GEOLOGICA CARPATHICA, 48, 4, BRATISLAVA, AUGUST 1997
221–229

TSUNAMITES IN A STORM-DOMINATED ANISIAN CARBONATE RAMP (VYSOKÁ FORMATION, MALÉ KARPATY MTS., WESTERN CARPATHIANS)

JOZEF MICHALÍK

Geological Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 842 26 Bratislava, Slovak Republic

(Manuscript received February 25, 1997; accepted in revised form June 24, 1997)

Abstract: The Vysoká Formation limestone sequence (Fatric Zone, Central Western Carpathians) reflects two striking contradictions in the character of the Anisian sedimentary record. Tempestite intercalations representing the first one are connected with the occurrence of violent storm events which interrupted the overwhelmingly stable sedimentary conditions of a restricted shallow carbonate ramp environment. The second contradiction (tsunamite layers) proves the occurrence of sudden seismic events which disturbed a long period of rather slow (20–30 mm/Ka) gradual subsidence. These events are interpreted as the effects of starting the oblique rifting of the Paleo-European shelf.

Key words: Alpine-Carpathian shelf, Anisian, sedimentology, carbonate ramp, tempestites, tsunamites.

Introduction

McKee (1959) recognized the character of storm sediments in Recent reef environments. Brenner & Davies (1973) and Ager (1974) reported the presence of Jurassic storm-generated sediments in Wyoming, Montana and Morocco. Dżuliński & Kubicz (1975) interpreted layers of coarse rudstone intercalated in fine grained Middle Triassic limestones of Silesia as storm sediments. Similar cases were presented by Aigner (1977, 1979, 1982) and Aigner et al. (1978) from the Middle Triassic German Muschelkalk, and by Blendinger (1983) from the Alpine Dont Fm of the same age. Such a layer called "tempestite" with a usually erosive base is formed by graded rudstone which contains clasts derived from the underlying bed (Chudzikiewicz 1975) together with reworked fragments of marine organisms. Sometimes, texture arrangement similar to the Bouma-sequence could be observed. Parallel, hummocky crossed and ripple laminated intervals, indicating a high-energy environmental regime (Aigner 1982) occur occasionally.

Tempestite records differ in different sedimentary environments. While in a mild and humid climate it mostly consists of quartz sand derived from river input (Wright & Walker 1981; Katsura et al. 1984; Ramli 1986; Schieber 1987; Goodbred & Hine 1995, etc), in a hot dry climate it is composed either of marine lime biodetritus on littoral flats (Perkins & Enos 1968; Lee 1988; Lee & Kim 1992; Sageman 1996), or of lime mud in oolite bars (Shinn et al. 1993; Major et al. 1996). The extent of shoreline erosion depends on shore morphology: being considerable on sandy coasts, but very slight in coastal marshes (Clague & Bobrowsky 1994). In spite of frequent destruction of tempestite record by subsequent erosion or bioturbation on low coasts with microtidal, low-wave energy environments, the sediment deposition can be affected by storm-driven transport here (Goodbred & Hine 1995). Landward transport of material dominates during the vanishing stage of the storm (Rudowski 1986). Downwelling streams are responsible for basinward transport in the deeper neritic zone. More basinwards, distal tempestites can pass into turbidites (Hayes 1967; Swift et al. 1987).

Some of the rudstone layers are supposed to be of seismic origin. Seismite interpretation can be supported by the presence of abrupt lithological change following sudden subsidence of the bottom (Philips et al. 1994; Clague & Bobrowsky 1994), liquefaction features such as dikes filled by unconsolidated basemental rocks, or their detailed micro-folding (Munson et al. 1995; Nelson et al. 1996). Some seismites are differentiated into plastically deformed base, fragment-supported middle part and matrix-supported top (Marco & Agnon 1995) of the layer. Shallow-water or coastal seismites can be overlain by tsunami-induced sand sheets (Hemphill-Halley 1995; Nelson et al. 1996). Tsunamites are special type of tempestites. They always contain clastic material and open marine organism remnants transported landwards (Clague & Bobrowsky 1994; Hemphil-Hailey 1995).

General setting

Vysoká Limestone Formation forms the lowermost part of the Vysoká Nappe belonging to the Krížna Unit of the Central Carpathian superficial nappe system. It is well developed in the middle part of the Malé Karpaty Mts. (Biele Pohorie Hills; cf. Michalík et al. 1992), where it forms several of the most prominents peaks (Mt Modranská skala, Mt Bartalová, Mt Vysoká, Mt Biela skala, Mt Geldek; Fig.1). During the Middle Triassic, the sedimentary area was situated in the flat part of a large steepened carbonate ramp on the margin of Paleo-European shelf (Michalík 1993a, 1994; Rüffer & Zühlke 1995) .

Lithostratigraphy

The Vysoká Limestone Formation was named by Vetters (1904) and Beck & Vetters (1904). Although it was later identified with the Gutenstein Limestone (Andrusov 1959; Maheľ 1961), its specific features were well known to Carpathian geologists (Mišík 1983, etc). More precise stratigraphical, lithological and sedimentological characterization has been given by Michalík et al. (1992) and by Zágoršek (1993), who based their descriptions on several dozen sections investigated in detail. Only the basal member, distinguished at that time, should be regarded as the Vysoká Formation proper. The name "Geldek Member" should be retained for its uppermost part lying both above the middle part, called here the "Oberheg Member", and the basal, poorly exposed and tectonically reduced part which could be named here as the "Uhliská Member" (Fig. 2). The authors mentioned have found fauna of crinoids, bryozoans, brachiopods, conodonts, foraminifers, ophiuroids, molluscs and calcareous sponges in several fossiliferous levels here. These enabled them to identify the early Pelsonian and early Illyrian age of the principal parts (Oberheg and Geldek Members, respectively) of the formation.

A dolomite complex found at a higher level should be regarded as the independent Ramsau Dolomite Formation. Similarly, shelly limestones containing Carnian molluscs, provisionally named by Michalík et al. (1992) as the "Parná Member", evidently belong to another, independent formation comparable to the Opponitz Limestone.

