

High-resolution ammonite, belemnite and stable isotope record from the most complete Upper Jurassic section of the Bakony Mts (Transdanubian Range, Hungary)

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(Manuscript received November 9, 2010; accepted in revised form March 17, 2011)

Abstract: This research focuses on the cephalopod fauna and biostratigraphy of the latest Jurassic succession of the Lókút Hill (Bakony Mts, Transdanubia, Hungary). Fossils were collected bed-by-bed from Ammonitico Rosso facies and from the subsequent Biancone type rock. The poorly preserved cephalopods from the lowermost part of the profile, immediately above the radiolarite, may represent a part of the Oxfordian stage. The rich Kimmeridgian ammonite fauna is published for the first time while the formerly illustrated Tithonian fauna is revised. All the successive Kimmeridgian and Early Tithonian Mediterranean ammonite zones can be traced. The highest documented ammonite zone is the Late Tithonian *Microcanthum* Zone. The beds above yielded no cephalopods. Particular attention was paid to the belemnite fauna of over 120 specimens collected under strict ammonite control. Among the belemnite faunas an Early Tithonian, an early middle Tithonian, a late middle Tithonian, and a latest Tithonian assemblage can be distinguished. Thereby, an association is distinguished in the middle Late Kimmeridgian and one that characterizes the Oxfordian–Kimmeridgian boundary beds. The main difference from previously published belemnite data appears to be that the Hungarian assemblages are impoverished with respect to contemporary faunas from Italy and Spain (Mediterranean Province). An isotopic analysis of the belemnites show that the carbon-isotope data are consistent with carbon-isotope stratigraphies of the Western Tethys and show a decrease in values towards the Jurassic–Cretaceous boundary.

Key words: Late Jurassic, Hungary, Bakony Mts, biostratigraphy, Ammonitico Rosso, ammonites, belemnites, stable isotopes.

Introduction

Pelagic Jurassic to Cretaceous sediments are exposed close to the village of Lókút, Bakony Mts, Hungary. These rocks are rich in invertebrate macrofossils which were originally collected by a team from the Geological Institute of Hungary, in the early 1960s. The collection work was supervised by the late Prof. József Fülöp. Among the macrofossils of the Lókút profile belemnites were collected, but have remained unstudied until now. A biostratigraphical framework is provided for the Tithonian by ammonites (Vigh 1984) which is revised and updated in this paper. More recently Grabowski et al. (2010) provided a stratigraphical scheme based on magneto- and calpionellid-stratigraphy.

The aim of this study is: (a) to provide an accurate and updated biostratigraphy for the ammonite rich Upper Jurassic (?Oxfordian–Tithonian) part of the Lókút section, (b) to document the diverse belemnite fauna, as no belemnites were previously described from this stratigraphic interval from Hungary, and (c) to perform oxygen and carbon isotope analyses on belemnite calcite to compare with the biostratigraphical data and with previously published isotope curves. Belemnites were studied and described by Nico M.M. Janssen, István Fözy summarized ammonite biostratigraphy,

while isotope analyses and interpretations were undertaken by Gregory D. Price.

Geological setting

The studied section is situated in the south-western part of the central Bakony Mts, about 600 meters from the village of Lókút, on the south-western edge of the Lókút Hill (Fig. 1). The outcrop is in the Transdanubian Range, representing a part of the Bakony Unit in the Austroalpine part of the AICAPA (Alpine–Carpathian–Pannonian) composite terrain (Csontos & Vörös 2004). Lókút Hill is an exceptional place, where 7 of the 11 Jurassic stages are represented by means of macrofossils (mainly ammonites). The succession of the Lókút Hill is the most complete and thickest Jurassic succession of Transdanubia, deposited in a deep, pelagic environment, within a “horst and graben” context (Galács & Vörös 1972). The Hettangian–Bajocian rocks are exposed in a long artificial trench and in a pit on the southern part of the hill (Galács 1975; Géczy 1976). The Upper Jurassic succession, which is in the focus of our study, is exposed in a shallow, 20 meter long artificial trench on the southern slope of the Lókút Hill. The geographical coordinates for the section are

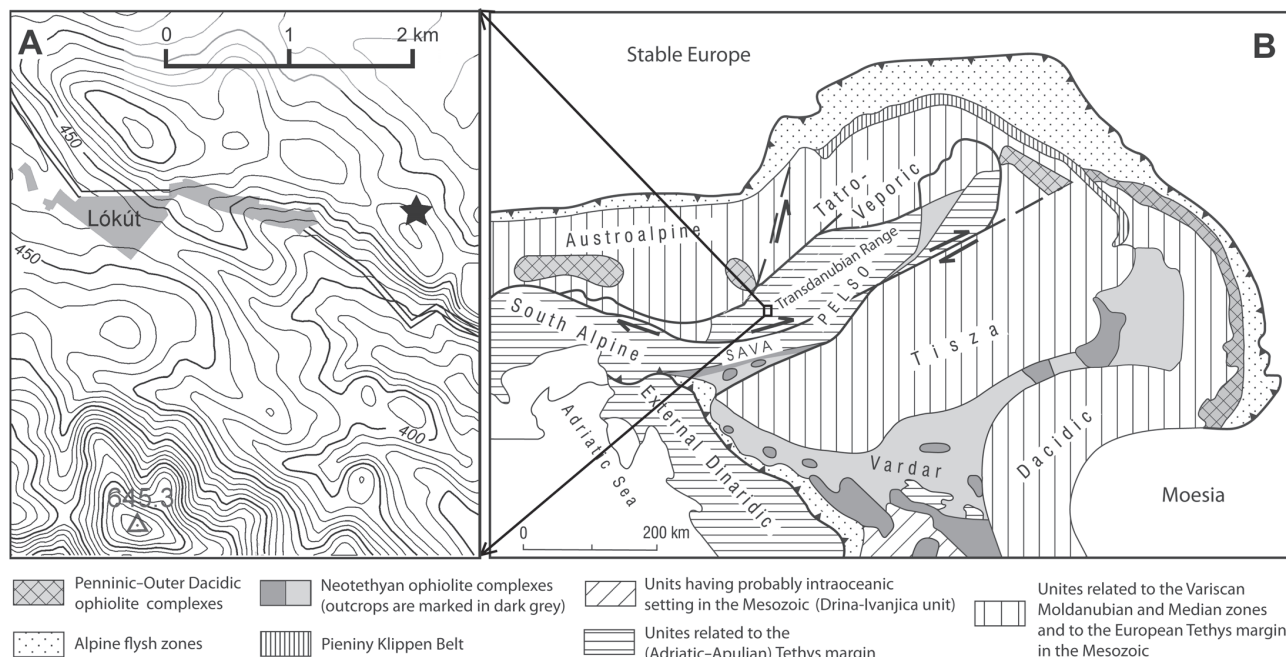


Fig. 1. The geographic (A) and tectonic position of the Lókút section (B). The location of the studied profile is marked by an asterisk. Map 'B' is modified Haas et al. (2006) showing the structural units of the pre-Cenozoic basement of the Pannonian Basin and the surrounding mountain ranges.

47°12'17"N, 17°52'56"E. Strata dip to north with mean orientation 360°/20°.

In the lowermost part of the section the cherty Lókút Radiolarite Formation crops out. This is succeeded by 0.1 m of light red-brown clay, followed by a light red-brown cherty limestone. The following few meters consist of red and yellowish, thick-bedded nodular limestone (the Pálhálás Limestone Formation), which passes continuously into light grey coloured, less nodular ammonite rich facies (the Szentivánhegy Limestone Formation). The uppermost part of the profile is formed by the white, thin-bedded, Biancone type limestone (of the Mogyórsdomb Limestone Formation), which continuously develops from the underlying formation. No sharp boundaries between the three carbonate formations are apparent. A brief description of the above-mentioned lithostratigraphical units are given in Császár (1997).

Stratigraphy

The cephalopods were gathered in 1962–1964. Because the original field notes are lost, the only available information on the sampling are the bed numbers written on the labels for each fossil and the thickness data of the beds in Vigh (1984). Vigh published the Tithonian ammonites of the section and also noted the presence of the Kimmeridgian strata. No details of the Kimmeridgian were, however, provided by Vigh (1984). Although it is not known exactly where the Bed 1 was placed in the section by Vigh (1984) as no obvious marker bed exists to anchor the succession, we were able to reconstruct the bed numbering after re-examination of the succession and comparing thickness, lithology and fossil

content. Furthermore, we have recently resampled a number of horizons of the section to gather further ammonite data.

Grabowski et al. (2010), recently published magneto- and biostratigraphical schemes of the upper part of the section. They were able to recognize magnetochrons M21r through to 18r spanning the Jurassic-Cretaceous boundary. They also undertook calpionellid studies and on this basis they assigned the uppermost 4.5 meters of the section to the Berriasian. Consequently the studied part of the Lókút profile represents a succession spanning the ?Late Oxfordian–Kimmeridgian to earliest Berriasian.

Cephalopod fauna

Ammonites were preserved as only internal moulds throughout the section. As the fauna consists of solely Mediterranean (Tethyan) elements, the zonation scheme of Enay & Geyssant (1975) and Olóriz (1978) was used. Vigh (1984) described only the Tithonian part of the ammonite succession. In this paper we not only re-evaluate his data, but we also give details on the possible Late Oxfordian and on the Kimmeridgian fauna as well. The stratigraphic distribution of the most characteristic ammonites is given in Table 1.

The belemnite material studied is of varying quality. Many belemnites appear to be incomplete or fragmentary, probably as a result of the rigidity of the host rocks. In the reddish coloured ?Oxfordian–Kimmeridgian part (Beds 68 to 77) belemnites appear to be partially corroded. The stratigraphic distribution of the belemnites is given in Table 2.

The Tithonian cephalopods from the Lókút section are deposited in the Museum of the Hungarian Geological Insti-

Table 1: Distribution of the diagnostic Late Jurassic ammonites in the Lókút section. Phylloceratids and lytoceratids are not indicated. *Haploceras elimatum* and related microconch forms (*H. carachtheis* and associated species), although common throughout the Tithonian, are also not shown. (Haplocer. — Haploceratidae; H. — Himalayitidae.)

Stage			Haplocer.	Oppeliidae	Simoceratidae	Aspidoceratidae	Perisphinctidae	H.
Substage								
Ammonite Zone								
Bed number								
Haploceras verruciferum (Zittel, 1869)								
Haploceras cassiferum Fözy, 1988								
Pseudosiphonoceras olórizi Fözy, 1989								
Streblites cf. fenulobatus (Oppel, 1863)								
Neocheiloceras sp.								
Taramelliceras sp.								
Taramelliceras strombecki (Oppel, 1873)								
Taramelliceras trachinotum (Oppel, 1863)								
Taramelliceras compsum (Oppel, 1863)								
Hemihaploceras nobile (Neumayr, 1873)								
Hemihaploceras schwageri (Neumayr, 1871)								
Nebroditis teres (Neumayr, 1871)								
Nebroditis cf. calisii (Gemmellaro, 1876)								
Nebroditis agrigentus (Gemmellaro, 1876)								
Nebroditis cf. helmi (Favre, 1877)								
Nebroditis cavouri (Gemmellaro, 1872)								
Nebroditis spp.								
Lessinicerias martirei Sarti, 1993								
Trenarites cf. enayi Sarti, 1993								
Trenarites cf. evolutus (Gemmellaro, 1876)								
Presimoceras sp.								
Virgatolimoceras cf. albertinum (Catullo, 1865)								
Virgatolimoceras dunali Scherzinger et al, 2010								
Virgatolimoceras sp.								
Volanoceras aesiense (Meneghini, 1885)								
Volanoceras perarmatiforme (Schauroth, 1865)								
Simolytoceras volanensoides (Vigh, 1984)								
Simolytoceras sp.								
Simoceras aff. admirandum Zittel, 1868								
Simoceras admirandum Zittel, 1868								
Simoceras strictum (Catullo, 1846)								
Simosiphonoceras lojense Olóriz et Tavera, 1977								
Eusiphonoceras sp.								
Orthaspidoceras sp.								
Physodoceras wolffi (Neumayr, 1873)								
Physodoceras altense (d'Orbigny, 1847)								
Physodoceras avelanum (Zittel, 1869)								
Physodoceras neoburgense (Oppel, 1863)								
Physodoceras sp.								
Aspidoceras rogoznicensis Zeuschner, 1868								
Aspidoceras rafaelli (Oppel, 1863)								
Aspidoceras sp.								
Pseudohimalayites kondai Vigh, 1984								
Pseudowaagenia acanthomphala (Zittel, 1870)								
Pseudowaagenia sp.								
Hybonotoceras cf. knopi (Neumayr, 1873)								
Hybonotoceras pressulum (Neumayr, 1871)								
Hybonotoceras cf. hybonotum (Oppel, 1863)								
Hybonotoceras sp.								
Katolliceras sp.								
Progonia spp.								
Trapanasites adelus (Gemmellaro, 1872)								
Pseudosimoceras stenonis (Gemmellaro, 1876)								
Subdichotomoceras pseudocobrinus (Kilian, 1889)								
Ataxioceras sp.								
Parapallasiceras sp.								
Discosphinctoides rhodaniforme Olóriz, 1978								
Discosphinctoides sp.								
"Pseudodiscosphinctes" chalmasi (Kilian, 1889)								
Subplanitoides sp.								
Lemencia cf. perigrata (Schneid, 1914)								
Lemencia sp.								
Olorziceras sp.								
Paraulacosphinctes sp.								
Moravosphinctes moravicus (Oppel, 1865)								
Micracanthoceras spp.								
TITHONIAN								
Upper Tithonian								
Microcanthum								
Fallauxi								
Lower Tithonian								
Semiforme								
Darwini								
Hybonotoceras								
KIMMERIDGIAN								
Upper Kimmeridgian								
Beckeri								
Comp. sc.								
L. Kim.								
P. sc.								
Oxfordian								

Table 2: Distribution of the Late Jurassic belemnites from Lókút section.

