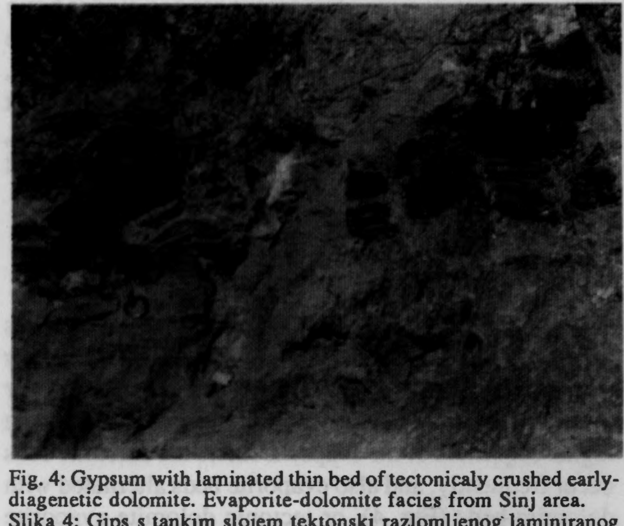


Fig. 4: Gypsum with laminated thin bed of tectonicaly crushed early-diagenetic dolomite. Evaporite-dolomite facies from Sinj area.

Slika 4: Gips s tankim slojem tektonski razlomljenog laminiranog ranodijagenetskog dolomita. Evaporitno-dolomitni facijes područja Labrovića kuća kod Sinja.

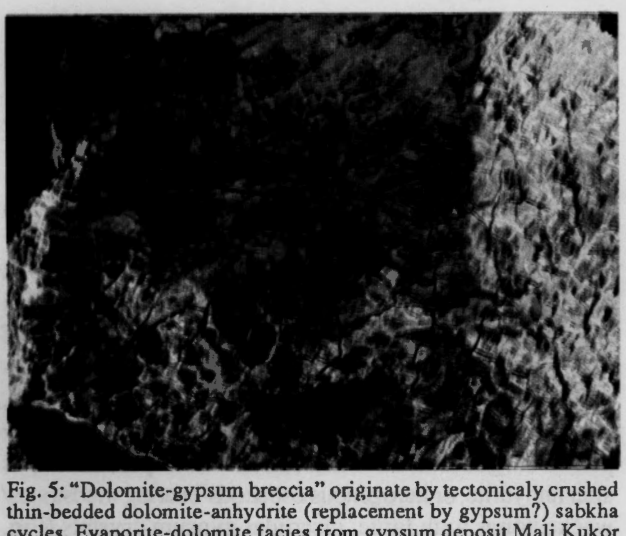


Fig. 5: "Dolomite-gypsum breccia" originate by tectonicaly crushed thin-bedded dolomite-anhydrite (replacement by gypsum?) sabkha cycles. Evaporite-dolomite facies from gypsum deposit Mali Kukor in the Kosovo polje.

Slika5: "Dolomitno-gipsna breča" nastala tektonskim drobljenjem sabkha ciklusa sastavljenih od tankoslojevitih izmjena dolomita i anhidrita (potisnutog gipsom?). Evaporitno-dolomitni facijes, gipsolom Mali Kukor u Kosovu polju.

At some sites (for example, gypsum quarry "Slane Stine", drill cores from Glavice, Sinjsko polje) the evaporites contain only dolomite fragments or relicts of dolomite-evaporite breccia which has resulted from either intensive tectonical crushing, diapirism, and/or replacement of dolomite by anhydrite. Often they contain, crumbled and broken, thin alternating laminae of dolomite and gypsum. Numerous outcrops contain dolomite carrying isolated gypsum nodules or dolomite with cavites and fissures filled with secondary gypsum which resulted from hydration of anhydrite or with anhydrite and secondary gypsum. Also gypsum occurs frequently embedding dolomite layers, laminae, or relics of laminated and stromatolitic dolomite (Figs.6,7 and 8).