As indicated in the Fig. 2, the Oberheg Member represents an independent depositional sequence limited from below by an erosional boundary, which can be parallelized with this designated as the An-3 by Rüffer & Zühlke (1995). LST of this sequence is incompletely preserved, TST is represented by channels filled by clastic limestone (Fig. 3). HST is fully recorded by thick laminated to vermicular limestones with tempestite intercalations. The topmost part of this sequence is cut by erosion during successive lowstand conditions.

The architecture of the Geldek Member (its lower boundary being parallelized with the An-4 of the authors mentioned above) is more complex. Its base is defined by a transgressive system boundary of the 1st order. The LST seems to be mostly represented by dolomite, followed by oolitic and biostromal limestones containing bryozoans, brachiopods and crinoids. However, the higher part of the sequence with several intercalations of tempestite beds, channel fillings, oolitic limestones and sabkha-type carbonates with pseudomorphs of evaporite crystals repeating in irregular cycles can be related rather to the autocyclic processes sensu Satterley (1996). The sedimentary rate was rapid enough to fill all the depositional space and to keep up very shallow-water sedimentary conditions. The rising sea-level can be indicated only by retreat of the oolitic bar towards the lagoonal flats (to the right in the figure). The

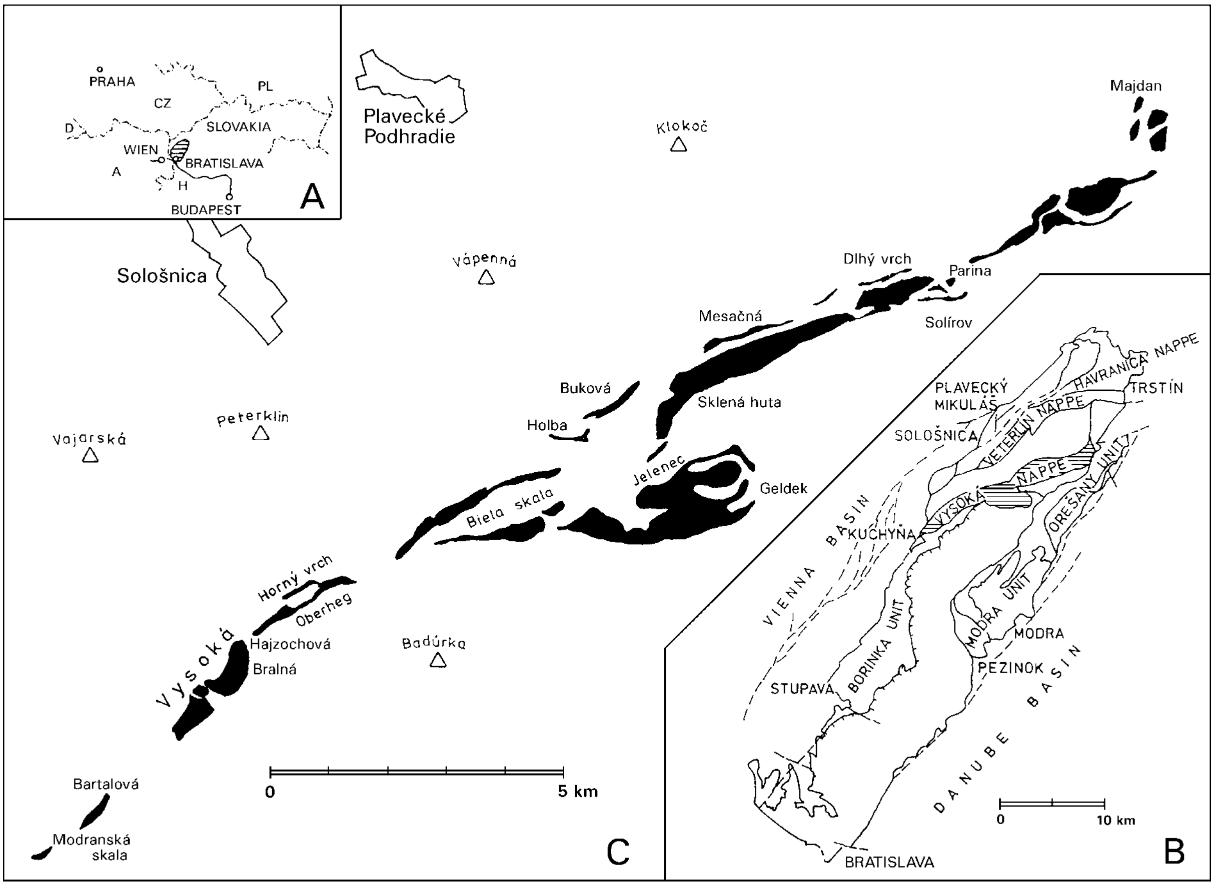


Fig. 1. Localization sketches. Upper left corner (A): The position of the Malé Karpaty Mts. (hatched quadrangle) in Slovakia. Lower right corner (B): Principal tectonic units of these mountains mentioned. Center (C): Important sections of the Vysoká Formation in the middle part of the mountains.