Stage	TITHONIAN										Mesohibolitidae	Duvaliidae	Success.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
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OXF.	L. Kim.	P	S	D	Comp.	C.	Beckeri	Hybon.	Darwini	Semiforme	Fallauxi	Po.	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228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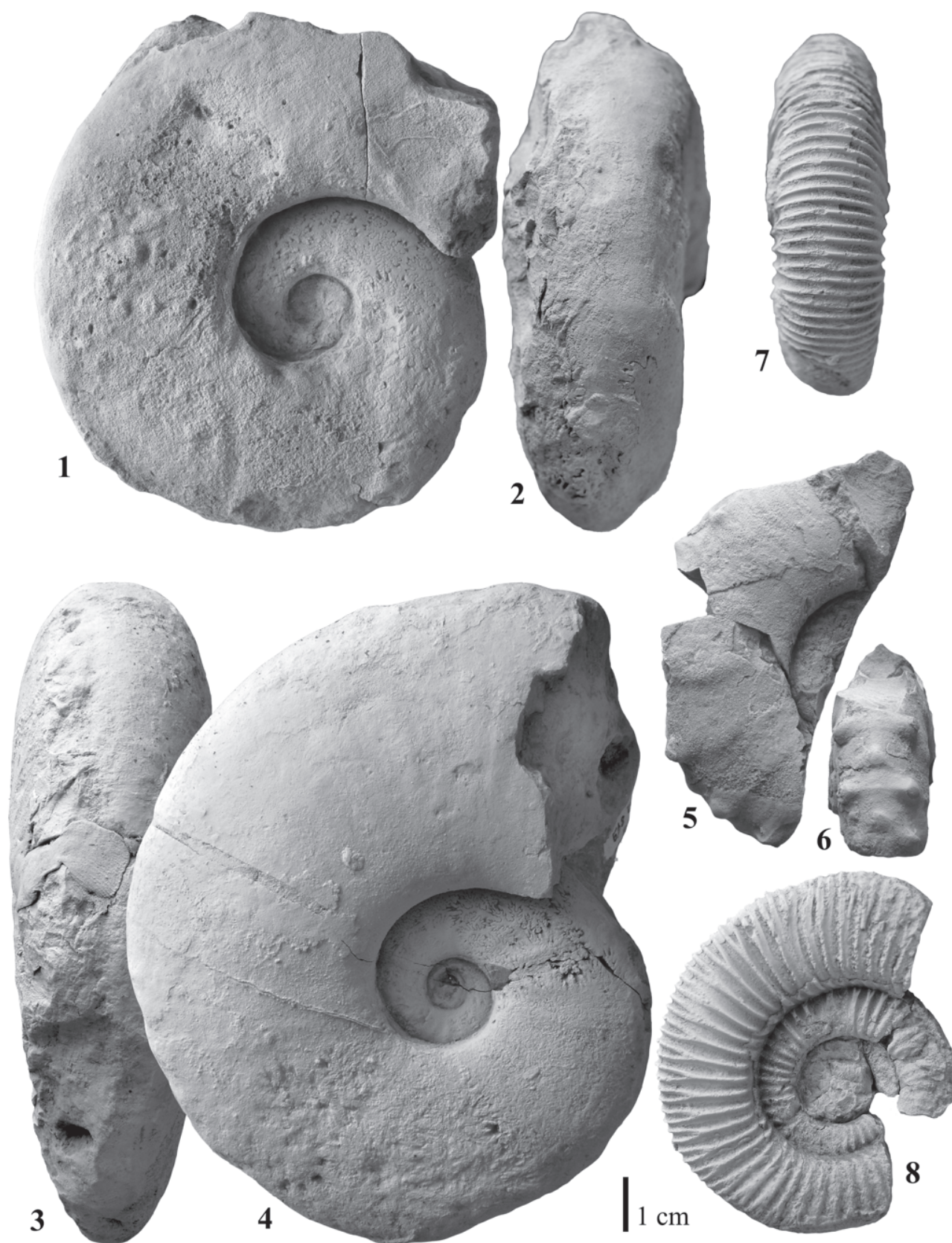


Fig. 2. Representative Kimmeridgian ammonites from the Lókút section. **1, 2** — *Physodoceras wolfi* (Neumayr, 1873) (Inventory number: M 92 852) Bed 75; **3, 4** — *Tarmelliceras strombecki* (Oppel, 1858) (M 92 879) Bed 73; **5, 6** — *Hemihaploceras schwageri* (Neumayr, 1873) (M 82 931) Bed 68; **7, 8** — *Trapanesites adelus* (Gemmellaro, 1872) (M 92 886) Bed 68.

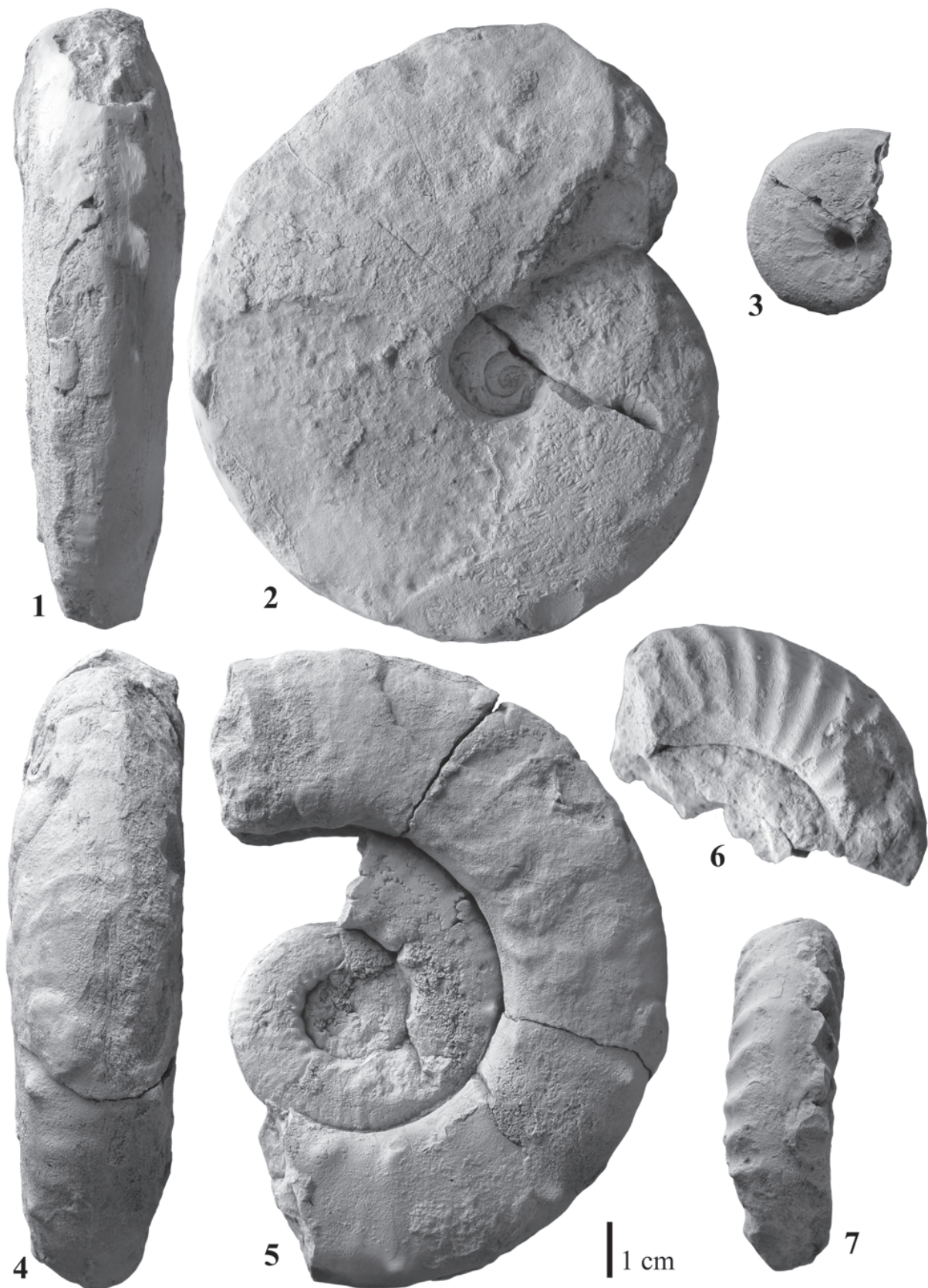


Fig. 3. Representative Kimmeridgian ammonites from the Lókút section. **1, 2** — *Taramelliceras compsum* (Oppel, 1863) (Inventory number: M 92 888) Bed 68; **3** — *Streblites* cf. *tenuilobatus* (Oppel, 1863) (M 92 1097) Bed 73; **4, 5** — *Pseudowaagenia acanthomphala* (Zittel, 1870) (M 92 1131) Bed 65; **6, 7** — *Trenerites* cf. *evolutus* (Gemmellaro, 1876) (M 92 958) Bed 73.

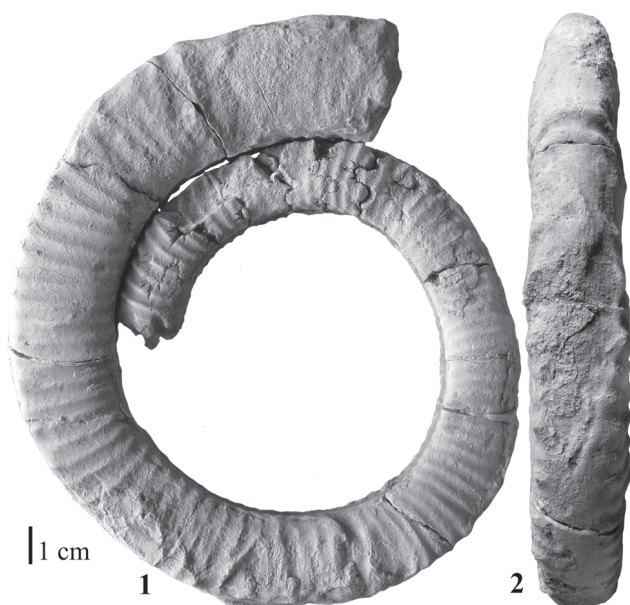


Fig. 4. A representative Kimmeridgian ammonite from the Lókút section. 1, 2 — *Nebroditites cavouri* (Gemmellaro, 1872) (M 92 1247) Bed 69.

Among the Kimmeridgian belemnites Mesohibolitidae are most abundant but overall belemnites are rather rare, apparently being restricted to the earliest Kimmeridgian and the middle part of the Late Kimmeridgian. The middle Late Kimmeridgian beds contain both Duvaliidae and Mesohibolitidae. As Late Kimmeridgian duvaliid belemnites are not known yet, the fauna is of particular interest. Unfortunately, the material is not well preserved and rather incomplete, hampering any certain specific determination. The earliest Kimmeridgian delivered a more abundant and diverse fauna. Here Mesohibolitidae (*Acutibelus*, *Hibolithes* and *Subulibelus*?) are clearly most abundant but some duvaliids do occur too (*Produvalia* aff. *nicosiai*).

Tithonian

The upper 61 beds of the red, nodular limestone, which become lighter coloured, nearly white up sequence, represent the Tithonian stage. All of the Early Tithonian ammonite zones were recognized, while the Late Tithonian is represented by the Microcathum Zone only. No younger cephalopods were found in Lókút.

Among phylloceratids, *Ptychophylloceras* (especially *P. ptychoicum*) is the most common. Lytoceratids, like the medium sized *Protetragonites* are also abundant, however bigger forms (*Lytoceras* and its allies) are common too. With respect to the Ammonitina, the genus *Haploceras* (especially *H. elimatum* and associated forms) is very frequent. It makes up 23 % of the whole Tithonian fauna (Vigh 1984). The stratigraphy is based on more than 70 ammonite specimens, which are indicated on Table 1.