The evaporites consist of either gypsum or anhydrite

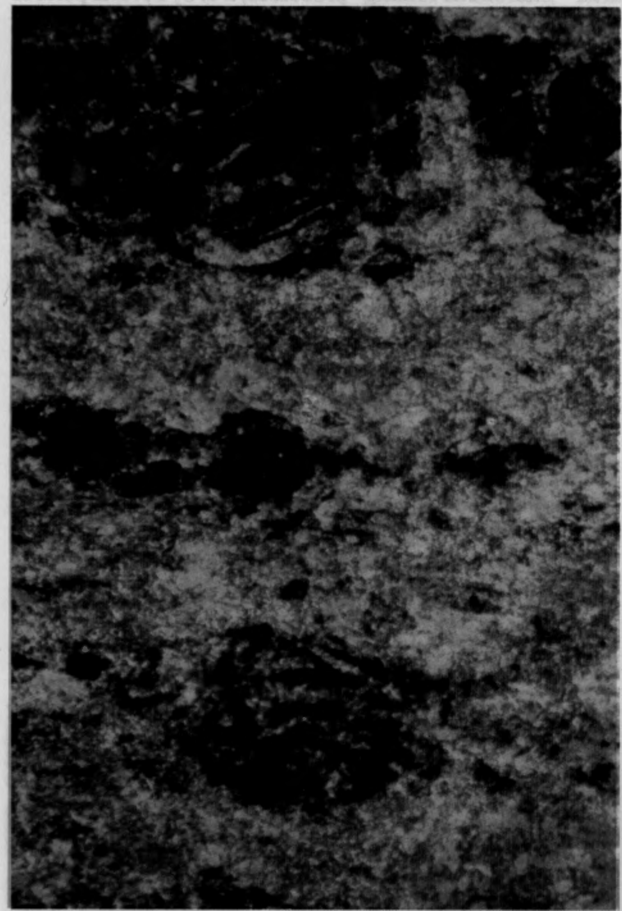


Fig. 6: Gypsum bed with relics of thin beded, organic matter-rich dolomicrite. Gypsum origin by hydration of anhydrite that has replaced a dolomite mudstone host in coastal sabkha environment. Evaporite-dolomite facies from Sinj; Thin-section (crossed nicols), height of photograph = 3,3 mm.
Slika 6: Gipsni sloj s reliktima tankoslojevitog, organskom materijom bogatog dolomikrita. Gips je nastao hidratacijom anhidrita koji je u sabkha uvjetima potiskivao dolomit. Evaporitno-dolomitni facijes Labrovića kuće kod Sinja; Visina slike = 3,3 mm (ukriženi nikoli).

or both gypsum and anhydrite (Figs. 4-10). Normally, gypsum is bedded, internally thinly layered (3-8 cm) and consists of undulatory but roughly parallel laminae of light mosaic and dark gypsum. Often it is characterized with the "enterolithic" folds.

The gypsum occurs on the surface or near the surface, while anhydrite is found in deeper sections of gypsum

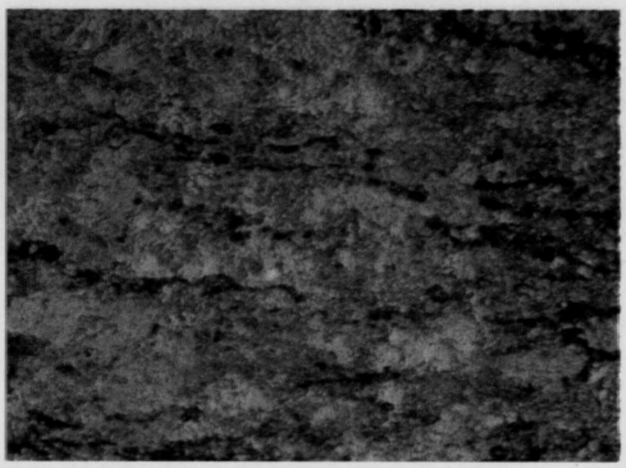


Fig. 7: Gypsum with thin laminae of dolomicrite (part of bed folded into an enterolithic structure). Gypsum is originated by hydration of sabkha anhydrite that have extensively replaced a laminated dolomite host. Evaporite facies from Kninsko polje, thin-section, width of photograph = 3,3 mm (crossed nicols).
Slika 7: Gips s tankim laminama dolomikrita (dio sloja boranog u enterolitnu strukturu). Gips potječe od hidratacije sabkha anhidrita koji je u sabkha okolišu potiskivao laminirani dolomit. Evaporitni facijes Kninskog polja, širina slike = 3,3 mm (ukriženi nikoli).

quarries and boreholes, due to the fact that the gypsum is, in general, a secondary mineral formed as a result of anhydrite hydration (Figs. 8 and 9). The hydration of anhydrite begins on the margins of anhydrite crystal cleavage planes and in tectonically disrupted and fissured zones, in shapes of fibrous gypsum veins. Advanced degrees of anhydrite hydration are characterized with gypsum crystals that poikilitically enclose anhydrite relics, or gypsum crystals produce an intersecting mass of oriented crystals which enclose and centripetally replace anhydrite (Figs.8 and 9).

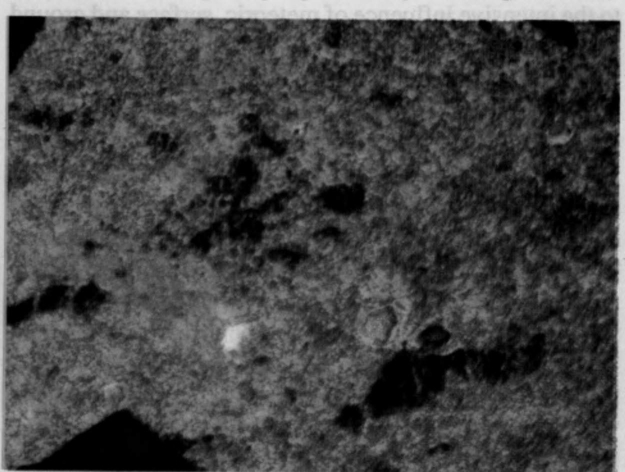


Fig. 8: Gypsum bed of the evaporite facies: thin-section showing more relics of dolomicrite (dark) and anhydrite (blue-purpur grain) within the gypsum mass originated by anhydrite hydration. Bistrica area, width of photograph = 3,3 mm (crossed nicols).
Slika 8: Sloj gipsa iz evaporitnog facijesa: mikroskopski izbrusak pokazuje više relikata dolomikrita (tamno) i anhidrita (plavoljubičasto) unutar gipsne mase nastale hidratacijom anhidrita. Područje Bistrice, širina slike = 3,3 mm (ukriženi nikoli).