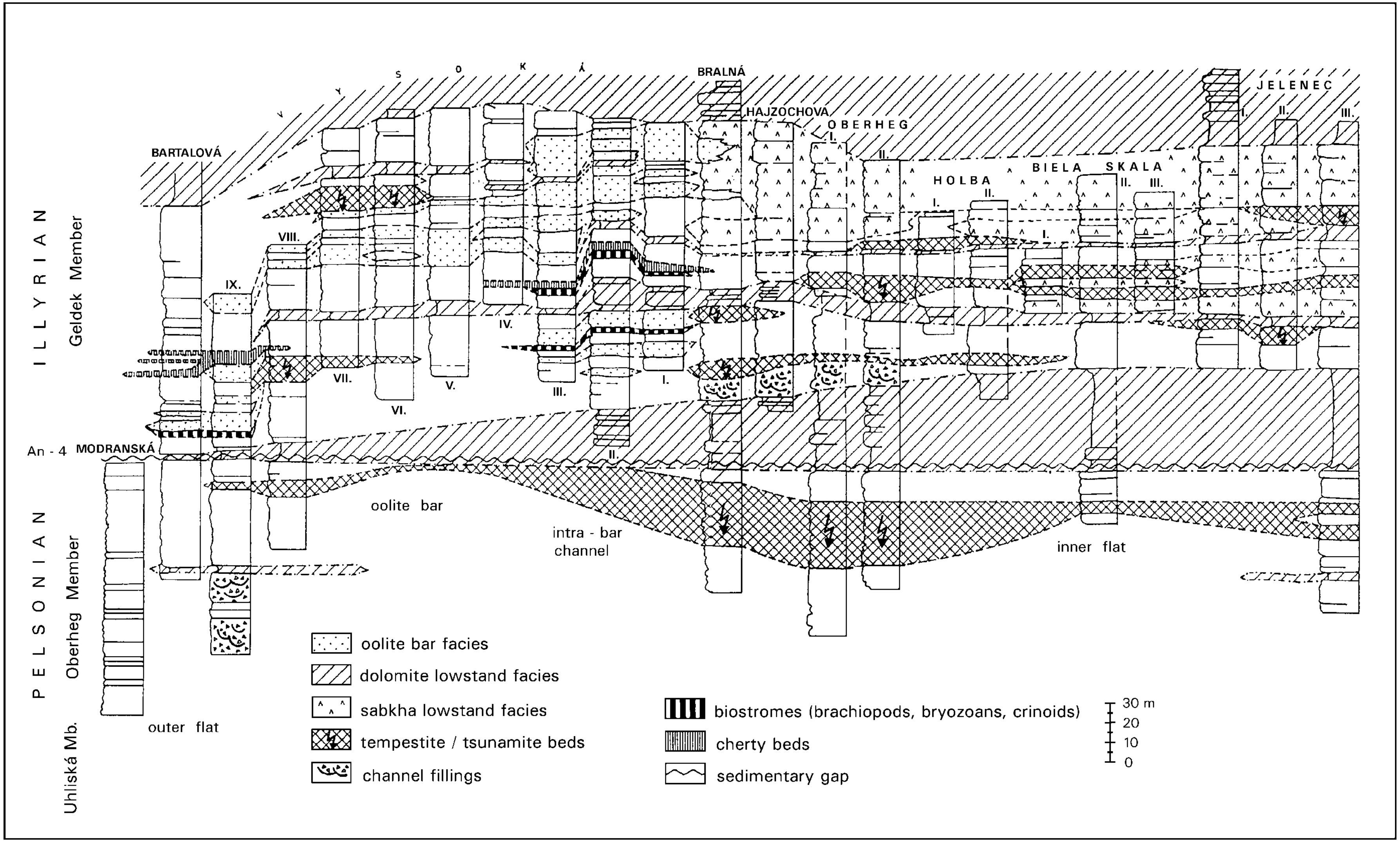


Fig. 2. Distribution of principal facies and elements of sequence stratigraphy in selected profiles of the Vysoká Formation in the Malé Karpaty Mts.

upper boundary with overlying Ramsau Dolomite is erosive, accompanied by a sedimentary gap.

Lithology

The most characteristic lithofacies of the Vysoká Formation consists of thick bedded dark grey limestone micrite and microsparite (mudstone, wackestone) with changeable clay admixture in thick laminae reflecting fluctuating environmental conditions. Its sedimentary environment was defined as restricted offshore shallow flats. Lithification of the sediment started in purer calcitic laminae which were probably deposited in warmer and dryer periods. Depending on the contrast between such lamina and the marly interval underlying it, bulks of semi-lithified rock "floated" on clayey matrix could have been frequently affected by disturbances due to reversed density gradient (Kasiński et al. 1978), sliding (Kotański 1955), bioturbation, or by subsequent erosion. The "banded" or, in extreme cases "vermicular", appearence of such limestone deposits (MF-5, MF-6 in Michalík et al. 1992) evidently resulted from their complex diagenesis.

Michalík et al. (1992) found layers of structureless (or slightly graded) grainstones to rudstones with large extraclasts in the Vysoká Fm. Sparites and microsparites contain coarse shell debris of bivalves, gastropods, ostracods, brachiopods, crinoids and foraminifers. Pellets, ooids and small intraclasts occur sporadically. Significant recrystallization and selective dolomitization is obvious. The base of each tempestite bed is sharp, sometimes stressed by stylolitization. Parallel bedded, hummocky crossed and ripple laminated intervals indicate the current regime. The character of the tempestite layers indicates a rapid, single deposition without subsequent reworking. A great part of the clastic intercalations belongs to distant tempestites.

The vermicular limestone directly underlying of several tempestite layers is characteristically sigmoidally deformed (Fig. 4.1). Usually, the oblique, middle arm of sigmoids formed by small imbricated limestone bulbs ("vermicles") is the most prominent. Only in several horizons, their ends are not bent backwards so that the resulting structure is similar to oblique bedding. Such transitions allow us to suppose several developmental stages of this "rope-ladder" texture (Figs. 4.1–3, 4.6).

In the first stage, a thin (several decimeters) incompletely lithified sediment layer has been liquefied by seismic shock. Lime bulbs have been shaped into elongated ellipsoids and completely isolated one from another by a more-or-less regularly distributed soft clayey matrix.

Subsequently, the stroke of an on-shore tsunami wave removed the liquefied sediment layer from the slightly elevated (or more exposed) parts of the bottom and caused imbrication oflime bulbs in more protected, shallow depressions (Fig. 5 A).

In third stage, drag caused by the returning off-shore wave deformed the ends of bulbs into sigmoids (Fig. 5 B). This deformation depended on the intensity of drag forces and on the mobility of the sediment, as well. Elastic behaviour of deformed soft sediments was caused by high pore water pressure during the shock event as indicated by the experiments of Einsele et al. (1974).

Finally, the sigmoidal lenses (several tens of metres wide and 3 to 30 cm thick) were covered by a tempestite-like layer consisting of clastic particles washed out from sediment eroded by the retreating off-shore wave (Figs. 4.4–5).