The lower part of the Tithonian succession contains some poorly preserved fragments of perisphinctids and aspidoceratids, including thickly ribbed *Hybonotoceras*, indicating the

base of the lowermost Tithonian Hybonotum Zone (Beds 58–61). The presence of *Virgatosimoceras* cf. *albertinum* in Bed 61 is somewhat controversial. The specimen (figured by Scherzinger et al. 2010: fig. 5.2) is thought to be characteristic for the subsequent Darwini Zone (= Albertinum Zone in Olóriz 1978). This zone is represented by Beds 54–57, which also yielded a rather poor fauna, mainly of perisphinctids and aspidoceratids. The base of the zone was drawn by the appearance of *Haploceras cassiferum*. This ammonite, which is often regarded as a macroconch of *H. verruciferum*, (Cecca & Enay 1991), the characteristic ammonite of the subsequent ammonite zone (Semiforme/Verruciferum), is however often found, below the Semiforme Zone. The middle Tithonian Semiforme, Fallauxi and Ponti Zones were documented on the basis of diagnostic haploceratids, aspidoceratids, and simoceratids. The base of the Semiforme Zone (Beds 45–53) is marked by the simultaneous appearance of *H. verruciferum* and *Volanoceras aesinense*. The zonal index was found only in debris. Densely ribbed *Discosphinctoides rhodaniforme*, *Pseudohimalayites* and *Virgatosimoceras* are also present and characteristic. The latter is represented by a recently described species (*V. dunaii*) which fills the gap between the earlier known older and younger chronospecies (Scherzinger et al. 2010). The subsequent Fallauxi Zone (Beds 27–44) contains a diverse simoceratid fauna which clearly indicate the presence of the upper part of the zone (Biruncinatum/Admirandum Subzone). *Simoceras admirandum* and allied forms are relatively frequent, while typical *Simoceras biruncinatum* was not found in Vigh's collection. It was gathered only during our recent collecting work. The lower part (Richter Subzone) cannot be documented by means of ammonites. Fragments of the large sized simoceratid (*Volanoceras perarmatifforme*) already mark the Ponti Zone (Beds 24, 25). Beds above yielded a moderately diverse fauna, including rare *Simospiticeras* and some specimens of *Moravispinctes* and *Paraulacosphinctes*. Some of the stratigraphically important Tithonian ammonites are illustrated on Figs. 5, 6.

On the basis of the distribution of the belemnites the Tithonian sediments can be divided into four belemnite assemblages. The base of the Tithonian is characterized by “*Pseudobelus*” *zeuschneri* while *Hibolithes semisulcatus* is common. This low relative diversity assemblage is called TiBA-I and encompasses the Beds 55 to 61. According to the accompanying ammonites this assemblage corresponds to the *Hybonotoceras hybonotum* and the *Semiformiceras darwini* Zones. The next belemnite assemblage (TiBA-II; Beds 41 to 46) yields *Duvalia ensifer* and *Conobelus strangulatus*. It is found in the top of the *Semiformiceras semiforme* Zone and the base of the *Semiformiceras fallauxi* Zone. *Duvalia* cf. *abeli* and common *H. semisulcatus* further characterize this assemblage. “*Pseudobelus*” ex gr. *zeuschneri* and *Hibolithes conradi* occur in the latest *Semiformiceras fallauxi* Zone (*Simoceras admirandum* Subzone) to *Micracanthoceras microcanthum* Zone. This part encompasses the Beds 16 to 32 and can be divided into two successive belemnite assemblages (TiBA-III and IV; Table 2). TiBA-III furthermore yields *Hibolithes* cf. *fellabrunnensis*, *Duvalia* cf. *esba*? and the last *Hibolithes semisulcatus*. TiBA-IV yields *Hibolithes conradi*, “*Duvalia*” *tithonia* and the last “*Pb.*” ex gr. *zeuschneri*.

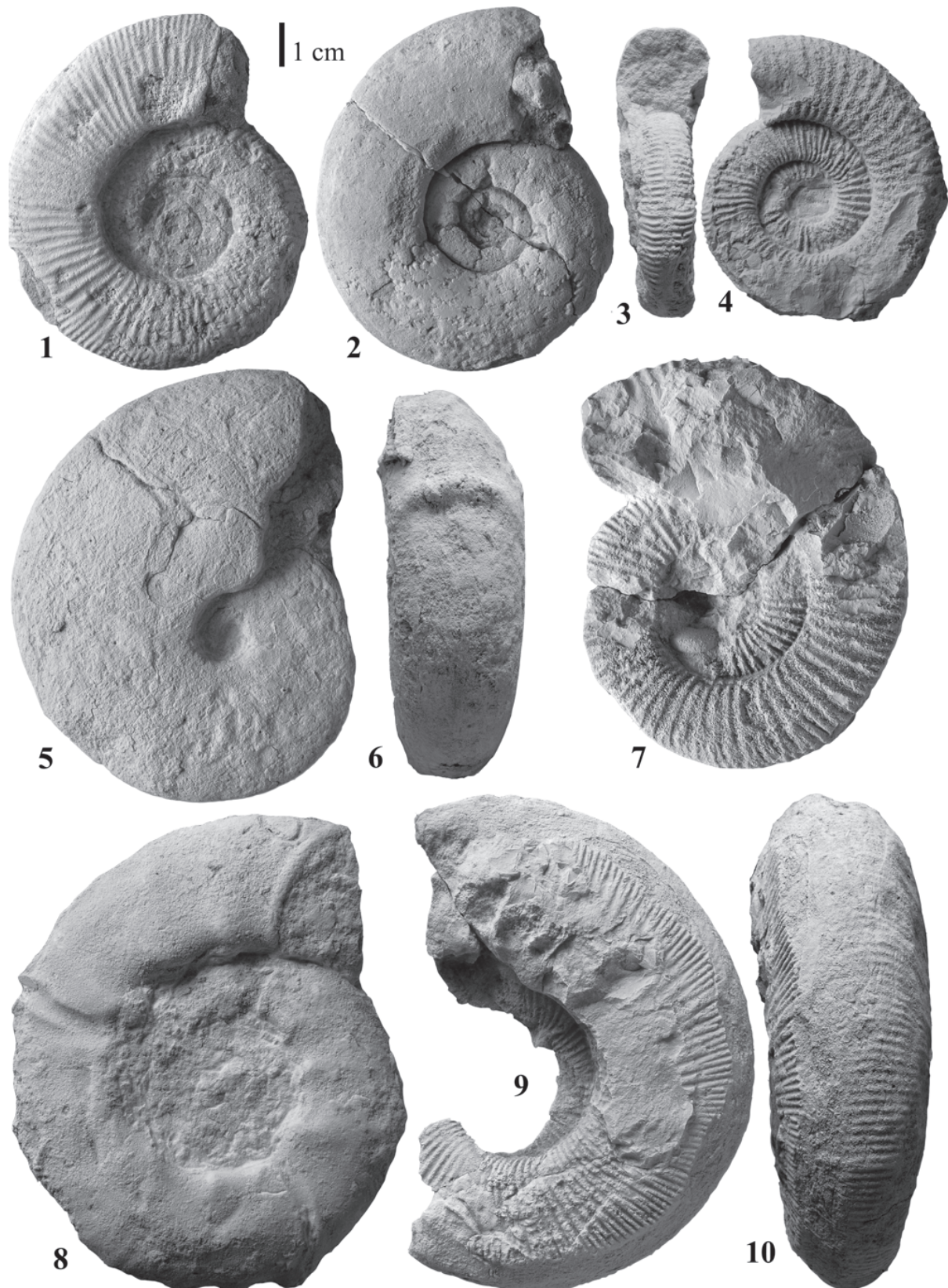


Fig. 5. Representative Tithonian ammonites from the Lókút section. **1** — *Lemencia* cf. *pergrata* (Schneid, 1914) (J 10.60.1) Bed 38; **2** — *Pseudolissoceras olorizi* Fözy, 1988 (J 9769) Bed 54; **3, 4** — *Paraulacosphinctes* sp. (J 10.61.1) Bed 20; **5** — *Neochetoceras* sp. (J 10879) Bed 43. **6** — *Haploceras cassiferum* Fözy, 1988 (J 10.63.1) Bed 57; **7** — *Subplanitoides* sp. (J 10.62.1) Bed 44; **8** — *Simospitoceras lojense* Olóriz & Tavera, 1977, (J 10.64.1) Bed 10; **9, 10** — *Discosphinctoides rhodaniforme* Olóriz, 1978 (J 10.65.1) Bed 53.



Fig. 6. Representative Tithonian ammonites from the Lókút section. **1, 2** — *Semiformiceras semiforme* (Oppel, 1865) (Inventory no: J 10.54.1) from loose; **3** — *Volanoceras perarmatiforme* (Schrauroth, 1865) (J 10.55.1) Bed 26; **4** — *Volanoceras aesinense* (Meneghini, 1885) (J 9778) Bed 53; **5** — *Simolytoceras* sp. (J 10.56.1) Bed 24; **6, 7** — *Orthaspidoceras* sp. (J 10.57.1) Bed 54; **8, 9** — *Physodoceras neoburgense* (Oppel, 1863) (J 10.58.1) Bed 55; **10, 11** — *Hybonoticeras hybonotum* (Oppel, 1863) (J 10.59.1) Bed 59.

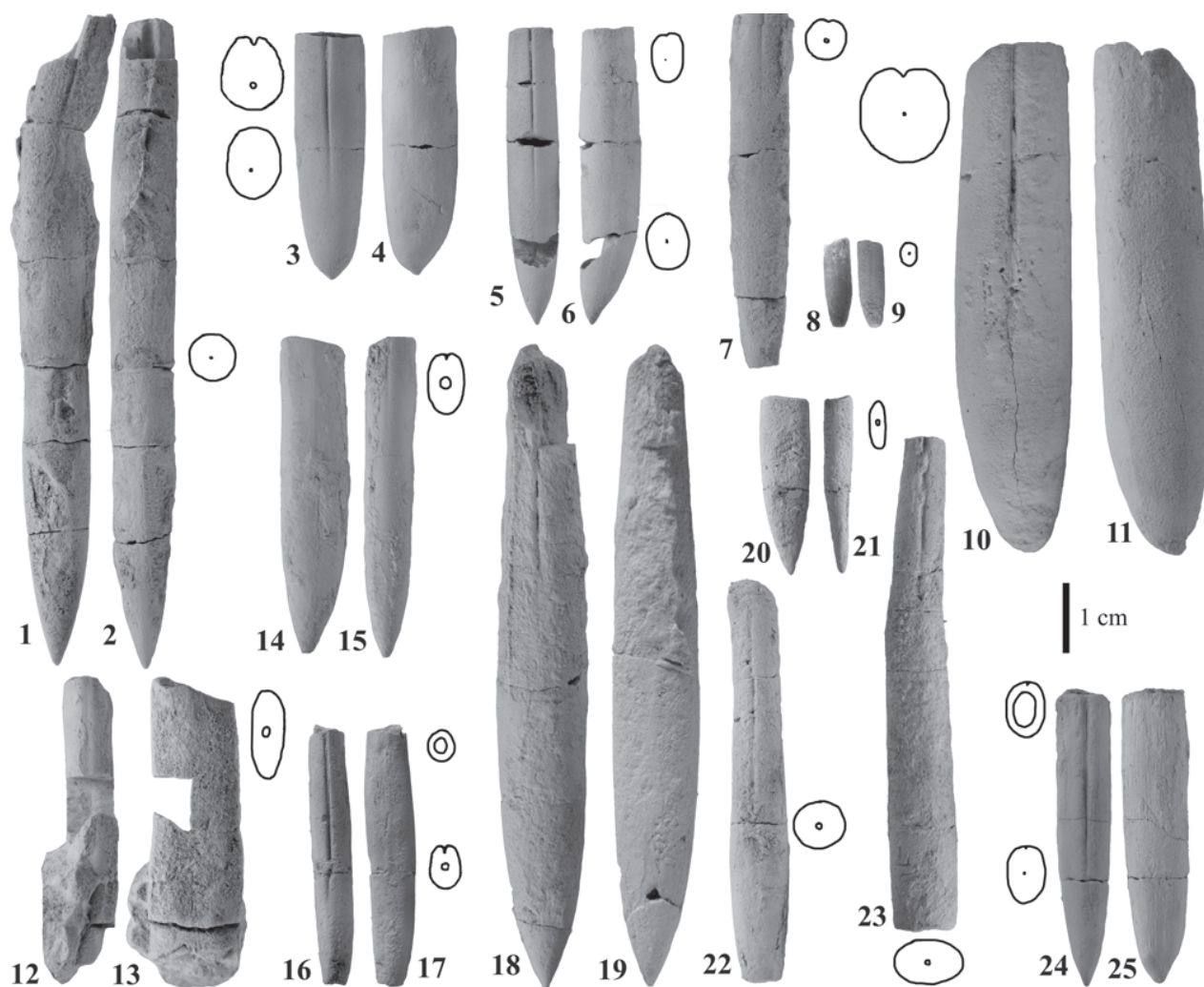


Fig. 7. Representative Tithonian belemnites from the Lókút section. **1, 2** — *Hibolithes* ex gr. *semisulcatus* (Münster, 1830) (Inventory no: J 10.1.1) Bed 46; **3, 4** — *Conobelus strangulatus* (Oppel, 1865) (J 10.2.1) Bed 41; **5, 6** — “*Pseudobelus*” ex gr. *zeuschneri* (Oppel, 1865) (J 10.3.1) Bed 32; **7** — *Hibolithes* cf. *fellabrunnensis* (Vetters, 1905) (J 10.4.1) Bed 32; **8, 9** — “*Pseudobelus*” *zeuschneri* (Oppel, 1865) juv. (J 10.5.1) Bed 61; **10, 11** — *Hibolithes conradi* Kilian, 1889 (J 10.6.1) Bed 24; **12, 13** — *Duvalia* cf. *abeli* (Vetters, 1905) (J 10.7.1) Bed 46; **14, 15** — *Duvalia ensifer* (Oppel, 1865) (J 10.8.1) Bed 45; **16, 17** — “*Pseudobelus*” *zeuschneri* (Oppel, 1865) (J 10.5.2) Bed 61; **18, 19** — *Hibolithes semisulcatus* (Münster, 1830) (J 10.9.1) Bed 25; **20, 21** — *Duvalia* cf. *esba* (de Gregorio, 1885) (J 10.10.1) Bed 32; **22** — *Hibolithes* ex gr. *semisulcatus* (Münster, 1830) (J 10.11.1) Bed 45; **23** — *Hibolithes* ex gr. *semisulcatus* (Münster, 1830) (J 12.12.1) Bed 58; **24, 25** — “*Pseudobelus*” *zeuschneri* (Oppel, 1865) (J 10.13.1) Bed 58.