Complete hydration of anhydrite is manifested by homogeneous, fibrous gypsum crystals that sporadically contain isolated coroded anhydrite relics and very thin dark-grey, here and there yellow-brown laminae or bands of organic matter, pyrite or gypsum pigmented with Fe-

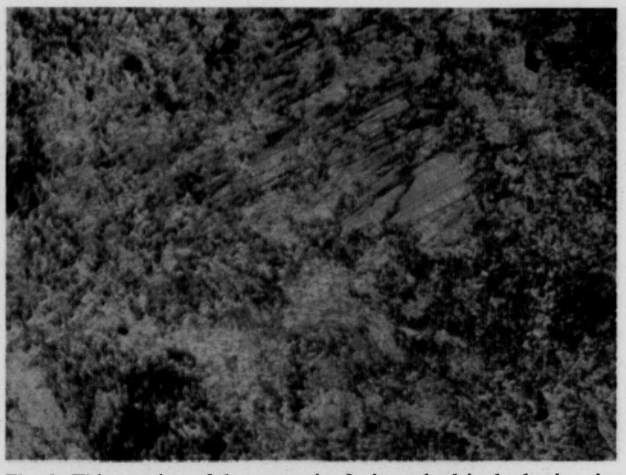


Fig. 9: Thin-section of the evaporite facies anhydrite hydration in gypsum is more effective along cleavage plane; width of photogrph = 7,5 mm (crossed nicols).
Slika 9: Mikroskopski izbrusak evaporitnog facijesa pokazuje hidrataciju anhidrita u gips koja je najintenzivnija duž pukotina kalavosti; širina slike = 7,5 mm (ukriženi nikoli).

minerals. Fibrous gypsum crystal aggregates sporadically contain coarser authigenic calcite or/ and less frequently secondary dolomite, and commonly early-diagenetic dolomicrite relics (Figs. 6, 7 and 8). Anhydrite hydration is increased with temperature and salinity decrease of pore water in evaporites. It is even enhanced after anhydrite is penetrated by circulation of fresh (meteoric) water (MURRAY, 1964). In our case the evaporites had been repeatedly intensively tectonically disrupted, crushed and faulted, and the hydration of anhydrite occurred after their emplacement near or at the surface by tectonical and erosional processes. In other words they were subjected to the intensive influence of meteoric, surface and ground waters.

Some evaporites contain macroscopically visible dolomite layers (Fig. 4), laminae or lamina relics and/or tectonically broken and brecciated thin layers of dolomite in shape of "dolomite-gypsum" breccia (Figs. 5 and 10), although in most evaporites these dolomites are not observed macroscopically; they are regularly present in thin sections of evaporites (Figs. 6, 7 and 8). Dolomite layers typically are lenticular, and may be laterally continuous for no more than 3 - 10 meters and laminae no more than a few cm. The most striking structure of the dolomite are long narrow tabular cavities, lensoid to ovoid vugs 0,5-2 mm in diameter. They appear to be linked to solution cracks or to leached tube. The observed dolomite texture, structure and composition define them as either dolomicrite, dolopelmicrite or stromatolite with desiccation cracks and/ or shrinkage cracks. All of these dolomites are supratidal early-diagenetical dolomites or evaporite dolomites originated in the same sedimentary cycle as anhydrite, i.e. in regressive sabkha cycles (firstly as mud accumulation in a shallow subtidal or restricted lagoon at the margin of a wide sabkha and then as early-diagenetic dolomitization at the supratidal environment). Evident alternating cycles of dolomite and gypsum (as a hydration product of anhydrite), have been preserved at many sites, although the dolomite and gypsum (or anhydrite) beds and thicker laminae have been intensively tectonically brecciated. These cyclic alternations can be interpreted as B and C members of regressive sabkha cycle similar to sabkha cycles in Arab-Darb Formation (WOOD & WOLFE, 1969).

Evaporites without distinctly macroscopically visible dolomite layers and laminae ("pure evaporites") usually contain dolomite (observed in thin sections - Figs. 6, 7 and 8) in shapes of thin, broken and "folded" laminae, termed "enterolithic structure" or "enterolithic folds" (BOSELLINI & HARDIE, 1973) and irregular clusters or aggregates. Dolomite occurences in these evaporites are actually relics of dolomite layers and laminae belonging to the B member of the sabkha depositional cycle preserved after "enterolithic folding" processes, i. e. by several periods of strain by hydration of anhydrite to gypsum and dehydration of gypsum to anhydrite. Diapiric uplift, and early-diagenetical anhydrite replacement of dolomite in sabkha environment is very strong and frequent (SHEARMAN, 1966). The processes of tectonical fracturing and anhydrite and/or gypsum replacement of dolomite here must be also taken into account. The relatively small amount of dolomite in "pure evaporites" can be the consequence of displacement and uplift of plastic evaporite strata by diapirsm, which separates them from the brittle undisplaced carbonate members of sabkha cycles.

The essential evaporite characteristics together with the petrological and sedimentary interpretations of associated dolomites, allow the interpretation of depositional environments of evaporites as follows.