Discussion

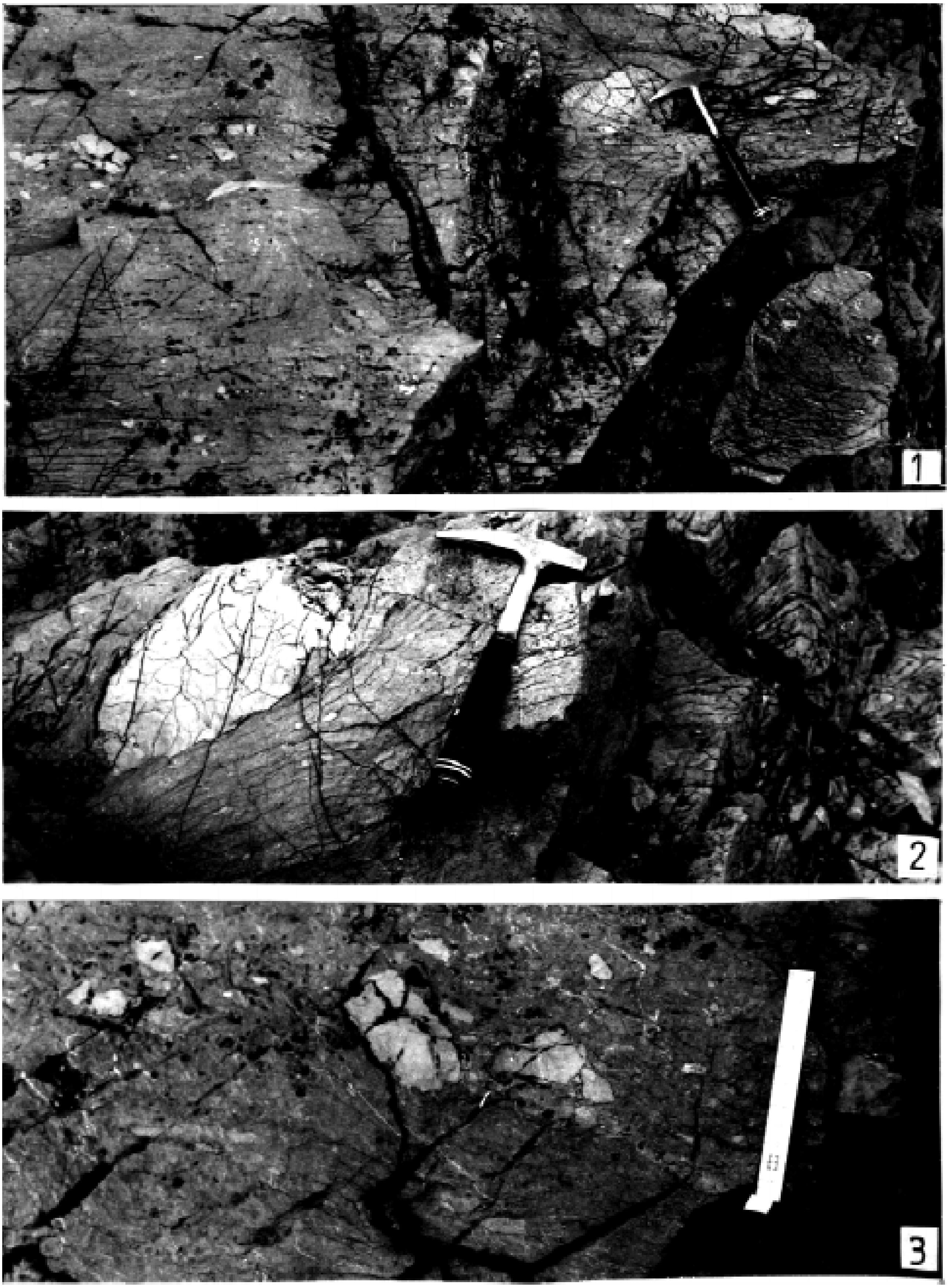
A similar texture from isochronous deposits (Misina Fm) was described by Nagy (1968) from the south-Hungarian Mecsek Mts. as "zürückgebogene Kreuzschichtung" (Figs. 4.7–8). Identical features occur in the upper Scythian limestones (Szinpetri Fm) of the Hungarian Aggtelek Karst, or in the Pelsonian limestones of the Lakatnik section (Iskar Valley) in Bulgaria. Schwarz (1975) described "sigmoidal slab joints" from the German Middle Triassic Wellenkalk: he regarded them as a result of vertical compression as a primary cause and a secondary lateral movement for space compensation. Alternatively, he connected this internal displacement with accelerated compaction assuming shock waves from earthquakes in the still unconsolidated beds. Kimura et al. (1989) interpreted the origin of sigmoidal deformation ("veins") from Recent soft sediments of the Mariana Trough as shears parallel to the stratification accompanied by reduction in the amount of pore water. A sudden increase in the pore water pressure by lateral strain caused the origin of coulisse-arranged slip surfaces (domino effect). This pressure event was ascribed to the effect of a tsunami wave (Coleman 1968; Catenacci 1976). Perceptible shock from on-surge wave movement effects unconsolidated (and seismically liquefacted) surface layers of sediment. Galli (1990) described similarly imbricated arrangement of bivalve shells underlying the actual tsunamite bed. On the other hand, Kastens & Cita (1981) did not observe any special texture in their lime "homogenite" of tsunamite origin. Evidently, the origin of the "rope-ladder" texture was connected with a very special carbonate ramp morphology, sediment composition and diagenesis, as well.