Three of the four assemblages are separated by beds that apparently contain virtually no belemnites, the Beds 47 to 54 and the Beds 33 to 40. So do the Beds 62 to 67 that separate the first Tithonian assemblage from the very condensed beds that contain ?Oxfordian–Kimmeridgian cephalopods. Some of the Tithonian belemnites from Lókút are illustrated in Fig. 7.

Stable isotopes

Methodology

Stable isotopes were determined on a VG Instruments Optima Isotope Ratio Mass Spectrometer with a Multiprep Auto-

mated Carbonate System (at the University of Plymouth) using 200 to 300 micrograms of carbonate. Isotopic results were calibrated against NBS-19. Reproducibility for both $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ was better than $\pm 0.1\text{‰}$, based upon multiple sample analysis. All belemnite samples were analysed additionally for trace element contents to evaluate diagenetic alteration. Thin section analysis in conjunction with trace element analysis was used to determine the state of preservation of each of the fossil types examined. Prior to chemical and isotopic analysis, areas of each belemnite deemed most susceptible to diagenetic alteration, principally the exterior of each shell were removed. The remains were fragmented, washed in ultra pure water and dried in a clean environment. Fragments were subsequently picked under a binocular microscope to secure those judged to be best

Table 3: Isotopic and elemental compositions of belemnite rostra from Lókút.

Belemnite species	Bed number	$\delta^{13}\text{C}$ (PDB)	$\delta^{18}\text{O}$ (PDB)	Ca (ppm)	Fe (ppm)	Mg (ppm)	Mn (ppm)	Sr (ppm)
<i>Hibolites</i> cf. <i>conradi</i> *	Bed 16	0.9	1.4	371684	100	1890	64	240
<i>Duvalia tithonia</i>	Bed 18	-1.7	-1.5	355032	60	2026	29	1049
<i>H.</i> cf. <i>conradi</i>	Bed 18	-1.8	-0.9	359047	109	2317	20	972
<i>Pseudobelus</i> ex.gr. <i>zeuschneri</i>	Bed 21	-1.0	-0.2	350100	17	1799	5	895
<i>Belemnites</i> sp.*	Bed 21	-0.3	-1.8	391288	68	1384	33	234
<i>H.</i> cf. <i>conradi</i> *	Bed 22	1.4	-0.4	356897	23	1615	26	270
<i>Hibolites</i> sp.*	Bed 23	0.6	-1.2	385583	195	1963	179	208
<i>H.</i> cf. <i>conradi</i>	Bed 24	-1.6	-1.3	351484	26	2567	11	1055
<i>Hibolites</i> sp.*	Bed 24	1.2	-2.6	361603	67	1993	140	525
<i>Pseudobelus</i> ex.gr. <i>zeuschneri</i>	Bed 25	-2.3	-2.9	353975	44	2151	24	898
<i>H.</i> cf. <i>semisulcatus</i> *	Bed 25	-1.9	-2.2	349514	23	2231	104	794
<i>H.</i> cf. <i>semisulcatus</i> *	Bed 30	-0.8	0.4	359052	53	2758	125	1002
<i>Pseudobelus</i> ex.gr. <i>zeuschneri</i>	Bed 32	-1.2	-0.9	351008	18	1860	10	955
<i>Hibolites</i> sp.	Bed 32	-0.8	-1.1	362398	29	2431	9	995
<i>H.</i> cf. <i>fellabrunnesis</i>	Bed 32	-0.6	-1.3	362530	32	2503	26	864
<i>Duvalia</i> cf. <i>ensifer</i> *	Bed 32	0.4	0.4	388057	87	1939	591	470
<i>H.</i> cf. <i>semisulcatus</i>	Bed 35	-1.4	-1.6	361858	22	2525	18	1119
<i>Hibolites semisulcatus</i> *	Bed 40	-1.2	-2.4	361213	72	1601	368	484
<i>Conobelus</i> cf. <i>strangulatus</i> *	Bed 42	-1.0	-1.4	348063	293	1936	435	482
<i>H.</i> cf. <i>semisulcatus</i> *	Bed 42	0.8	-1.2	349304	73	1933	69	536
<i>Hibolites</i> sp.	Bed 43	-1.8	-2.2	365793	41	1861	20	1020
<i>Duvalia</i> cf. <i>ensifer</i>	Bed 44	-0.2	-0.1	358767	93	2004	14	908
<i>Conobelus</i> cf. <i>strangulatus</i> *	Bed 44	-0.8	-1.7	344693	121	1937	111	860
<i>Hibolites</i> cf. <i>semisulcatus</i> *	Bed 44	-0.4	-1.1	328534	136	2240	248	801
<i>Duvalia ensifer</i> *	Bed 45	-3.2	-2.1	365216	82	1365	115	334
<i>Conobelus</i> cf. <i>strangulatus</i> *	Bed 45	0.0	-1.0	358167	61	2255	734	690
<i>Duvalia ensifer</i> *	Bed 45	1.3	-0.8	363919	493	2585	134	442
<i>Hibolites</i> sp.*	Bed 45	-0.8	-0.9	355709	19	2253	99	939
<i>Hibolites semisulcatus</i> *	Bed 45	1.3	-0.7	331695	152	2015	55	680
<i>Hibolites semisulcatus</i>	Bed 46	-0.7	-1.1	339289	14	2286	11	771
<i>Conobelus</i> cf. <i>strangulatus</i>	Bed 46	-1.5	-1.2	351746	31	2166	19	1016
<i>H.</i> cf. <i>semisulcatus</i>	Bed 46	-0.9	-1.2	329436	34	2030	42	955
<i>Conobelus</i> cf. <i>strangulatus</i> *	Bed 46	-1.5	-0.1	343629	61	1792	68	996
<i>Duvalia</i> cf. <i>abeli</i> *	Bed 46	1.9	-1.2	347496	318	2163	118	215
<i>Duvalia</i> cf. <i>ensifer</i> *	Bed 46	-1.2	-0.4	362948	24	1738	84	981
<i>Duvalia</i> cf. <i>ensifer</i> *	Bed 46	-0.5	0.3	361830	24	2171	84	1029
<i>Hibolites</i> sp.*	Bed 47	-0.1	-1.3	356315	195	1834	869	458
<i>Pseudobelus</i> cf. <i>zeuschneri</i>	Bed 55	0.4	-1.2	356031	93	1827	8	989
<i>H.</i> cf. <i>semisulcatus</i> *	Bed 55	0.3	-1.6	363467	55	2851	68	1097
<i>Hibolites</i> sp.	Bed 56	1.8	-1.4	381341	17	2627	36	932
<i>Hibolites</i> sp.*	Bed 57	0.3	-0.5	346926	128	1927	684	713
<i>Pseudobelus</i> cf. <i>zeuschneri</i>	Bed 58	0.5	1.1	368994	76	1810	52	856
<i>Hibolites semisulcatus</i>	Bed 58	1.4	-0.6	339196	80	1804	31	436
<i>Hibolites semisulcatus</i> *	Bed 58	-0.4	-1.4	377196	69	2788	82	1131
<i>Pseudobelus zeuschneri</i> *	Bed 61	-0.7	-1.8	347528	63	1960	105	1067
<i>Hibolites</i> sp.*	Bed 62	-0.1	-0.4	368284	75	2635	93	1077
<i>Belemnites</i> sp.	Bed 76	-0.3	0.5	365134	8	2328	8	855
<i>Belemnites</i> sp.	Bed 76	-0.6	0.2	369019	64	1626	8	918
<i>Belemnites</i> sp.	Bed 77	-0.5	0.3	370522	7	1500	6	901

* Deemed diagenetically altered

preserved, which were then analysed for oxygen and carbon isotopes. Subsamples for chemical analysis weighing 5–10 mg were dissolved in nitric acid and analysed using a Varian 725-ES Inductively Coupled Plasma spectrometer. According to analysis of duplicate samples, reproducibility was better than ± 4 % of the measured concentration of each element.

Fossil preservation

The belemnites were not only fragmentary and frequently displayed solution marks, as noted above, they were also often

‘chalky’ in appearance. After the death of an organism, microbial agents may attack the shells, digesting the organic matrix that surrounds the calcium carbonate crystallites (Glover & Kidwell 1993; Brand 1994). The disassociation of these crystallites due to the loss of the organic matrix holding them together has an effect similar to chemical dissolution and causes pitting of the surface, chalkiness, and loss of colour and/or lustre (Glover & Kidwell 1993; Brand 1994). A chalky appearance alone is however, not a reliable criterion for defining the degree of diagenetic alteration. Diagenetic alteration was also apparent using standard thin section analysis. Many rostra examined (Fig. 8b–e) displayed a mottled texture and possible cloudy opaque dissolution residues. Mottling and cloudiness was often concentrated around the apical line as well the margins of the rostra. Within those samples showing a better state of preservation (Fig. 8a,f) the calcite is generally clear and primary growth lines are apparent. Those rostra appearing cloudy in hand specimen were also those that displayed the mottling and cloudiness seen in thin section.

Our trace elemental analysis is consistent with these petrographic observations in that they reveal the poor state of preservation of many of the belemnite rostra. Fe concentrations range from 15–493 ppm, Mn concentrations from 5–869 ppm, Mg concentrations from 1341–2851 ppm and Sr concentrations from 186–1131 ppm in all 49 belemnite rostra analysed (Table 3). Well-preserved belemnites typically show low concentrations of Mn (< 50 ppm) and Fe (< 200 ppm) and

higher concentrations of Sr (ca. 600–1600 ppm) (e.g. Nunn et al. 2009; Price et al. 2009). Fe and Mn concentrations are typically higher in diagenetically altered calcite, as Fe^{2+} and Mn^{2+} are more soluble under reducing conditions and thus available for replacing Ca^{2+} in the calcite lattice (Brand & Veizer 1980; Veizer 1983). Under such conditions there may also be a loss of ‘marine’ Mg and Sr (Veizer 1983). Hence many belemnites were excluded on the basis of relatively high concentrations of Mn and Fe or reduced concentrations of Sr and Mg potentially reflecting dissolution as indicated by the chalky nature of many of the belemnites.

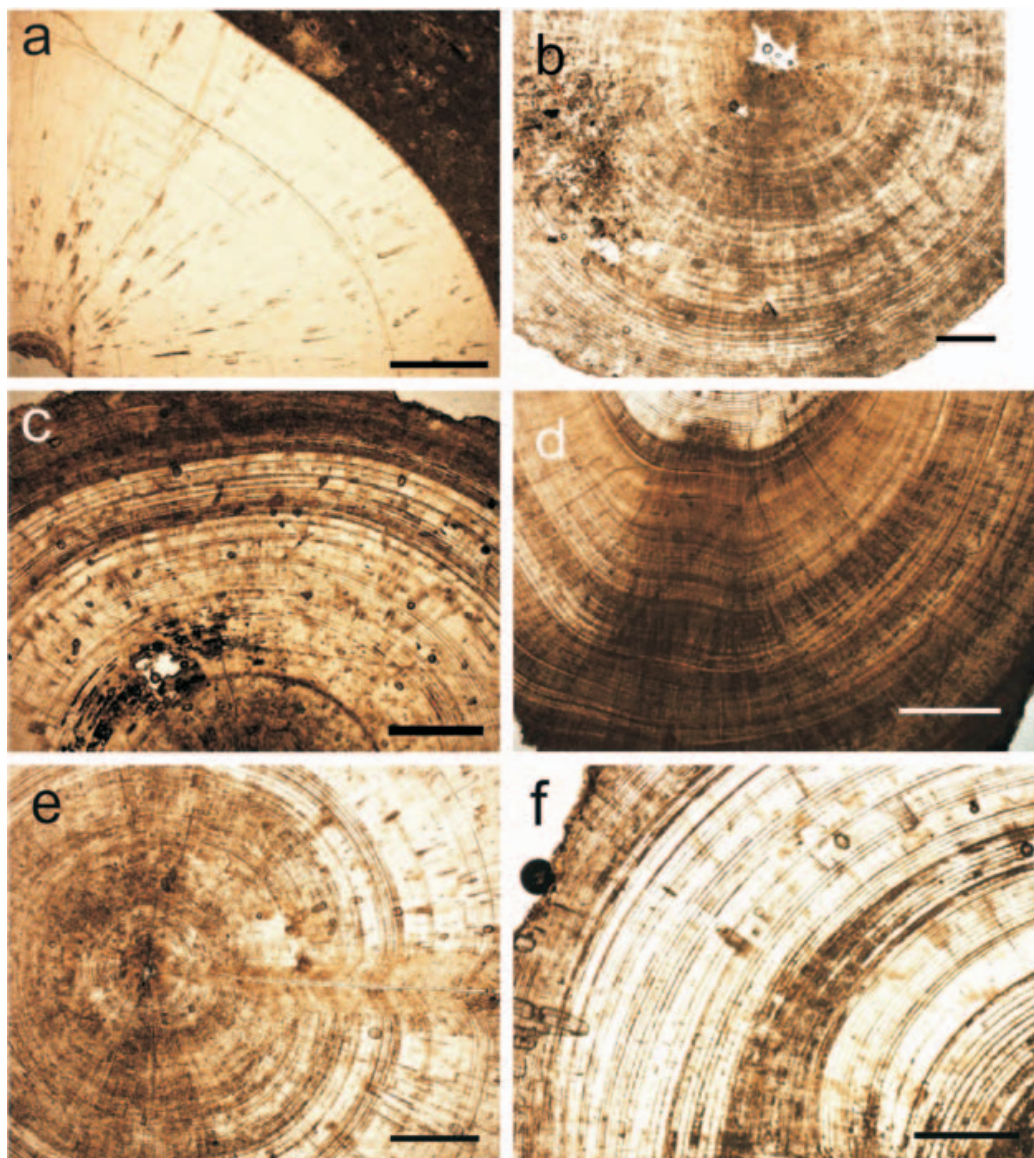


Fig. 8. Photomicrographs of belemnite rostra. **a** — Sample *Belemnites* sp., Bed 77 displaying clear and translucent growth lines. Scale bar is 1 mm. **b** — Sample *Hibolithes semisulcatus*, Bed 58 showing a mottled texture particularly concentrated around the apical line. Scale bar is 1 mm. **c** — Sample *Hibolithes* sp., Bed 57 showing mottling and opaque cloudy texture particularly around the margin of the rostrum. Scale bar is 1 mm. **d** — Sample *Duvalia* cf. *abeli*, Bed 46 shows a dense mottling and opaque cloudy texture. Scale bar is 1 mm. **e** — Sample *Hibolithes* cf. *semisulcatus*, Bed 44 shows a mottled texture particularly concentrated around the apical line. Scale bar is 1 mm. **f** — *Duvalia tithonia*, Bed 18 shows generally clear calcite and primary growth lines with more opaque calcite around the margin of the rostrum. Scale bar is 0.5 mm.