While evaporites associated with early-diagenetical dolomites exhibit principal features of the origin coming from coastal sabkha depositional environments, the evaporites without macroscopically visible dolomite or with dolomite which occurs in shapes of thin broken laminae, pleated bands and relics, cannot be interpreted

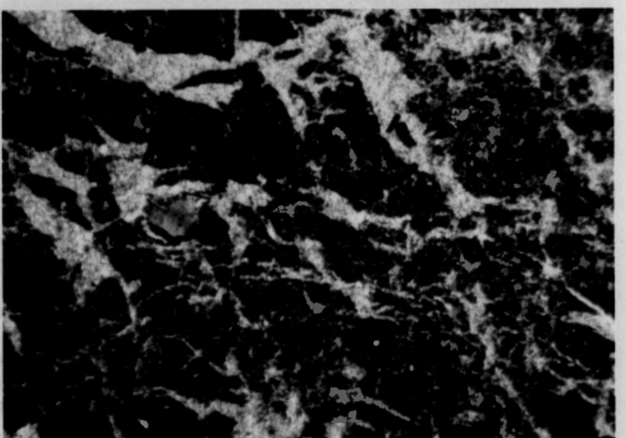


Fig. 10: Tectonicaly crushed dolomicrite replaced by veins of gypsum, respectively. Small relict of anhydrite (yellow) in dolomicrite point at sabkha cycle. Evaporite-dolomite facies from Bistrica area, thin-section, width of photograph = 7,5 mm (crossed nicols).
Slika 10: Tektonski razdrobljeni dolomikrit po pukotinama intenzivno potiskivan žilama gipsa. U dolomikritu se nalaze i sitni relikti anhidrita (žuto) koji ukazuju na dolomitno-anhidritni sabkha ciklus. Evaporitno-dolomitni facijes područja Bistrice, širina slike =7,5 mm (ukriženi nikoli).

unambiguously with respect to depositional conditions and environments.

The present surface gypsum evaporites (products of hydration of anhydrite), were deposited in evaporation conditions around the edges of an epeiric marine basin, i. e. in the large belt on desert carbonate-shoreline coastal sabkhas, which existed in the conditions of general regressive tendency and permanent coastal progradation originated by continual sea-level fall (Fig. 3). These conditions ended with the development of long-lasting sabkha and playa environments, and finally with lake (either salty or brakish water), river and land environments. It is evident that the intertidal and supratidal zones (clastic and carbonate) have been prograding seawards, thus making the sediments of these facies diachronous (Fig. 3).

In restricted shoals, lagoons and intertidal environments contemporaneous limestone deposition occurred, while on the fore-shore and shore-face with dominanting siliciclastic sediments (i. e. siliciclastic shore-lines), playas and lakes (salt, brakish and/or fresh water) with small deltas and rivers, clastic deposition prevailed (Fig.3). These clastic sediments, especially deposited in fore-shore, playa and salt lake environments, often contain cube molds of leached halite crystals which originally precipitated in dry periods of semi-arid or arid climate conditions. Although Upper Permian evaporite outcrops, with a complete "regressive sabkha cycle" (WOOD & WOLFE, 1969) were not found in the central Dinarides area, frequently B and C members, or A member succesion (section 3.1), of the sabkha cycle were observed. Thus, we can conclude that the evaporites which contain earlydiagenetical dolomites were formed in coastal sabkha environments (Fig. 3). However, massive evaporites, which contain only dolomite relics, were probably formed in similar conditions of high evaporation on marginal parts of a shallow epeiric sea with a permanent regression tendency and development of long-lasting sabkhas. Namely, in these evaporites, in spite of their thickness (due to diapirism), absolutely no observation was made of laminated alternations of carbonates enrichment with organic matter, anhydrite and halite. The bulk of evaporites deposited in subtidal and deeper marine environments (lagoons, bays et. c.) are either distinguished by previously mentioned regular thin laminated alternations inside a few hundred meters thick, continuous evaporite sequences or they belong to the "banded anhydrites" or "varve anhydrites" rich in organic matter, "Stinkenkarbonate", and alternations with halite (RICHTER-BERNBURG, 1955; SCHREIBER, 1986). As it is known, halite deposits are uncommon or fail in carbonate-anhydrite sabkha evaporite sequences (SELLEY, 1988).

Since, in our case such evaporite features have not been observed, this excludes the interpretation of their origin in subtidal or deeper marine environments.

The comparatively small amount of dolomite and absence of complete sabkha cycles (A-phase: algal limestone - homogeneous, B-phase: laminar and bird's,- eye dolomite - algal mat dolomite, and C-phase: nodular anhydrite; WOOD & WOLFE, 1969) in the Upper Permian evaporites of the central Dinarides, especially in deeper portions of evaporite sequences, can be interpreted as:

- sabkha anhydrites have been deposited in long-lived sabkha environments with semi-arid to arid climate in the C-phase of the regressive sabkha cycle with high concentrations and influx of Ca-sulphates, and in which anhydrite more or less completely replaces dolomite formed in B-phase;
- displacement by diapirism from the primary sabkha cycle succession of evaporite matter, without any significant uplift of carbonates, resulted in concentration of evaporite;
- due to intensive tectonical activity the brittle carbonate beds (i.e. B dolomite member of sabkha cycles) were severly disrupted and milonitized, and their remains were later more or less completely replaced by gypsum. Due to leaching of gypsum on the surface of outcrops, dolomite remains are repeatedly concentrated and formed either as "dolomite-gypsum breccias" or "rauhwackes"- cavity breccias.