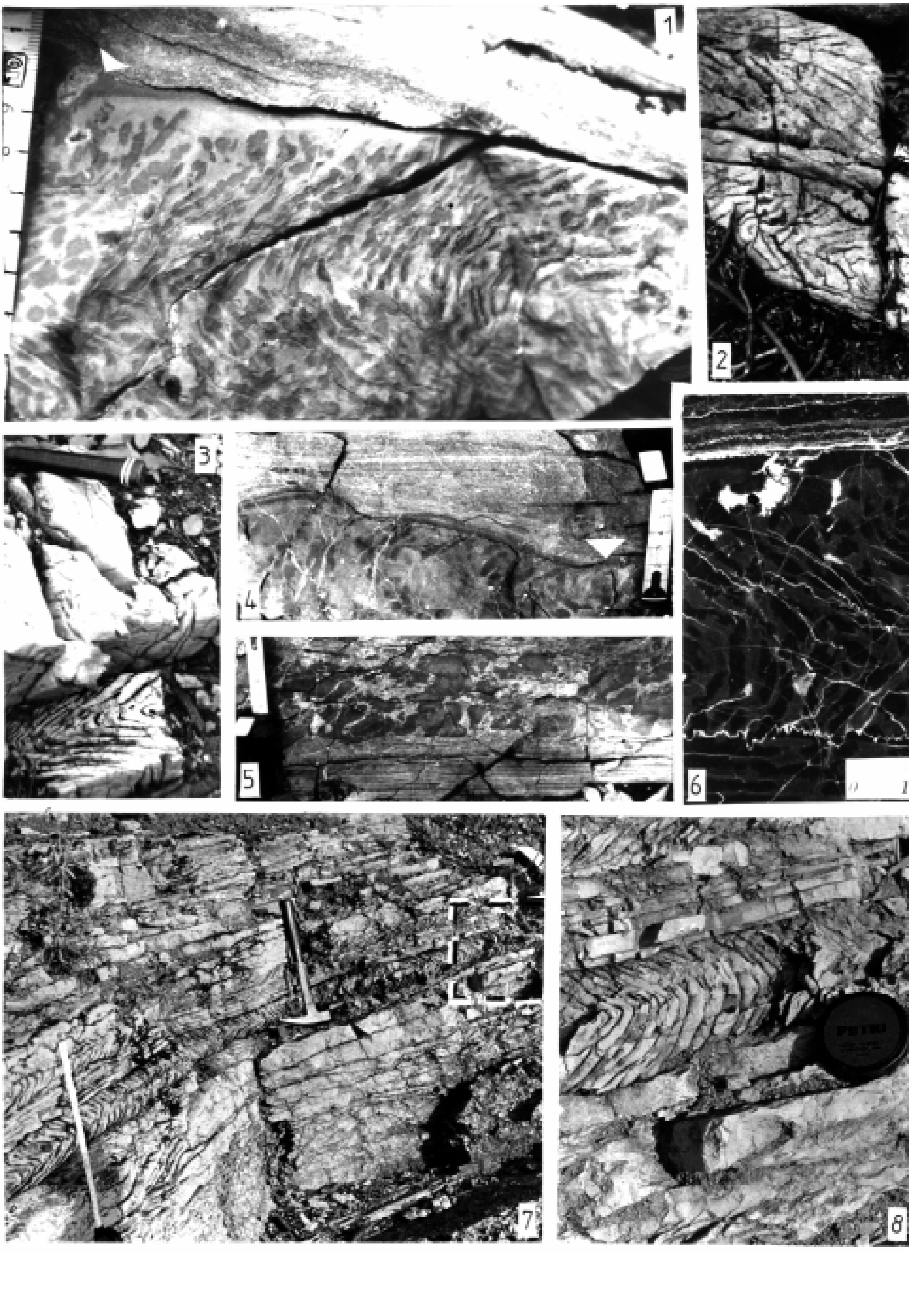
The Anisian morphology of Tethyan carbonate ramps was unique: the indicators of extremely shallow sedimentation were recorded in a belt several hundred kilometers wide and rimming all the Mediterranean shelf. Michalík (1993a–b, 1994) calculated the sedimentary rate in the northern, near-

→

Fig. 3. Channel filling facies in the layer 42, Oberheg section on Horný Vrch Hill, Malé Karpaty Mts. 1) more general view (upside down position), 2) detail of large limestone clast in the right part of the top figure, 3) clastic cycle with erosive base and limestone clasts (left part of the top figure).

Fig. 4. 1–6: Tsunamite layers in the Geldek Mb, Oberheg section: 1) "rope-ladder texture" in bed No. 42 and its contact (arrow) with the "tempestite", 2) couple of tsunamites in the bed No. 40, 3) weathered cross-section of the tsunamite in the bed No. 52, 4) erosional groove below the base of "tempestite" part (arrow) of the bed No 18), 5) bed No. 18 (all "tempestite" represented by breccia, 6) polished section of the bed No. 16. 7–8: Tsunamites from the Misina Formation, Mecsek Mts., Hungary (8 is a detail from the right side of the Fig. 4.7).