Isotope results

Apart from the isotope data from the lowermost (?Oxfordian) beds, the carbon isotope values of the belemnite calcite through the Tithonian part of the section show a decline in values from 1.8 ‰ in the Darwini Zone to -1.7 ‰ (V-PDB) in the Microcanthum Zone. The belemnite oxygen isotopes show some variability ranging from -2.9 to -0.1 ‰ (V-PDB). Obvious stratigraphic trends are not evident. Likewise although a range of species were analysed (e.g. *Hibolithes* and *Duvalia*), because of the generally poor state of preservation only two *Duvalia* were deemed well-preserved. Hence potential ecological trends were not discernable from the isotope data.

The oxygen isotope data from the ?Oxfordian samples show a narrow range (0.2–0.5 ‰ V-PDB). These data are a little more positive than our Tithonian data.

Discussion

Ammonites

The Upper Jurassic ammonite fauna of the Lókút section has a strong Mediterranean character, which is reflected by the presence of numerous exclusively Tethyan ammonite genera and species, as well as by the proportion of ammonite

suborders. As a result of this phylloceratids and lytoceratids are very common throughout the section. For example, in the Tithonian part of the succession these groups comprise about 60 % of the whole fauna (Vigh 1984).

Data for the Oxfordian are very scarce in Lókút, therefore it cannot be discussed in detail. In contrast, the Kimmeridgian is well developed and can be compared with some of the well-documented Tethyan fauna, especially known from the Subbetics (Olóriz 1978), Southern Alps (Sarti 1984, 1993) and Sicily (Pavia & Cresta, Eds. 2002). The Kimmeridgian succession of the Lókút Hill — although still condensed, as always in the Rosso Ammonitico facies — is the thickest and most complete representation of the stage in Hungary, where all Kimmeridgian ammonite zones can be traced.

Because the Tithonian in Lókút also shows a strong Mediterranean affinity and its ammonite succession can be compared easily with those known from other Tethyan localities, the novel zonal scheme, introduced by Vigh (1984) was revised and replaced by a standard scheme. As in other localities of the Transdanubian Range the middle Tithonian is better represented than the lowermost part of the stage. The *Semiforme* and *Fallauxi* Zones contain more beds than those of the *Hybonotum* and *Darwini* Zones. The *Ponti* Zone is thin, but the base of the Upper Tithonian (*Microcanthum* Zone) is characterized by numerous beds and a relatively diverse and typical, but poorly known assemblage. This fauna contains some little known ammonites, including flat, discoidal perisphinctids with, or without a ventral groove (like *Paraulacosphinctes* and *Oloriziceras*), and some himalayitids (*Microcanthoceras*) which are best known from the Subbetics (Tavera 1985).

Belemnites

The most recent information regarding Mediterranean Late Jurassic belemnites originates from Italian sections (Combémoré & Mariotti 1986a,b, 1990; Mariotti 1995, 2002a,b, 2003). However, knowledge about the bed-by-bed distribution of Tethyan belemnites is sparse (Mariotti 1995: p. 222–225). Combémoré & Mariotti (1986a) described belemnites from the Central Apennines. They dealt with belemnites from either the *S. semiforme* Zone or the *Volanoceras volanense* Zone, although later on Mariotti (1995) accepted a *Volanense* (= *Ponti*) age for the sediments. Cecca & Enay (1991) mentioned *Duvalia ensifer* from the *R. richteri* Subzone, from Tithonian sediments in the southeast of France. Combémoré & Mariotti (1986b) described *Duvalia tithonia* from the A2 Calpionellid Zone and discuss to some more extent stratigraphical details about this species.

Janssen (1997: text-fig. 2) described and mentioned some belemnites from the latest Jurassic and earliest Cretaceous from the southeast of Spain. However, especially the *Conobolus*-species most probably are erroneous and additional material (a.o. “*Pseudobolus*” *fischeri* Combémoré & Mariotti, 1990) still needs to be published. It appears, however, that many belemnites that occur in TiBA-III and IV disappear in the beds that straddle the Jurassic-Cretaceous boundary.

The latest Kimmeridgian to earliest Tithonian is characterized by belemnite faunas which are very low in diversity but are generally very abundant (Riegraf 1981; Combémoré 1997). Most numerous are *Hibolites*, a group of belemnites

which in general lack unambiguous traits. *Hibolites* ex gr. *semisulcatus* are well known from the Kimmeridgian-Tithonian boundary sediments and occur abundantly in both the Submediterranean as in the Mediterranean Province, and occasionally even in the Boreal-Atlantic Realm.

Duvalia-like belemnites are known from the Tethyan Late Bathonian to Oxfordian, and probably the late Early Kimmeridgian (Mariotti 2002a,b). Recently Hikuroa (2004) and Challinor & Hikuroa (2007) published sedimentary successions from the Antarctic Peninsula which yielded Duvaliidae from sediments of comparable ages. For the moment, there appears to be a period (within the literature) from the Late Kimmeridgian to earliest Tithonian in which the Duvaliidae do not occur. The “reappearance” of Duvaliidae (*Conobolus* and duvaliid belemnites related to *Duvalia* ex gr. *ensifer*) coincides approximately with the boundary between the Lower and middle Tithonian.

In comparing the Hungarian belemnite assemblages with assemblages from Italy (Combémoré & Mariotti 1986a; Mariotti 1995, 2002b, 2003), some discrepancies occur, moreover the Hungarian assemblages appear to be impoverished. TiBA-IV contains belemnites that are characteristic for the latest Jurassic. However, characteristic genera and species like *Conobolus* and “*Pb.*” *fischeri*, are absent. *Duvalia tithonia* is not known from older sediments than with calpionellids that characterize the A2 Calpionellid Zone. Apparently, our specimen occurs within the top of the Chitinoidea Calpionellid Zone (cf. Grabowski et al. 2010).

Moreover, the Hungarian material indicate that much more distinct assemblages emerge between the Early-middle Tithonian and the middle-Late Tithonian than previously indicated. The assemblage described by Combémoré & Mariotti (1986a) from the *V. volanense* Zone (Mariotti 1995) appears to be comparable to TiBA-II in the Lókút section (top *S. semiforme* and base *S. fallauxi* Zones) but the Hungarian assemblage is clearly less diverse. In the Lókút section TiBA-I encompasses almost the entire Early Tithonian (if distinguishing between the Lower and middle Tithonian). The characteristic belemnite (“*Pb.*” *zeuschneri*), would be the first indication that duvaliids occur in the earliest Tithonian, shortening the previously mentioned interval of “lacking duvaliids”.

Duvaliids also occur in the Bed 68 (base *Hybonotoceras beckeri* Zone). Due to the rigidity of the host-rock only the transverse section can be studied, which shows an elongated subquadrangular laterally flattened cross-section, typical for duvaliid belemnites. Moreover, the Beds 68 and 70 yielded conoboloid belemnites, and in the Bed 70 one resembles *Conobolus massimoi* (Mariotti, 2002). The latter has been described from the *Crussolicerias divisum* Zone of northern Italy. In the Beds 75 and 77 (probably Oxfordian-Kimmeridgian boundary beds) duvaliids occur again.

Isotopes

Increasingly negative $\delta^{18}\text{O}$ values in carbonates can be related to higher temperatures in environmental settings where continental ice volume over time is relatively constant (and therefore $\delta^{18}\text{O}_{\text{seawater}}$ is relatively invariable) and evaporation or freshwater input are minor factors. Belemnites are also

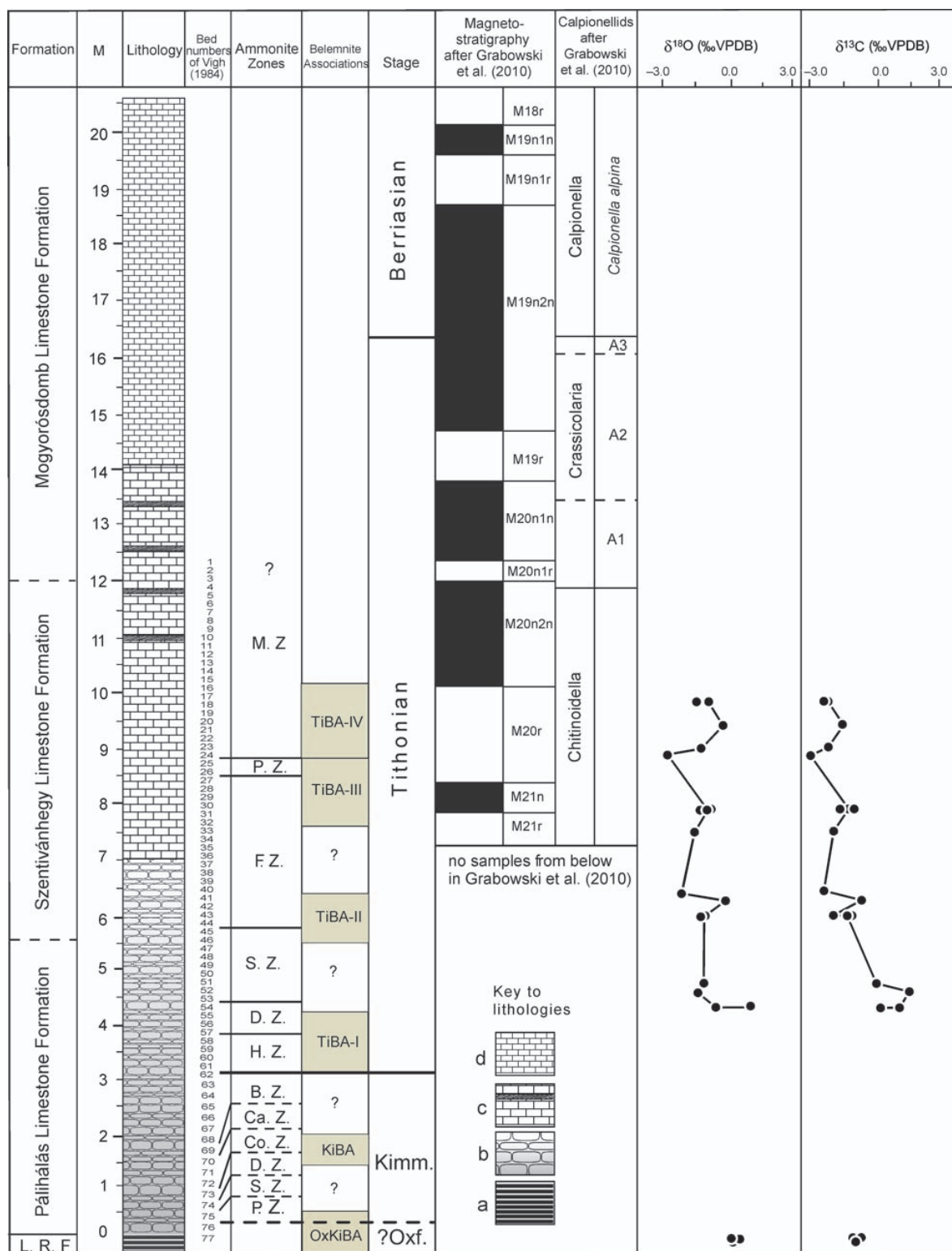


Fig. 9. Integrated stratigraphy of the Lókút section showing the correlation between biostratigraphic data and those based on magnetostratigraphy. The measured log is tentatively correlated with the bed numbers published by Vigh (1984). Correlation is based on known thickness of the Tithonian part of the section, observed lithological changes and re-sampling of the profile. Ammonite zones for the Kimmeridgian and Tithonian follow the standard zonation scheme by Enay & Geyssant (1975) and Olóriz (1978), respectively. Abbreviations: (a) radiolarite (Lókút Fm), (b) red nodular limestone (Pálhálás Fm), (c) light coloured, thin-bedded limestone, with cherty layers (Szentivánhegy Fm), (d) white, Biancone type limestone (Mogorósdomb Fm). For the zonal names, from the oldest to the youngest: Platynota, Strombecki, Divisum, Compsum Cavouri, Beckeri, Hybonotum, Darwini, Semiforme, Fallauxi, Ponti, Microcathum Zones. Belemnite Assemblages are in accordance with the data published herein.

thought to have secreted their carbonate in isotopic equilibrium with ambient seawater (e.g. Lowenstam & Epstein 1954; Price & Mutterlose 2004). This assumption is supported by the fact that the $\delta^{18}\text{O}$ values of modern *Sepia* shells (an extant relative of belemnites) also appear close to equilibrium fractionation (Bettencourt & Guerra 1999). Hence assuming oxygen isotope equilibrium, relatively cool temperatures are seen in the Oxfordian and warmer conditions in the Tithonian. The $\delta^{18}\text{O}$ values of belemnites imply temperatures as low as 8 °C, if a δ_{seawater} value of -1.0 ‰ (SMOW), thought to be appropriate for assumed non-glacial periods (Shackleton & Kennett 1975) using the paleotemperature equation of Anderson & Arthur (1983) is used. According to the same assumptions the warmest paleotemperatures reach 22 °C consistent with the paleolatitude of the site. As the few Oxfordian samples were derived from just above the Lókút Radiolarite, cooler conditions may be indicative of a deeper depositional setting although warmer conditions in the Tithonian are consistent with data published from elsewhere (e.g. the Russian Platform, Riboulleau et al. 1998; Price & Rogov 2009).