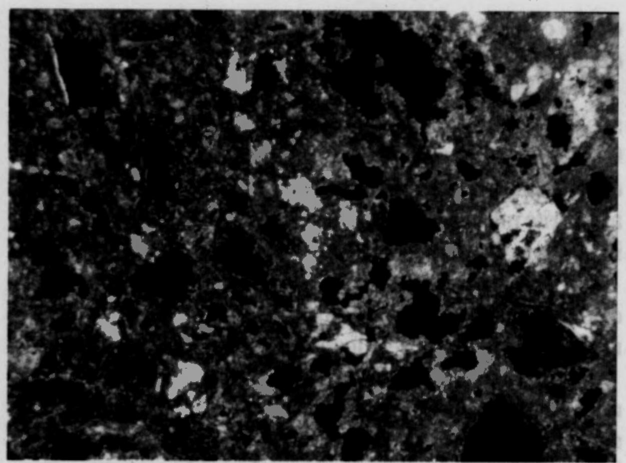
Thus we can assume that one, two or all the three processes had an important role in various periods of geological history of central Dinaric Upper Permian evaporites and associated sediments.

3.3 ORIGIN OF CARBONATE CAVITY BRECCIAS

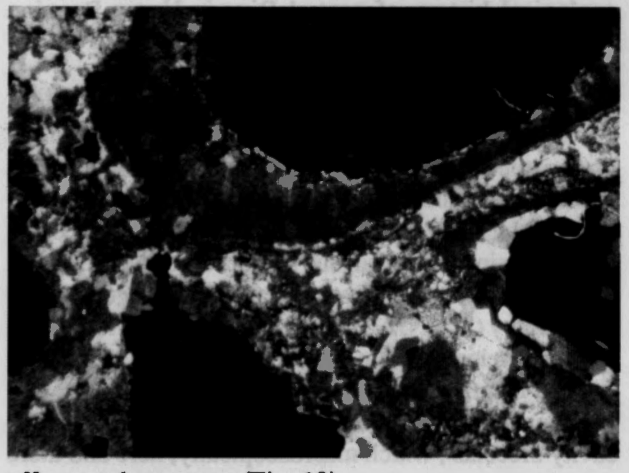
Carbonate cavity breccias or the "rauhwackes" often go together with evaporites in various and somewhat indistinct relationships. Although the problem of their stratigraphical connection with the evaporite and carbonate facies remains undefined, due to more breccia generations ranging from the Late Permian and Pre-Neogene to the Quarternary (ŠUŠNJARA et al., 1992) and also to the type of their development, the observed features imply a similar or even identical origin.

They are highly porous, cellular, full of small holes, cavity breccias , which macroscopically, here and there resemble travertine. Breccias contain various amounts of not sorted, angular fragments with corroded surfaces and edges, and also different amounts of cement (Figs. 11 and 12). The fragments of Permian limestones, early-diagenetical dolomites and evaporites predominate. The dolomite fragments are usually more or less dedolomitized and evaporite fragments fully or partially leached (large cavities in breccia, Figs. 11 and 12). The cement consists of cryptocrystalline to macrocrystalline laminar, pisoid-like or speleothem-like calcite accumulation pigmented with Fe-oxides and hydroxides, and impurites of siliciclastic material (Fig. 12).

Not only did the leaching of evaporite fragments occur, but also dedolomite fragments from the latter, friable dedolomitized mass could have been mechanically and chemically removed, and the remained molds-vugs could be subsequently partialy or sometimes completely filled with calcite cement. Mostly this was the reason why the breccia had cellular and cavity-like structures and why the leaching of rock fragments usually occured after they had been partially or completely cemented into breccia (Figs. 11 and 12). The leaching usually had little or no



Figs. 11(above) and 12 (below) : Thin-sections of the carbonate cavity breccia: the evaporite and dolomite fragments and vugs and molds of leached fragments; microcrystalline and pisoid-like or calcrete cement around of the fragments and vugs. Sinjsko polje; width of photograph = 7,5 mm.
Slika 11 (gore) i 12 (dolje):Mikroskopski izbrusci karbonatnih šupljikavih breča: fragmenti evaporita i dolomita i šupljine nastale izluživanjem pojedinih fragmenata; mikrokristalasti i pizoidni kalcitni cement oko fragmenata i šupljina. Sinjsko polje, širina slike = 7,5 mm.



effect on the cement (Fig. 12).

Cavity breccias are definitly not of marine origin but they exhibit distinct terrestrial features. Their occurrence on elevated surfaces of hills, as well as their discordant overlapping of underlying evaporite or carbonate deposits, regardless of the position of footwall beds, composition and structure, imply that they are secondary products of physical and chemical weathering of tectonically disrupted Upper Permian evaporite and carbonate sediments. Whether it was due to a terrestrial phase at the and of Permian, or a post-Permian tectonical uplift and surface emplacement of Permian evaporite and carbonate sediments, the sediments were weathered in terrestrial conditions. The products of such weathering alterations were carbonate cavity breccias. The weathered products, beings either of semi-arid to arid climate with scarce rainfals and intensive evaporation, or meteoric and pore waters saturated with Ca-hydrosgen-carbonate, were gradually cemented with crust-like to pisoid-like and speleothem-like calcite cement into more or less compact breccia. Due to leaching of evaporite and dedolomite fragments, cavities develop in the breccia thus giving them cellular and/or cavity appearance. Intensive dedolomitization is enhanced by high Ca content of pore solutions (i. e. low molar Mg/Ca ratio) which again is linked with dissolution and leaching of gypsum. This can also be an explanation why the cavity breccias or "rauhwackes" usually occur in association with the carbonate-evaporite facies.