1
2
3


1
2
3
4
5
6
7
8

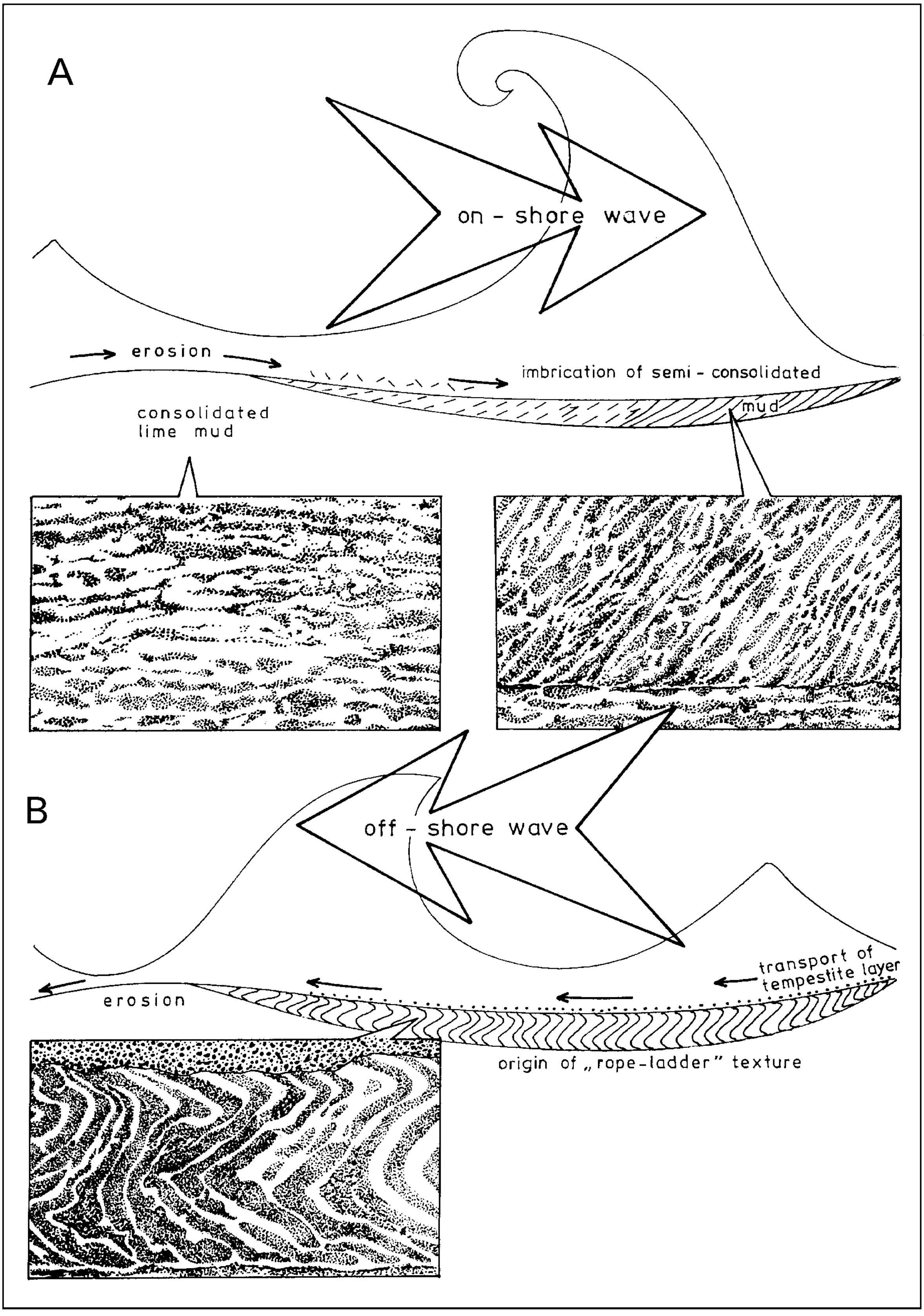


Fig. 5. Interpretative sketch, illustrating the origin of tsunamite bed. Above (A): imbrication of semi-consolidated sediment by the stroke of an on-shore tsunami wave, below (B): origin of "rope-ladder texture" by deformation evoked by the off-shore wave (see the text).

shore zones of the central Western Carpathians as 20–39 mm/Ka during Anisian (in comparision with the Scythian 5–20 mm/Ka). In these extensive marginal seas (800 thousand square kilometers in area according to the former author), tidal currents were hampered by the high friction of a thin water column above an extremely shallow bottom. On the other hand, Godbred & Hine (1985) argued that the storm-driven transport was especially important precisely in these microtidal, low-wave energy environments with low coast morphologies. Sageman (1996) also stressed the extremely low gradient of the basin floor, in which skeletal limestones of tempestite origin have developed. The mineralogy of the sediments indicates a hot climate with low precipitation. Liu & Fearn (1993) supposed the rise of hurricane activity (ca. 40–50 %) precisely during greenhouse warming of their model.

Wide nearshore flats have been affected both by large storm and tsunami waves. The mobility of the substratum causing occasional earthquakes was interpreted by Michalík (1994) as the result of the beginning of oblique rifting in the Penninic Zone. This process formed Ladinian tensional Reifling-type basins in the Alpine-Carpathian shelf (Michalík 1993a,b) and resulted in formation of the Jurassic/Cretaceous Penninic branch of the Mediterranean Tethys.

Finally, the tsunami events were well recorded by the lime ooze of the Gutenstein type only. The rate of diagenesis hampered by the clay and organic matter content allowed the semiconsolidated mud layer both to be liquefied by seismic shock and to preserve enough plastic "vermicular" lump bodies which recorded imbricated and sigmoidal textures. From this point of view, it is rather striking that the huge Cambrian/Ordovician carbonate ramp sequence near Dingjiatan and Qingbaikou (Western Beijing Hills) demonstrated in August 10-11th, 1996 during the 30th IGC, China (although developed in a "Gutenstein-like" facies with numerous tempestite intercalations) does not contain any "rope-ladder" beds.

Conclusions

The Anisian Vysoká Formation sequence is a good example of Middle Triassic sedimentation on an extensive carbonate ramp system along the northern Tethyan sea-shore. Thick-laminated to vermicular limestones deposited on a restricted offshore flats area contain grainstone and packstone intercalations of tempestite origin. These two contrasting lithologies indicate special climatic conditions on a wide shallow carbonate shelf. The monotonous thick sequence of thick-laminated and "vermicular" limestones seems to prove slight, relatively constant subsidence without any disturbing tectonic events. However, this assumption contrasts with the occurrence of tsunamite layers: grainstone/packstone layers similar to tempestites, which are accompanied by sigmoidal deformation ("rope-ladder structure") of underlying beds. These typical structures repeated occur in "Gutenstein-like" Mediterranean carbonates of Pelsonian age, recording the seismic activity of that age.

Their origin was connected with the start of oblique rifting in Paleo-European shelf which during the Jurassic/Cretaceous time led to the formation of the Penninic branch of the Tethys.

Acknowledgments: Author express his sincere thanks to Prof. Milan Mišík (Bratislava) and to Dr. M. Kázmér (Budapest) for their constructive critical comments. The participants of the 4th Shallow Tethys Symposium (Albrechtsberg, 1994) and these of the Symposium No. 15/3 in the 30th International Geological Congress (Beijing, 1996) are acknowledged for their stimulating discussions. The paper contributes to the Grant Project VEGA 4076 of the Slovak Academy of Sciences and to the activity of Subcommission on Triassic stratigraphy IUGS.