The carbon isotope data show a decrease through the Tithonian part of the section that is consistent with carbon-isotope stratigraphies of the Western Tethys (e.g. Weissert & Channell 1989; Weissert & Mohr 1996) and also the Russian Platform (Price & Rogov 2009) which show a decrease in values towards the Jurassic-Cretaceous boundary. Weissert & Channell (1989) interpret this $\delta^{13}\text{C}$ decline as evidence of increasingly oligotrophic conditions in the Tethyan seaway. This pattern is therefore thought to reflect a global signal of carbon cycling in the Late Jurassic oceans. Further stable isotope data from the Lókút section are, however, required to substantiate linkages between global records.

Conclusions

Re-measuring and re-sampling the section of the Lókút Hill allowed us to allocate and anchor the cephalopod collection, gathered nearly 50 years ago.

Based on the rich and relatively well preserved, bed-by-bed collected ammonite fauna, the biostratigraphical subdivision of the lower, cephalopod bearing part of the Upper Jurassic-Lower Cretaceous section was precisely done. Above the lowermost (possibly Oxfordian) beds, a relatively complete succession of the Kimmeridgian Platynota, Strombecki, Divisum, Compsum, Cavouri and Beckeri Zones was recognized, which is followed by the Tithonian Hybonotum, Darwini, Semiforme, Fallauxi, Ponti and Microcanthum Zones.

The belemnite fauna — also collected under strict stratigraphic control, together with the ammonites — allowed us to recognize four belemnites assemblages (TiBA-I to TiBA-IV) for the Tithonian part. We distinguished one assemblage in the middle late Kimmeridgian and one for the ?Oxfordian-Kimmeridgian boundary beds. However, due to the low amount and quality of the material the latter two are only tentatively distinguished. The Tithonian assemblages can be compared with previously published belemnite assemblages but appear impoverished in relation to Mediterranean (Italy, Spain) assemblages. The rather species poor Kimmeridgian belemnite assemblage cannot be

compared because belemnite stratigraphical and taxonomical details are missing from literature except for Mariotti (2002b, 2003). The latter author published a highly diverse assemblage from the *C. divisum* Zone of northern central Italy.

The ?Oxfordian-Kimmeridgian assemblage which appears rather diverse (mainly Mesohibolitidae) cannot be compared in detail to other areas yet, because detailed stratigraphical data are also missing. However, the general picture, repeated in literature showing an abundance of Mesohibolitidae in the Upper Oxfordian to Lower Tithonian sediments of the Mediterranean Tethys could actually be artificial due to lack in well investigated sections, as demonstrated by Mariotti (2002b, 2003). Moreover, we find indications that duvaliids occur throughout the interval we investigated.

Despite the poor preservation of many of the rostra our geochemical analyses of belemnite specimens from a stratigraphically well-constrained section yielded new data for reconstructions of paleoclimate and paleoecology. These data point to a cool (or deeper) ?Oxfordian and a warmer Tithonian. Our $\delta^{13}\text{C}$ data are consistent with other isotope stratigraphies and allude to the possibility of the Lókút section recording global events.

Systematic section

On a family level there appear to be no large differences between latest Jurassic and Early Cretaceous belemnites, only abundances fluctuate heavily. The belemnites described here can be divided into two families, namely the Mesohibolitidae and Duvaliidae. This division is based on the position of the siphon towards the alveolar groove, being opposite in Duvaliidae and situated on the same side in Mesohibolitidae. In addition the general morphology of the rostrum adds to this separation, in which Duvaliidae are generally laterally flattened, while Mesohibolitidae are rounded or dorso-ventrally flattened and spindle-shaped (hastate or (sub)fusiform). However, the alveolar area of some *Hibolithes* can be laterally compressed, as in *Hibolithes conradi*. Some suspected Duvaliidae also show the same outer morphology during their ontogenetical development, especially *Conobelus*. Thus generic attribution is not always definite, as the position of the siphon is often not known. Moreover, the stratigraphical record of the Duvaliidae is momentarily incomplete. There are gaps in our knowledge regarding the phylogenetic relation between Late Jurassic and Early Cretaceous genera, although morphological differences are often meagre. This is largely the result of the near absence of published stratigraphical data on belemnites from the Berriasian.

The main quandary is represented by the Tithonian belemnites attributed to the genus *Pseudobelus*. There is momentarily no firm ground to place them in the genus created by Blainville (1827) other than a morphological resemblance (pers. observ. Janssen). For the moment they appear to belong to a genus closely related to the Tithonian-earliest Cretaceous duvaliids, or representing a genus between *Produvalia* and *Duvalia*. These belemnites do show some characteristics of *Produvalia* or *Duvalia* and of *Pseudobelus*. Yet, lateral lines or incisions are often noted in other duvaliids too, and espe-

cially juvenile to immature specimens do tend to have the same morphology as compared to pseudobeloid belemnites. *Pseudobelus* s.s. are currently known to occur in uppermost Berriasian to lower Upper Hauterivian sediments only.

Family: **Mesohibolitidae** Nerodenko, 1983

Genus: *Acutibelus* Riegraf, 1981

Acutibelus sp.

?1877 *Belemnites semisulcatus* Münster — Favre, pl. I, fig. 3a-b

Material: One incomplete specimen from Bed 75 and one doubtful specimen from Bed 70.

Description: A very elongated specimen with rather faint alveolar groove. The juvenile or immature specimen from Bed 70 shows a very deep and very sharp alveolus.

Range: Early to earliest Late Kimmeridgian.

Occurrence: Late Early to earliest Late Kimmeridgian of southwest Germany (Riegraf 1981), Savoie (?Favre 1877) and Hungary.

Genus: *Hibolites* Denys de Montfort, 1808

Hibolites conradi Kilian, 1889

(Fig. 7.10,11)

1868 *Belemnites* cfr. *semisulcatus* Münster — Zittel, pl. I, fig. 8 (fide Kilian, 1889)

?1871 *Belemnites* cfr. *semisulcatus* Münster — Gemmellaro, p. 21, pl. III, figs. 2-3

1889 *Belemnites* (*Hibolites*) *Conradi* n. sp. Kilian, pp. 635, 690 (cf.), pl. XXVI, fig. 4

?1922 *Belemnites Conradi* Kilian — de Gregorio, p. 8, pl. I, fig. 12 pars 1990 *Hibolites semisulcatus* (Münster): Combémoré & Mariotti, pl. II, fig. 9

pars 1997 *Hibolites semisulcatus* (von Münster) — Janssen, pp. 12-13

Material: Six incomplete specimens from Beds 24 to 16.

Description: A robust rounded semihastate rostrum with pointed, centrally placed apex. The alveolar area is characterized by lateral compression. Alveolus shallow with well developed wide alveolar groove. The apical line is central.

Range: Latest Tithonian (*M. microcanthum* Zone) to Late (?)Berriasian (Zone unknown).

Occurrence: Hungary, Italy, Spain and (?)northern Alps.

Hibolites cf. *fellabrunnensis* (Vetters, 1905)

(Fig. 7.7)

1905 *Belemnites Fellabrunnensis* Vetters, p. 245, text-fig. 1

Material: One incomplete rostrum from Bed 32 (the alveolar part is lacking).

Description: Elongated rounded to slightly dorso-ventrally compressed rostrum with a relative long alveolar groove, well on to the *rostrum sollidum*, and a shallow alveolus. The alveolar area is rounded (cf. Vetters 1905) but not preserved in our material.

Range: Late middle Tithonian (top *S. fallauxi*).

Occurrence: Hungary and northern Alps.

Hibolites semisulcatus (Münster, 1830)

(Fig. 7.1,2,18,19,22,23)

1830 *Belemnites semisulcatus* Münster, pp. 6-7, pl. 1, figs. 1-8, 15

1862 *Belemnites diceratiana* Etallon, p. 69

1870 *Belemnites* cfr. *semisulcatus* Münster — Zittel, p. 30, pl. I (25), fig. 5

1886 *Belemnites diceratiana* Etallon — Lorient, pp. 37-38, pl. I, figs. 1-4

1986a *Hibolites semisulcatus* (Münster) — Combémoré & Mariotti, pp. 312-313, pl. 2, figs. 14-16 (cum syn.)

1986a *Hibolites* sp. — Combémoré & Mariotti, pp. 314, pl. 2, figs. 17-20

pars 1990 *Hibolites semisulcatus* (Münster) — Combémoré & Mariotti, p. 213, pl. 2, figs. 5-8, 10

1995 *Hibolites semisulcatus* (Münster) — Mariotti, p. 235, pl. III, figs. 3-4

1999 *Hibolites semisulcatus* (Münster) — Schweigert, pp. 3-4, text-figs. 1, 3-4, pl. 1, figs. 1-4, pl. 2, figs. 1-6, pl. 3, figs. 1-2, pl. 4, figs. 1-7, pl. 7, fig. 3 (cum syn.)

2002b *Hibolites semisulcatus* (Münster) — Mariotti, pp. 218-219, text-fig. 5.1-4

?2006 *Hibolites* (*Hemiholites*) ex gr. *semisulcatus* (Münster) — Ippolitov, pp. 57, 59, 60, text-figs. 3a-g (morph A), 3d-z (morph B)

2009 *Hibolites* (gr.) *semisulcatus* (Münster) — Lukeneder, pl. 3, fig. G

Material: 31 near complete to fragmentary specimens from Beds 77 to 25.

Description: A slender rounded to dorso-ventrally compressed hastate rostrum with pointed to obtuse centrally placed apex. The alveolar area is characterized by a well-developed constriction towards the *rostrum sollidum*. Lateral compression of the alveolar area is not always apparent, or might be absent. The alveolus is shallow with a well developed fine but clear alveolar groove. The length of the groove various, but might run well onto the *rostrum sollidum*. The apical line is central.

Range: Latest Oxfordian to middle Tithonian.

Occurrence: Throughout the (sub-) Mediterranean Tethys. Occasional occurrences outside this Province are noted (Russian Platform; cf. Ippolitov 2006).

Genus: *Subulibelus* Riegraf, 1981

Subulibelus problematicus? Riegraf, 1981

1981 *Subulibelus problematicus* n. gen. et n. sp. Riegraf, pp. 99-100, text-fig. 231, pl. 7, fig. 69

1981 *Subulibelus* cf. *problematicus* n. gen. et n. sp. — Riegraf, pp. 101-102, text-fig. 232, pl. 7, fig. 70

Material: One near complete specimens from Bed 76 and three incomplete specimens from 75.

Description: Small to medium sized very elongated, very hastate specimens. In Bed 77 an incomplete specimen shows a very shallow alveolus. No alveolar groove visible or preserved.

Range: Latest Oxfordian (?) to earliest Kimmeridgian.

Occurrence: Latest Oxfordian (*Ringsteadia pseudocordata* Zone) and earliest Kimmeridgian (*S. platynota* Zone) of southwest Germany (Riegraf 1981) and eventually Hungary.

Subulibelus? sp. or juvenile *Hibolithes* sp.

Material: Two specimens from Bed 75 and one from Bed 76.

Description: Very small specimens (<15 mm) which show a clear hastate sagittal section. However, the potential elongated proximal part of the rostrum is not preserved.

Range: They occur in the ?Oxfordian-Kimmeridgian boundary beds.

Occurrence: *Subulibelus* is described from the latest Oxfordian and the Oxfordian-Kimmeridgian boundary beds of southwest Germany (Riegraf 1981).