4. DISCUSSION AND CONCLUSIONS

Although there is a limited number of large and for study favourable outcrops that exhibit clear relationships between vertical succession and lateral transition of the three main Upper Permian facies, i. e. carbonate, evaporite and clastite facies, the interpretation of conditions and environments of deposition and origin of each individual facies and the existence of the general regressive cycle in the Upper Permian, allows for a general interpretation concerning the conditions and environments of deposition. The relation between the deposition of clastites and evaporite conditions is implied by occurrences of the halite molds inside clastite units from Vrlika and Knin (ŠĆAVNIČAR, B., 1973). On the basis of lithological characteristics of clastites from the surrounding areas of Drniš and Vrlika (central Dalmatia; IVANOVIĆ et al.,1971), there is correlation with the top part of "the Groeden facies" (after Groedental = Val Gardena) from the wider region of the Dinarides.

Taking into account the fact that during the Late Permian the general Permian regressive cycle was at its peak, and that narrowing of the epicontinental marine depositional basin was in constant progress, that the Upper Permian limestones belong to lagoonal and intertidal environments - often to the starting A member of the regressive sabkha cycles - that also the evaporite facies which major characteristics of sabkha sediments, and that the clastic facies exhibit transition from off shore, shore face, fore shore, over playa and salt lake environ-ments to alluvial environments, these characteristics show general depositional model on Fig. 3.

In general, during the Late Permian in the present day central parts of the Dinarides, assuming a more or less continuous regressive tendency, various deposition conditions and environments existed and were defined by the existence of a shallow epicontinental sea with a very differentiated coastline, bays and lagoons. Also, due to the general regressive tendency, this concerns wide zones of coastal sabkhas which gradually pass into playas and/or salt lakes with or without alluvial sedimentation and which finally pass into terrestrial environments (Fig. 3). It appears that, simultaneously at different places, deposition of lagoonal and intertidal sediments (carbonate facies), supratidal and sabkha sediments (early-diagenetical dolomites and evaporites) was possible. This was also accompanied by clastic deposition in coastal environments, playa and salt lake environments with or without river mouths and deltas, and partially by river depositional environments (clastic facies) and the common terrestrial environments (Upper Permian cavity breccia). In case of a generally continuous regressive succession, exhibiting probably with more or less positive or negative fluctuation, the normal facies succession would be: carbonte facies - evaporite and/or clastic facies (Fig. 3). Since depositional environments are not only under the influence of the general regressive tendency, which plays an important part in development of large lateral differences of facies, but are also under the influence of rapid changes of deposition, of periodical sea-level fluctuations, global and local synsedimentary tectonics, autocyclicity, coast and tidal flat progradation, climate variation, alternation of semi-arid to arid and rainy periods, various lateral and vertical facies succession from one locality to another have resulted. For example, in the central part of the Velebit Mt. (Oštarije near Gospić) in the Late Permian were deposited only peritidal carbonates without evaporites in the following succession: 1.- subtidal to lower intertidal fusuline-bearing limestones; 2.-supratidal dolomites; 3.- black organical-rich mudstones and bioclastic packstones deposited as organical-rich mud in a restricted shallow bay and/or on the edge of a shallow lagoon between large supratidal areas, and 4.- supratidal dolomites with reddish-brown or grey shale intercalations in the uppermost part (TIŠLJAR et al., 1991). From the presented data and schematic diagram (Fig. 3) it is evident that during the Late Permian in the wider region of the central parts of the Dinarides various deposition environments existed with both gradual lateral and vertical sequence transitions. After and/or during shalow marine limestone and sabkha evaporite deposition together with associated early-diagenetic supratidal dolomites in the generally regressive regime and locally varying conditions of time, gradually ceased to exist shallow marine environments with carbonate deposition and coastal sabkhas with dolomite and evaporite accumulation. These deposition environments were either gradually or abruptly replaced by clastic deposition in coastal, playa or (salt, brackish?) ephemeral lake or river environments, and finally, by terrestrial conditions. The latter were at their peak in the terminanting stages of the Permian. The reestablishment of the shallow marine deposition regime occurred at the beginning of the Triassic.

The correlation of the Upper Permian evaporites from the central part of Dinarides compared to the similar northern and western European evaporites, for example "the Zechstein evaporites" from Poland, Germany, Netherlands and Denmark, due to lithological composition, depositional environments and conditions of Upper Permian evaporites from the Dinarides excludes the application of the first (Z-1) and second (Z-2) "Zechstein evaporite deposition cycle models". The third (Z-3) "Zechstein cycle" model of deposition (SCHREIBER, 1986), however, is partially applicable. To be more precise, the concluding sequences of the third (Z-3) cycle including the deposition of evaporites in the evaporite basin, has a basin reducing tendency accompanied by shallowing. Only anhydrite and early-diagenetical dolomite in sabkhas and limestone and gypsum in the subtidal to intertidal zones developed here whereas halite and K-Mg-salt deposition are not present in these environments.

The lithological characteristics, sabkha cycles and general depositional environment of the Upper Permian evaporites from the Dinarides are quite similar to the Upper Permian evaporites of the Bellerophon Formation from the Southern Alps, Italy. The Bellerophon evaporite cycle is interpreted as a regressive cycle which was formed in an arid marginal marine environment by a prograding tidal flat building seaward over a shallow subtidal lagoon and leaving behind an exposed sabkha (BOSELLINI & HARDIE, 1973).