References

Ager D.V., 1974: Storm deposits in the Jurassic of the Maroccan High Atlas. *Palaeog., Palaeoclim., Palaeoecol.*, 15, 83–93.

Aigner T., 1977: Schalenpflaster im Unteren Hauptmuschelkalk bei Cralsheim (Württemberg, Trias, mo 1) — Stratinomie, Ökologie, Sedimentologie. *Neu. Jb. Geol. Paläont., Abh.*, 153, 2, 193–217.

Aigner T., Hagdorn H. & Mundlos R., 1978: Biohermal, biostromal and storm-generated coquinas in the Upper Muschelkalk. *Neu. Jb. Geol. Paläont., Abh.*, 157, 1, 52–52.

Aigner T., 1979: Schill-Tempestite im Oberen Muschelkalk (Trias, SW Deutschland). *Neu. Jb. Geol. Paläont., Abh.*, 157, 3, 326–343.

Aigner T., 1982: Calcareous tempestites: storm-dominated stratification in Upper Muschelkalk limestones (Middle Trias, SW Germany). In: Einsele G. & Seilacher A. (Eds.): *Cyclic to event stratification. Springer Verlag,* Berlin, 180–198.

Andrusov D., 1959: Geology of the Czechoslovak Carpathians, pt.II. *Edit. House of Slovak Academy of Sciences,* Bratislava, 1–375 (in Slovak).

Beck H. & Vetters H., 1904: Zur Geologie der Kleinen Karpathen, eine stratigraphisch-tektonische Studie. *Beitr. Paläont. Geol. Österr.-Ung. Orients,* 16, 1–2, 1–106.

Blendinger W., 1983: Anisian sedimentatiopn and tectonics of the Mt. Pore – Mt. Cernera area (Dolomites). *Riv. Ital. Paleont. Stratigr.*, 89, 2, 175–208.

Brenner R.L. & Davies D.K., 1973: Storm-generated coquinoid sandstone: Genesis of high-energy marine sediments from the Upper Jurassic of Wyoming and Montana. *Geol. Soc. Amer. Bull.,* 84, 1685–1698.

Catenacci V., 1976: Breve rassegna delle consequenze di alcuni eventi rari e catastrofici: processi recenti e attuali provocati da forti tempeste e da tsunamis. Implicazioni geologiche. *Studi Geol. Camerti (Camerino),* 2, 113–125.

Chudzikiewicz L., 1975: Intraformational conglomerates in the Gogolin Beds (Middle Triassic, southern Poland). *Roczn. Pol. Tow. Geol.*, 45, 1, 3–20.

Clague J.J. & Bobrowsky P.T., 1994: Tsunami deposits beneath tidal marshes on Vancouver Island, British Columbia. *Geol. Soc. Amer. Bull.,* 106, 1293–1303.

Coleman P.J., 1968: Tsunamis as geological agents. *J. Geol. Soc. Aust. (Sydney),* 15, 2, 267–273.

Dżuliński S. & Kubicz A., 1975: Storm accumulations of brachiopod shells and sedimentary environment of the "Terebratula Beds" in the Muschelkalk of Upper Silesia (southern Poland). *Roczn. Pol. Tow. Geol.*, 45, 2, 157–169.

Einsele G., Overbeck R., Schwarz H.U. & Unsold G., 1974: Mass physical properties, sliding and erodibility of experimentally deposited and differently consolidated clayey muds. Approach, equipment and first results. *Sedimentology (Oxford),* 21, 339–372.

Elrik M., 1996: Sequence stratigraphy and platform evolution of Lower – Middle Devonian carbonates, eastern Great Basin.

Geol. Soc. Amer. Bull., 108, 4, 392–416.

Galli G., 1990: Origin of event beds in the Jurassic "Calcari Grigi" Formation, Venetian Alps, Italy. *Geol. en Mijnb.,* 69, 375–390.

Goodbred S.L. & Hine A.C., 1995: Coastal storm deposition: salt marsh response to a severe extratropical storm, March 1993, west-central Florida. *Geology (Boulder),* 23, 8, 679–682.

Hayes M.O., 1967: Hurricanes as geological agents: case studies of Hurricanes Carla 1961, and Cindy, 1963. *Texas Bur. Econ. Geol. Rept. Invest*., 61, 1–54.

Hemphill-Haley E., 1995: Diatom evidence for earthquake-induced subsidence and tsunami 300 year ago in S coastal Washington. *Geol. Soc. Amer. Bull.,* 107, 3, 367–378.

Kasiński J., Czapowski G. & Gąsienica-Szostak M., 1978: Contemplations on the genesis of the "vermicular limestones". *Przegl. Geol*., 78, 3, 151–155.

Kastens K.A. & Cita M.B., 1981: Tsunami-induced sediment transport in the abyssal Mediterranean Sea. *Buletin Geol. Soc. Amer. (Baltimore),* 92, 845–857.

Katsura Y., Masuda F. & Obata I., 1984: Storm-dominated shelf sea from the Lower Cretaceous Choshi Group, Japan. *Ann. Rep. Inst. Geosci. Univ. Tsuk*., 10, 92–95.

Kimura G., Koga K. & Fujioka K., 1989: Deformed soft sediments at the junction between the Mariana and Yap Trenches. *J. Struct. Geol.,* 11, 4, 463–472.

Kotański Z., 1955: Middle Triassic vermicular limestones of the Tatric "series" in the Tatra Mts. *Acta Geol. Pol*., 5, 3, 343–362.

Lee Y.I., 1988: Storm sedimentation in the Middle Ordovician Duwibong Formation, southern Taebaeg City. *J. Geol. Soc. Korea (Seoul),* 24, 3, 234–242.

Lee Y.I. & Kim Ch.K., 1992: Storm-influenced siliciclastic and carbonate ramp deposits, the Lower Ordovician Dumugol Formation, South Korea. *Sedimentology (Amsterdam),* 39, 951–969.

Liu Kam-biu & Fearn M.L., 1993: Lake-sediment record of late Holocene hurricane activities from coastal Alabama. *Geology (Boulder),* 21, 793–796.