Family: **Duvaliidae** Pavlow, 1914

Genus: *Conobelus* Stolley, 1919

Conobelus strangulatus (Oppel, 1865)
(Fig. 7.3,4)

1865 *Belemnites strangulatus* Oppel, p. 545

1868 *Belemnites strangulatus* Oppel — Zittel, pp. 35–36, pl. 1, figs. 6–7

1890 *Belemnites Orbignyi* Duval-Jouve — Toucas, pp. 587–588, pl. XV, fig. 1

1890 *Belemnites Orbignyi* Duval-Jouve var. *suborbignyi* Toucas, p. 588, pl. XV, fig. 2

?1922 *Belemnites strangulatus* Oppel — de Gregorio, p. 8, pl. I, fig. 15

1942 *Conobelus strangulatus* Oppel — Mandev, pp. 51–52, pl. III, figs. 3–4

(sic)1986a *Rhopaloteuthis strangulatus* (Oppel) — Combémoré & Mariotti, pp. 307–308, pl. 1, figs. 12–15 (cum syn.)

(sic)1995 *Rhopaloteuthis strangulatus* (Oppel) — Mariotti, p. 233, pl. II, fig. 11

(sic)1997 *Rhopaloteuthis strangulatus* (Oppel) — Combémoré, pl. 28, fig. 13 [cast of HT]

non?1997 *Rhopaloteuthis strangulata* (Oppel) — Janssen, pp. 31–32, pl. 3, figs. 3–4 [?non], nec figs. 5–6 [= *Conobelus incertus* Weiss]

Material: Twelve complete to fragmentary specimens from Beds 46 to 41.

Description: Rounded to laterally flattened conobeloid rostrum with well developed alveolar area. The dorsal and ventral sides are near parallel, except for the apical part. The alveolus is shallow and a faint but clear alveolar groove runs well onto the *rostrum sollidum*. The apex is obtuse to mucronate (in gerontic specimens) and shifted to the dorsal side; this might not be clearly visible in (incomplete) immature to juvenile specimens. The apical line is shifted to the ventral side.

Range: Middle Tithonian to (?) earliest Berriasian (top *S. semiforme*–(?)early *B. jacobi* Zones).

Occurrence: Mediterranean Tethys.

Conobelus cf. *massimoi*? (Mariotti, 2002)

?1873 *Belemnites Benecke* nov. sp. Neumayr, p. 156 (16), pl. XXXI, fig. 1

Material: One incomplete, weathered specimen (Bed 70).

Description: Stout, slightly hastate, medium to small sized rostra with rounded cross-sections, a deep alveolar cav-

ity (almost halfway the rostrum). The alveolar groove could not be seen. See Mariotti (2002b) for more specific details.

Remarks: The specimen resembles the species described by Mariotti (2002b). However, as the ontogeny is not known the immature specimens from the same bed, and from Bed 68, are gathered as *Conobelus*? sp.

Range: Middle Late Kimmeridgian.

Occurrence: Latest Early Kimmeridgian (*Crussoliceras divisum* Zone) of northern Italy, and possibly the uppermost *T. compsum* to basal *H. beckeri* Zones of Hungary.

Genus: *Duvalia* Bayle, 1878

Duvalia cf. *abeli* (Vetters, 1905)
(Fig. 7.12,13)

?1894 *Duvalia ensifer* (Oppel) — Retowski, pp. 218–219, pl. XIV, fig. 1

1905 *Belemnites Abeli* Vetters, pp. 246–247, text-fig. 3

1986a *Duvalia aasinensis* nov. sp. — Combémoré & Mariotti, pp. 304–305, pl. 1, fig. 4

1995 *Duvalia aasinensis* Combémoré & Mariotti — Mariotti, pp. 230–231, pl. II, fig. 4

Material: One incomplete specimen from Bed 46.

Description: The rostrum is characterized by an extremely laterally flattened *rostrum sollidum* with an angular cross-section and with an expanded alveolar area (not preserved in our specimen). The alveolar opening is more or less quadrangular, with a shallow alveolus and a short alveolar groove (cf. Vetters 1905).

Range: Middle Tithonian (top *S. semiforme*–(?)*M. ponti* Zones).

Occurrence: Crimea(?), Hungary, Italy and northern Klippenbelt of Calcareous Alps.

Duvalia ensifer (Oppel, 1865)
(Fig. 7.14,15)

1865 *Belemnites ensifer* Oppel, p. 545

1868 *Belemnites ensifer* Oppel — Zittel, p. 36, pl. 1, figs. 9 [“Normalform”], 10

?1868 *Belemnites ensifer* Oppel var. Zittel, pl. 1, fig. 11 [= ?*Duvalia esba*]

?1875 *Belemnites ensifer* Oppel — Pillet & de Fromentel, pp. 14, 65, pl. VIII, figs. 1–3 [= ?*Duvalia esba*]

non1889 *Belemnites ensifer* Oppel — Sokolov, pp. 131–132, pl. II, fig. 8a–c [= *Duvalia* gr. *lata*]

non1894 *Belemnites ensifer* Oppel — Retowski, pp. 218–219, pl. XIV, fig. 1 [= ?*Duvalia abeli*]

?1897 *Belemnites ensifer* Oppel — Roman, p. 279, pl. I, fig. 1 [= ?*Conobelus*]

?1904 *Belemnites ensifer* Oppel — Schiller, p. 27 (133), text-fig. 3 [= ?*Conobelus*]

non1922 *Belemnites ensifer* Oppel — de Gregorio, p. 8, pl. I, figs. 20 [= ?*Conobelus* sp. indet.], 21 [= ?“Pb.” gr. *zeuschneri*]

1935 *Belemnites ensifer* Oppel — Beregov, pp. 68 (19), 106 (56), 110 (60), pl. I, fig. 10

1986a *Duvalia ensifer* (Oppel) — Combémoré & Mariotti, pp. 303–304, pl. 1, figs. 1–3

1990 *Duvalia ensifer* (Oppel) — Combémoré & Mariotti, pp. 210–211, pl. 1, figs. 4–5

Material: Five incomplete specimens from Beds 46 to 44.

Description: Typical duvaloid rostrum with (strong) lateral compressed rostrum with elongated rounded cross-

sections and a dorsally orientated apex. The alveolus is moderately deep and an alveolar groove is well developed, generally running well on to the *rostrum sollidum*. Lateral lines (two parallel lines) may be visible on well-preserved specimens. Juvenile to immature specimens do not show the same outer-morphology as mature specimens.

Range: Middle Tithonian (topmost *S. semiforme*-base *S. fallauxi* Zones).

Occurrence: Mediterranean Tethys.

Duvalia cf. *esba* (de Gregorio, 1885)
(Fig. 7.20,21)

?1868 *Belemnites ensifer* Oppel var. Zittel, pl. I(25), fig. 11

?1875 *Belemnites ensifer* Oppel — Pillet & de Fromentel, pp. 14, 65, pl. VIII, figs. 1-3

1885 *Belemnites esbus* de Gregorio, p. 242

1886 *Belemnites esbus* de Gregorio — de Gregorio, p. 4, pl. 1, figs. 12a-c

?1917 *Belemnites (Duvalia) latus* Blainville — Kilian & Révil, pl. XV, fig. 1

?1997 *Duvalia* sp. nov? spec. indet. Janssen, pp. 26-27, pl. 2, figs. 5-6

Material: One incomplete, juvenile specimen from Bed 32.

Description: Typical duvaliid latatoid rostrum with a laterally strongly compressed *rostrum sollidum* and a constricted alveolar area. The alveolar groove is short and the alveolus is shallow. This species most probably belongs to the group of belemnites around *ensifer*, but the overall shortage of material does not permit more than morphologically comparison with the specimen depicted by de Gregorio. It appears to be much more laterally compressed as compared to typical *ensifer*-species, with a more constricted alveolar area and consequently a much shallower alveolus.

Range: Late middle Tithonian-earliest Berriasian (top *S. fallauxi*-(?)base *B. jacobi* Zones).

Occurrence: Hungary, Italy, and possibly in Spain and the Swiss Alps.

Duvalia tithonia (Oppel, 1865)

1865 *Belemnites tithonius* Oppel, p. 545

1868 *Belemnites tithonius* Oppel — Zittel, p. 37, pl. I, figs. 12-13

1889 *Belemnites (Duvalia) Decekei* n. sp. Kilian, p.636, pl. XXVI, fig. 5

1894 *Belemnites tithonius* Oppel — Retowski, pp. 221-222, pl. XIV, figs. 3-4

non1922 *Belemnites tithonius* Oppel — de Gregorio, p. 8, pl. I, fig. 11

1983 *Biplanidelus* [sic!; recte *Biplanibelus*] *tithonia* (Zittel) — Nerodenko, p. 42

(sic)1986b *Duvalia tithonica* (Oppel) emend. Zittel — Combémoré & Mariotti, pp. 36-39, text-fig. 2 (cum syn.)

(sic)1990 *Duvalia tithonica* (Oppel) — Combémoré & Mariotti, p. 211, pl. 1, fig. 6

(sic)1992 *Pseudoduvalia tithonica* (Oppel) — Barskov & Weiss, p. 74

(sic)1995 *Duvalia tithonica* (Oppel) em. Zittel — Mariotti, pp. 231-232, pl. II, figs. 5-6, pl. III, fig. 10

(sic)1996 *Duvalia tithonica* (Oppel) — Eliáš et al., pp. 263, 267, pl. IV, figs. 12-14

Material: One poorly preserved, incomplete juvenile to immature specimen from Bed 18.

Description: An atypical duvaliid rostrum characterized by dorsal and ventral hollows. These are barely visible on

the dorsal side of this immature specimen. The *rostrum sollidum* is laterally flattened, and the alveolar area is characterized by a constriction. See Combémoré & Mariotti (1986b) for more details.

Range: Latest Tithonian-earliest Berriasian (Microcantum-early Jacobi Zones).

Occurrence: Mediterranean Tethys.

Genus: *Produvalia* Riegraf, 1981

Produvalia(?) sp. 1

Material: One incomplete specimen (Bed 68) which shows the typical laterally flattened sub-rectangular duvaliid cross-section. The section shows rounded lateral sides. The ventral side is rounded to sub-angular while the dorsal outline is slightly flattened and a trace of a groove appears to be visible. The alveolar cavity, just visible in the specimen, is centrally placed.

Remarks: The cross-section does remind of *Produvalia*, more specific of the late Early to early Late Oxfordian *Produvalia neyrivensis* (Favre) hence the generic attribution.

Range: Late Kimmeridgian (earliest *H. beckeri* Zone).

Produvalia(?) aff. *nicosiai*? (Mariotti, 2002)

Material: Two incomplete specimens from the Beds 75 and 77 which show sub-rounded to sub-rectangular cross-sections. These sections are laterally compressed with near straight lateral sides. Lateral incisions are faint but visible. Both the ventral (slightly more inflated) as well as the dorsal side are rounded. The part from Bed 77 is best preserved (30 mm), and shows an almost straight dorsal side and a slightly curved ventral side, in lateral view. The ventral side narrows towards the alveolar area. A dorsal groove is not visible and no alveolar part is preserved. The alveolar line is centrally placed. In this specimen the cross-section near the alveolar region is visible. It shows a rounded outline with weak dorso-lateral depressions. Overall, the outline and lateral compression point to a duvaliid rostrum.

Remarks: The general form is similar to *Produvalia nicosiai* (Mariotti, 2002) but the anterior cross-section appears much more rounded and the dorsal side is less hastate.

Range: Latest Oxfordian(?) to earliest Kimmeridgian (*S. platynota* Zone).

Genus: *Pseudobelus* Auctorum non de Blainville, 1827
(= *Pseudobelus* s.l.; =?genus novum)

"*Pseudobelus*" *zeuschneri* (Oppel, 1865)
(Fig. 7.8,9,16,17,24,25)

1865 *Belemnites Zeuschneri* Oppel, p. 545

1870 *Belemnites Zeuschneri* Oppel — Zittel, p. 28, pl. (I) 25, fig. 9

1889 *Belemnites Zeuschneri* Oppel — Sokolov, pp. 122-123, pl. III, fig. 5

pars?1922 *Belemnites Zeuschneri* Oppel sp. aff. — de Gregorio, p. 8, pl. I, figs. 14, 21

1986a *Pseudobelus zeuschneri* (Oppel) — Combémoré & Mariotti, pp. 310-311, pl. 2, figs. 1-6 (cum syn.)

1990 *Pseudobelus zeuschneri* (Oppel) — Combémoré & Mariotti, p. 212, pl. 1, figs. 11-14

1995 *Pseudobelus zeuschneri* (Oppel) — Mariotti, p. 234, pl. II, fig. 10, pl. III, fig. 9 (cum syn.)

Material: Six incomplete to fragmentary specimens from Beds 61 to 55.

Description: Medium sized elongated duvaliid belemnites with vague lateral impressions, especially in the apical area. The alveolus is relative deep and the alveolar groove runs well on to the *rostrum sollidum*. The apex is shifted to the dorsal side. Lateral sides are near parallel.

Remarks: The lateral depressions which characterize *Pseudobelus* s.s. appear to be different from the Tithonian-earliest Berriasian *Pseudobelus* s.l. but are clearly comparable to morphological features as can be observed on some *Produvalia* and *Duvalia*. Combémoré & Mariotti (1986a: p. 310) indicate that the original as depicted by Zittel (1870) is not complete (anymore; lacking the alveolar part). Despite that they do not mention it, in my opinion, the depth of the lateral incisions is exaggerated.

Range: Late Early Tithonian to earliest Late Tithonian (probably Semiforme-Ponti Zones).

Range: Early Tithonian (*H. hybonotum*-*S. darwini* Zones), probably also in younger sediments.

Occurrence: Mediterranean Tethys.

“*Pseudobelus*” ex gr. *zeuschneri* (Oppel, 1865)
(Fig. 7.5,6)

Material: Four incomplete to fragmentary specimens from Beds 32 to 21.