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Geneza i okoliši taloženja gornjopermskog karbonatnog i evaporitnog kompleksa središnjeg dijela Dinarida (južna Hrvatska i zapadna Bosna)

J. Tišljar

U ovom radu su prikazani rezultati petroloških i sedimentoloških istraživanja karbonatnih i evaporitnih sedimenata, interpretacija geneze, uvjeta i okoliša taloženja evaporita i pratećih sedimenata "permo-trijasa" središnjeg dijela Dinarida (srednja i sjeverna Dalmacija i granično područje između Like i jugozapadne Bosne - sl. 1). Po tome je ovaj rad normalni nastavak na rad ŠUŠNJARA et al. (1992) s kojim čini dio cjeline prezentiranja rezultata kompleksnih geoloških istraživanja "permo-trijaskog" kompleksa središnjeg dijela Dinarida. Rezultati se odnose na područja istraživanja prikazana na sl. 1 i na geološkim kartama sl. 2 i 3 u radu ŠUŠNJARA et al. (1992).

Brojnim palinološkim dokazima ŠUŠNJARA et al. (1992) su utvrdili da "permo-trijaski" evaporitni kompleks s pratećim sedimentima središnje Dalmacije pripada gornjem permu (donji dio gornjeg perma), a šireg područja Srba u Lici srednjem katu gornjeg perma.

Gornjopermski sedimenti središnje i sjeverne Dalmacije, Like i zapadne Bosne su zastupljeni s tri glavna facijesa: 1.- karbonatima; 2.- evaporitima (gips, anhidrit) s ranodijagenetskim dolomitima i 3.- klastitima, tj. pelitima, siltitima, pješčenjacima i vrlo rijetko konglomeratima (vidi sl. 1, 2 i 3 u radu ŠUŠNJARA et al.,1992 str. 96-99).

Poseban facijes su karbonatne šupljikave breče ("rauhwacke"). Superpozicijski slijed ta tri facijesa i šupljikavih breča nije svugdje isti, a niti potpuno jasan zbog pokrivenosti terena i intenzivne tektonske poremećenosti naslaga. Općenito su, međutim, najstariji evaporiti, a na njima leže klastiti i/ili karbonati ili karbonatne šupljikave breče (ŠUŠNJARA et al.,1992). Odnos evaporitnog facijesa i karbonatnih šupljikavih breča je složeniji jer su breče terestičke tvorevine nastale na površini zemlje u više različitih kronostratigrafskih jedinica. Nepostojanje većeg broja izdanaka s jasnim međusobnim vertikalnim slijedom i jasnim bočnim odnosima triju glavnih facijesa, kao i činjenica da uvijek ne postoji egzaktno utvrđeni odnos tih facijesa u vremenu i prostoru, stvara znatne poteškoće pri općoj interpretaciji uvjeta i okoliša taloženja gornjo-permskih sedimenata.

Karbonatni facijes gornjeg perma se sastoji od dobro slojevitih, mjestimice horizontalno laminiranih, tamnosivih i crnih vapnenaca bogatih kerogenom, uglavnom madston do vekston tipa. Nerijetko su manje ili više intenzivno kasnodijagenetski dolomitizirani ili rekristalizirani. Rjeđe se u tom facijesu nalaze i kasnodijagenetski dolomiti nastali dolomitizacijom vekstona i madstona. Vapnenci mjestimice sadrže pseudomorfoze kalcita po anhidritu. Kerogenski ostrakodni madstoni koji sadrže krupne kristale gipsa (sl. 2) ili kalupne šupljine kristala gipsa, koji su se izlučivali u karbonatnom mulju u bočnim rubnim plinskim dijelovima laguna koje postupno prijelaze u sabkhe (sl. 3) i to u početnoj fazi regresivnog sabkha ciklusa ("gypsum much" - SELLEY, 1988), su tipični bočni ekvivalenti potplimsko-plimske faze sabkha ciklusa, tj. član A sabkha ciklusa taloženog u plitkom potplimskom do plimskom okolišu s povišenim salinitetom i stalnom evaporizacijom.

Dio vapnenaca tog facijesa je vjerojatno taložen kao istovremeni bočni ili mlađi facijes sa sabkha i plaja sedimentima u istom, općem regresivnom ciklusu na rubnim dijelovima epikontinentalnog mora (slika 3).

Evaporitni facijes na mnogobrojnim izdancima, bušotinama i u gipsolomima pokazuje da se u njegovim dubljim dijelovima uglavnom nalaze evaporiti bez značajnijih pojava ili makroskopski vidljivih proslojaka dolomita, a da se u vršnim dijelovima evaporitnog facijesa obično s evaporitima pojavljuju proslojci laminiranih dolomita (sl. 4), nekontinuirane lamine dolomita u evaporitu (sl. 6) ili dolomitno-evaporitne breče nastale naknadnim tektonskim, a ne sinsedimentacijskim procesima drobljenja proslojaka dolomita i evaporita (sl. 5 i 10). Najčešći su slojeviti i laminirani gipsevi u kojima se pojavljuju proslojci, lamine ili relikti laminiranih i stromatolitnih dolomita (sl. 6, 7 i 8) s tzv. "enterolitičkim boranjem" (BOSELLINI & HARDIE, 1973). Premda po obliku vrlo slična tektonskim deformacijama, ta su "enterolitička boranja" ili tzv. "enterolithic folds" nastala kemisjkim promjenama volumena sedimenta uslijed stezanja i rastezanja proslojaka i slojeva evaporita pri procesima hidratacije anhidrita u gips i dehidratacije gipsa u anhidrit. Naime, pri hidrataciji anhidrita u gips, tj. primanju vode, povećava se volumen za cca 38% što, jasno, izaziva snažna naprezanja posebice kad se taj reverzibilni proces više puta ponavlja tijekom geološke povijesti.