Maheľ M., 1961: Geology of the Malé Karpaty Mts. *Excursion Guide of the Slovak Geological Society, 12th Plenary Meeting,* Bratislava, 43–61 (in Slovak).

Major R.P., Bebout D.G. & Harris P.M., 1996: Recent evolution of a Bahamian ooid shoal: Effects of Hurricane Andrew. *Geol. Soc. Am. Bull. (Boulder),* 108, 2, 168–180.

Marco S. & Agnon A., 1995: Prehistoric earthquake deformations near Masada, Dead Sea graben. *Geology (Boulder),* 23, 8, 695–698.

McKee E.D., 1959: Storm sediments on a Pacific atoll. *J. Sed.. Petrology,* 29, 3, 354–364.

Michalík J., Masaryk P., Lintnerová O., Papšová J., Jendrejáková O. & Reháková D. , 1992: Sedimentology and facies of a storm-dominated Middle Triassic carbonate ramp (Vysoká Formation, Malé Karpaty Mts., Western Carpathians). *Geol. Carpathica,* 43, 4, 213–230.

Michalík J., 1993 a: Mesozoic tensional basins in the Alpine - Carpathian shelf.- *Acta Geologica Hung.,* 36, 4, 395–403.

Michalík J., 1993 b: Geodynamic and paleogeographic interpretation of development of Mesozoic tensional basins in the Alpine-Carpathian shelf. In: Rakús M. (Ed.): *Geodynamic model of the Western Carpathians. GÚDŠ,* Bratislava, 79–86 (in Slovak).

Michalík J., 1994: Notes on the paleogeography and paleotectonics of the Western Carpathian area during the Mesozoic. *Mitt. Österr. Geol. Gesell*., 86, 101–110.

Mišík M., 1983: Study of microfacies inf the Vysoká and Wetterstein limestones, the Malé Karpaty Mts. *MS, unpubl. report of the Natural Sci. Faculty, Comenius University,* Bratislava, 61–91 (in Slovak).

Munson P.J., Munson C.A. & Pond E.C., 1995: Paleoliquefaction evidence for a strong Holocene earthquake in south-central Indiana. *Geology (Boulder),* 23, 4, 325–328.

Nagy E., 1968: Triasbildungen des Mecsek Gebirges. *Magy. Áll. Földt. Intéz. Évk.* ,51, 1, 1–198.

Nelson A.R., Jennings A.E. & Kashima K., 1996: An earthquake history derived from stratigraphic and microfossil evidence of relative sea-level change at Coos Bay, southern coastal Oregon. *Geol. Soc. Amer. Bull. (Boulder),* 108, 2, 141–154.

Perkins R.D. & Enos P., 1968: Hurricane Betsy in the Florida – Bahama area : Geologic effects and comparison with hurricane Donna. *J. Geology (Boulder),* 76, 4, 710–717.

Phillips S., Bustin R.M. & Lowe L.E., 1994: Earthquake-induced flooding of a tropical coastal peat swamp: A modern analogue for high-sulfur coals ? *Geology (Boulder),* 22, 929–932.

Ramli N., 1986: Depositional model of a Miocene barred wave- and storm - dominated shoreface and shelf, southeastern Malay Basin, offshore West Malaysia. *AAPG Bull*., 70, 1, 34–47.

Rudowski S., 1986: Sedimentary environment at the barred coast of a tideless sea: southern Baltic, Poland. In: Gradziński R. (Ed.): *Results of sedimentological studies in Poland. Selected problems, pt.* 4. *Stud. Geol. Pol.,* 87, 5–76.

Rüffer Th. & Zühlke R., 1995: Sequence stratigraphy and sea-level changes in the Early and Middle Triassic of the Alps: a global comparison. Chapter 7. In: Haq B.U. (Ed.): *Sequence stratigraphy and depositional response to eustatic, tectonic and climatic forcing. Kluwer,* Amsterdam, 161–207.

Sageman Bradley B., 1996: Lowstand tempestites: Depositional model for Cretaceous skeletal limestones, Western Interior Basin. *Geology (Boulder),* 24, 10, 888–892.

Satterley A.K., 1996: The interpretation of cyclic successions of the Middle and Upper Triassic of the Northern and Southern Alps. *Earth Sci. Rev. (Amsterdam),* 40, 181–207.

Schieber J., 1987: Storm-dominated epicontinental clastic sedimentation in the Mid-Proterozoic Newland Fm, Montana, U.S.A. *Neu. Jb. Geol. Paläont. Mh*. 1987, 7, 417–439.

Schwarz H.U., 1975: Sedimentary structures and facies analysis of shallow marine carbonates (Lower Muschelkalk, Middle Triassic, SW Germany). *Contrib. Sedimentol. (Stuttgart),* 3,1–100.

Shinn Eugene A., Steinen R.P., Dill R.F. & Major R., 1993: Lime-mud layers in high-energy tidal channels: A record of hurricane deposition. *Geology (Boulder),* 21, 603–606.

Swift J.P., Hudelson P.M., Brenner R.L. & Thompson P.,1987: Shelf construction in a foreland basin: storm beds, shelf sandbodies, and shelf-slope depositional sequence in the Upper Cretaceous Mesaverde Group, Book Cliffs, Utah. *Sedimentology (Amsterdam),* 34, 423–457.

Vetters H., 1904: Die Kleinen Karpathen als geologisches Bindeglied zwischen Alpen und Karpathen. *Verh. K.-kön. Geol. Reichsanst. (Wien),* 5, 134–143.

Wright M.E. & Walker R.G., 1981: Cardium Formation (U. Cretaceous) at Seebe, Alberta: storm-transported sandstones and conglomerates in shallow marine depositional environments below fair - weather wave base. *Canad. J. Earth Sci*., 18, 795–809.

Zágoršek K., 1993: New Anisian (Middle Triassic) Bryozoa (Trepostomata) from the Vysoká Formation (Malé Karpaty Mts, Western Carpathians), Slovakia. *Geol. Carpathica* 44, 1, 49–58.