Glede strukture i sastava dolomiti pripadaju dolomikritima, dolopelmikritima ili dolomitnim stromatolitima s desikacijskim pukotinama ili pukotinama stezanja (shrinkage cracks) te šupljinama otapanja. Kod evaporita u kojima makroskopski obično nije moguće zamijetiti dolomitne proslojke i lamine ("čisti evaporiti") dolomit je, kako to pokazuju mikroskopske analize, i tu redovito prisutan obliku tankih, raskinutih i plisiranih ("boranih") lamina, gnijezda, grudastih relikata ili nepravilnih nakupina i agregata (sl. 5, 6 i 7). Sve su to ranodijagenetski ili evaporitni dolomiti nastali u istom sedimentacijskom ciklusu s anhidritom u rubnim dijelovima prostranih sabkhi koje su zbog sužavanja marinskog bazena progradirale preko potplimskih okoliša u smjeru mora (sl. 3). Usprkos snažnog tektonskog lomljenja u gipsevima se još mogu zapaziti cikličke izmjene dolomit-gips koje odgovaraju članovima B i C sabkha ciklusa sedimentacije.

Evaporiti su zastupljeni gipsom ili anhidritom ili gipsom i anhidritom (sl. 2-10). Gips se obično nalazi na površini ili blizu površine, a anhidrit u dubljim dijelovima gipsoloma ili u bušotinama jer je gips pretežnim dijelom ovdje sekundarni mineral nastao hidratacijom anhidrita, kako je to jasno vidljivo u mikroskopskim izbruscima (sl. 8 i 9). Hidratacija anhidrita je uvjetovana opadanjem temperature i smanjivanjem saliniteta pornih voda sadržanih u evaporitima, osobito nakon što su anhidriti došli u doticaj sa slatkom oborinskom vodom. U našem slučaju gdje su evaporiti višekratno intenzivno tektonski lomljeni, drobljeni i rasjedani, očigledno je da je hidratacija anhidrita u gips nastupila nakon što su evaporiti tektonikom, dijapirizmom i erozijom dospjeli vrlo blizu površini ili na samu površinu gdje su bili izloženi jakom utjecaju oborinskih i slatkih površinskih i podzemnih voda.

Evaporiti, koji su danas na površini zastupljeni gipsom nastalim hidratacijom iz anhidrita, su taloženi u evaporitnim uvjetima u rubnim dijelovima epikontinentalnog marinskog bazena koji je zbog opće regresivne tendencije i permanentne progradacije obale, odnosno stalnog povlačenja mora, završavao formiranjem i duže vremena održavanjem sabkha i plaja uvjeta (sl. 3). Takvi okoliši su egzistirali na velikom prostoru duž prostranog i širokog područja uz stalne bočne migracije. Tu su u rubnim dijelovima mora mogle biti veće ili manje lagune, zatvoreni plićaci, sabkhe i slane bare s visokom koncentracijom Ca-sulfata koje su općom tendencijom smanjivanja marinskog područja, tj. općom regresijom i progradiranjem obale prema moru, postupno prelazile u natplimske i priobalne sabkhe i vjerojatno kontinentalne sabkhe i slana jezera sa stvaranjem ranodijagenetskih dolomita i nodularnih anhidrita. Bočno u plitkim lagunama i plimskoj zoni taloženi su vapnenci, a na prednjem žalu (foreshore) i obalnom licu (shore face) s prevladavajućim siliciklastičnim materijalom, kao i plajama i oslađenim jezerima, klastični sedimenti u kojima se tijekom sušnih razdoblja izlučuje halit koji danas nalazimo u klastitima u obliku kalupa kubičnih kristala.

Evaporiti, premda imaju veliku debljinu (dijapirizam, tektonika ?), nigdje ne sadrže debele pakete laminacijske izmjene karbonata, anhidrita i halita. Naime, većina evaporita taloženih u marinskim okolišima s nešto dubljom vodom (lagune, zaljevi i sl.) se odlikuje spomenutom pravilnom tanko laminiranom izmjenom unutar kontinuirane debljine evaporitnih sedimenata od više stotina metara ili pak pripada tzv. "trakastim anhidritima", odnosno "Varven anhidritima" bogatim organskom supstancijom i izmjenom s halitima (RICHTER-BERNBURG, 1955; 1957; SCHREIBER, 1986). Kako takvi evaporiti u našem slučaju nisu nigdje nađeni, taj način njihovog mogućeg postanka je isključen iz ove interpretacije. Razmjerno mali udio dolomita i nepostojanje kompletnih sabkha ciklusa: vapnenac-dolomit-anhidrit u gornjopermskim evaporitima, osobito u dubljem dijelu evaporitnih naslaga, moguće je objasniti na slijedeći način:

- sabkha anhidriti su pretežno nastali u dugotrajno postojanim sabkha uvjetima C faze regresivnog sabkha ciklusa s visokom koncentracijom i donosom Ca-sulfata u kojima je anhidrit manje-više potpuno potisnuo dolomit;
- dijapirizmom su iz primarne sukcesije sabkha ciklusa bile kretane uglavnom samo evaporitne mase a ne i značajnije količine karbonata (vapnenci i dolomiti) što