Description: Comparable to *zeuschneri* but with a well-developed constriction between the alveolar area and the *rostrum sollidum*. In the Hungarian material the alveolar areas are not preserved. Given the strong constriction, the alveolus is most probably very shallow. Lateral lines are very vague. The apex is pointed to mucronate, and shifted towards the dorsal side. In general, these belemnites give the impression of immature *Duvalia*.

Range: Latest middle Tithonian-early Late Tithonian (top *S. fallauxi*-base of *M. microcanthum* Zones).

Occurrence: Hungary.

Acknowledgments: Prof. József Pálfi and PhD student Márton Rabi (ELTE University, Budapest) are thanked for their kind assistance in the field. Willem Bont (Naturalis, Leiden) is thanked for some of the photographic work. This work has been supported by the Hungarian Scientific Research fund (OTKA) Grant: 68453 and received support from the SYNTHESYS Project (<http://www.synthesys.info/>), which is financed by European Community Research Infrastructure Action under the FP6 Structuring the European Research Area Program. The paper benefited from the comments of reviewers, Drs Evgenij J. Baraboshkin (Moscow) and Johann Schnyder (Paris).

References

- Anderson T.F. & Arthur M.A. 1983: Stable isotopes of oxygen and carbon and their application to sedimentologic and environmental problems. In: Arthur M.A., Anderson T.F., Kaplan I.R., Veizer J. & Land L.S. (Eds.): Stable isotopes in sedimentary geology. *SEPM Short Course* 10, 1–151.
- Barskov I.S. & Weis A.F. 1992: On the ontogeny of some Early Cretaceous belemnoids. *Paleontological J.* 26, 2, 70–85, 1 pl.
- Bayle E. 1878: Fossiles principaux des terrains. *Explication de la carte géologique de France, série 4*, 1 (Atlas), 176 pls.
- Beregov R. 1935: Geology of the western part of Radomirsko. *Rev. Bulgar. Geol. Soc.* 7, 2, 51(1)–113(63), 1 pl. (in Bulgarian).
- Bettencourt V. & Guerra A. 1999: Carbon and oxygen isotope composition of the cuttlebone of *Sepia officinalis*: a tool for predicting ecological information? *Mar. Biology* 133, 651–657.
- Blainville H.M. Ducratoy de 1827: Mémoire sur les bélemnites, considérées zoologiquement et géologiquement. *F.G. Levrault*, Paris, Strasbourg, 1–136, 5 pls.
- Brand U. 1994: Morphochemical and replacement diagenesis of biogenic carbonates. In: Wolf K.H. & Chilingarian G.V. (Eds.): Diagenesis, IV. *Elsevier*, Amsterdam, 217–282.
- Brand U. & Veizer J. 1980: Chemical diagenesis of a multicomponent carbonate system: 1. Trace elements. *J. Sed. Petrology* 50, 1219–1286.
- Cecca F. & Enay R. 1991: Les ammonites des zones à *Semiforme* et à *Fallauxi* du Tithonique de l'Ardèche (sud-est de la France): stratigraphie, paléontologie, paleobiogéographie. *Palaeontographica* A219, 1–87, 10 pls.
- Challinor A.B. & Hikuroa D.C.H. 2007: New Middle and Upper Jurassic belemnite assemblages from West Antarctica (Latady Group, Ellsworth Land): taxonomy and paleobiogeography. *Palaeontologia Electronica* 10, 1, 6A, 1–29.
- Combémoré R. 1997: Bélemnites. In: Cariou E. & Hantzperque P. (Eds.): Biostratigraphie du Jurassique ouest-européen et méditerranéen: zonations parallèles et distribution des invertébrés et microfossiles. *Bull. Cent. Rech. Explor.-Production Elf Aquitaine, Mém.* 17, 157–162.
- Combémoré R. & Mariotti M. 1986a: Les bélemnites de la carrière de Serra San Quirico (Province d'Ancona, Apennin central, Italie) et la paléobiogéographie des bélemnites de la Téthys méditerranéenne au Tithonique inférieur. *Géobios* 19, 3, 299–321.
- Combémoré R. & Mariotti M. 1986b: First record of *Duvalia tithonica*, a marker of Upper Tithonian, in Central Apennines. *Boll. Soc. Paleont. Ital.* 25, 35–39.
- Combémoré R. & Mariotti M. 1990: Taxonomic and biostratigraphic remarks on Tithonian belemnites from Sicily. *Atti del II Convegno Internazionale. Fossili, evoluzione, ambiente. Pergola*, 1987, 207–219.
- Csontos L. & Vörös A. 2004: Mesozoic plate tectonic reconstruction of the Carpathian region. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 210, 1–56.
- Császár G. (Ed.) 1997: Basic lithostratigraphic units of Hungary. *Hung. Geol. Inst.*, Budapest, 1–114.
- de Gregorio A. 1885: Tithonian fossils (Stramberger Schichten) of the biancone of Roverè di Velo. *Il Naturalista Siciliano* 4, 1–6 (in Italian).
- de Gregorio A. 1886: Fossiles tithoniques des Stramberger Schichten du “Biancone”, “Roverè di Velo” des Alpes de Verone. Note paléontologique. *Ann. Géol. Paléont.* 3, 1–8, 1 pl.
- de Gregorio A. 1922: Monography on the Tithonian fossils of “Casale di Sopra” (Busambra), preserved in my personal collection (zone of *Terebratula diphyæ e janitor*). *Ann. Géol. Paléont.* 36, 3–28, 12 pls. (in Italian).
- Denys de Montfort P. 1808: Conchyliologie systématique, et classification méthodique des coquilles; offrant leurs figures, leur arrangement générique, leurs descriptions caractéristiques, leurs noms; ainsi que leur synonymie en plusieurs langues. Tome 1. *F. Schoell*, Paris, 1–409, 100 pls.
- Eliáš M., Martinec P., Reháková D. & Vašíček Z. 1996: Geology

- and stratigraphy of the Kurovice Limestone and Tlumačov Marl Formation at the Kurovice quarry (Upper Jurassic, Lower Cretaceous, Outer Western Carpathians, west Carpathians, Czech Republic). *Věst. Čes. Geol. Úst.* 71, 3, 259–276 (in Czech).
- Enay R. & Geyssant J. 1975: Faunes Tithoniques des chaînes bétiques (Espagne méridionale). In: Colloque Limite Jurassique-Crétacé, Lyon-Neuchatel, 1973. *Mém. BRGM* 86, 39–55.
- Etallon A. 1862: Études paléontologiques sur la haut-Jura. Monographie du Corallien. Vertébrés, articulés, mollusques (Séances des 8 janvier et 12 mars 1859). *Mém. Soc. Émulation du Département du Doubs, Ser.* 3, 6 (for 1861), 53–227.
- Favre E. 1877: La zone à *Ammonites acanthicus* dans les Alpes de la Suisse et de la Savoie. *Mém. Soc. Paléont. Suisse* 4, 1–115, 9 pls.
- Fözy I. & Meléndez G. 1997: Middle and Upper Oxfordian ammonite succession from the Transdanubian Central Range and from the Mecsek Mountains (Hungary): Biostratigraphy and paleobiogeographic affinities. *Comunicaciones IV Congreso de Jurasico de Espana*, Alcaniz 1997, 69–72.
- Galácz A. 1975: Coupes bajociennes dans le Bakony Septentrional. *Földt. Közl.* 105, 208–219 (in Hungarian).
- Galácz A. & Vörös A. 1972: Jurassic history of the Bakony Mountains and interpretation of the principal lithological phenomena. *Földt. Közl.* 102, 2, 122–135 (in Hungarian).
- Gemmellaro G.G. 1871: Paleontological studies on the “calcare a *Terebratula janitor*” in the north of Sicily. Part 1. *Lao*, Palermo 1–56, 12 pls. (in Italian).
- Géczy B. 1976: Les ammonites du Carixien de la Montagne du Bakony. *Akadémiai Kiadó*, Budapest, 1–223.
- Glover C.P. & Kidwell S.M. 1993: Influence of organic matrix on the post-mortem destruction of molluscan shells. *J. Geol.* 101, 729–747.
- Grabowski J., Haas J., Márton E. & Pszczółkowski A. 2010: Magneto- and biostratigraphy of the Jurassic/Cretaceous boundary in the Lókút section (Transdanubian range, Hungary). *Stud. Geophysica et Geodaetica* 54, 1–26.
- Haas J., Görög Á., Kovács S., Oszvárt P., Matyók I. & Pelikán P. 2006: Displaced Jurassic foreslope and basin deposits of Dinardic origin in Northeast Hungary. *Acta Geol. Hung.* 49, 125–163.
- Hikuroa D.C.H. 2004: The fauna and biostratigraphy of the Jurassic Latady Formation, Antarctic Peninsula, Auckland. [Unpublished Thesis University of Auckland], 1–399.
- Ippolitov A.P. 2006: On the possible expression of sexual dimorphism in *Hibolites* Montfort, 1808 from the Middle and Upper Jurassic of European Russia. In: Barskov I.C. & Leonovoi T.B. (Eds.): Contributions to current cephalopod research: morphology, systematics, evolution, ecology and biostratigraphy. Moscow, 8–10 November 2006. Dedicated to the 90th birthday of the distinguished Russian researchers on fossil cephalopods V.N. Shimansky and V.V. Drushchits. *Russian Acad. Sci., Paleont. Inst.*, Moscow, 57–60 (in Russian).
- Janssen N.M.M. 1997: Mediterranean Neocomian belemnites. Part 1: Río Argos sequence (province of Murcia, Spain): the Berriasian–Valanginian and the Hauterivian–Barremian boundaries. *Scripta Geol.* 114, 1–55.
- Kilian W. 1889: Études paléontologiques sur les terrains secondaires et tertiaires de l'Andalousie. In: Bertrand M. & Kilian W. (Eds.): Mission d'Andalousie. *Mém. Acad. Sci. Inst. Nat. France* 30, 2, 601–739, pls. 24–37.
- Kilian W. & Révil J. 1917: Études géologiques dans les Alpes occidentales. Contributions à la géologie des chaînes intérieures des Alpes françaises. II. Description des terrains qui prennent part à la constitution géologique des zones Intra-Alpines françaises (Suite, système jurassique). *Mém. pour servir à l'Explication de la Carte Géologique détaillée de la France* 1912, 1–273, pls. A–E, XII–XIX.
- Loriol P. de 1886: Étude sur les mollusques des couches Coralli-gènes de Valfin (Jura), précédées d'une notice stratigraphique par l'abbé E. Bourgeat. Partie I. *Mém. Soc. Paléont. Suisse* XIII, 3, 1–120, pls. A–C, I–XI.
- Lowenstam H.A. & Epstein S. 1954: Paleotemperatures of the post Albian Cretaceous as determined by the oxygen isotope method. *J. Geol.* 62, 207–248.
- Lukeneder A. 2009: New biostratigraphic ammonite data from the Jurassic/Cretaceous boundary at Nutzhof (Gresten Klippenbelt, Lower Austria). *Ann. Naturhist. Mus. Wien* 110A, 313–329.
- Mandev P. 1942: Géologie de la Zlatiška Planina et de ses avant-monts dans le circuit du courant supérieur de la rivière Vit. *Rev. Bulgar. Geol. Soc.* 13, 1 (for 1941), 1–71, pl. I–VI (in Bulgarian with French abstract).
- Mariotti N. 1995: Jurassic belemnites and aulacocerites from central Italy. In: Farinacci A. (Ed.): Biostratigraphy of central Italy. *Stud. Geol. Camerti, Vol. Spec.* 1994, parte A, 217–254 (in Italian).
- Mariotti N. 2002a: Upper Callovian–Middle Oxfordian belemnite assemblages from the Monte Kumeta (Jurassic of western Sicily, Italy). *Boll. Soc. Paleont. Ital.* 41, 13–35.
- Mariotti N. 2002b: Systematics and taphonomy of an Early Kimmeridgian belemnite fauna from the Mediterranean Tethys (Monte Nerone, Central Apennines, Italy). *Geobios* 35, 213–232.
- Mariotti N. 2003: Systematics and taphonomy of an Early Kimmeridgian belemnite fauna from the Mediterranean Tethys (Monte Nerone, Central Apennines, Italy). *Geobios* 36, 603–623 [corrected reprint of 2002b].
- Münster G. Graf zu 1830: Bemerkungen zum näheren Kenntniss der Belemniten. *F.C. Birner*, Bayreuth, 1–18, 2 pls.
- Nerodenko V.M. 1983: Early Cretaceous belemnites of the western USSR. In: Starobogatov Ya.I. & Nesis K.N. (Eds.): Systematics and evolution of cephalopod molluscs. *Scientific Acad. USSR, Zoological Inst.*, Leningrad, 42–43 (in Russian).
- Neumayr M. 1873: Die Fauna der Schichten mit *Aspidoceras acanthicum*. *Abh. K.-Kön. Geol. Reichsanst.* V, 141–257, pl. 31–43.
- Nunn E.V., Price G.D., Hart M.B., Page K.N. & Leng M.J. 2009: Terrestrial and marine carbon isotope signals from the Callovian–Kimmeridgian (Late Jurassic) succession at Staffin Bay, Isle of Skye, Scotland. *J. Geol. Soc. London* 166, 633–641.
- Oloriz F. 1978: Kimmeridgian–lower Tithonian of the central part of the Betic Cordilleras (Subbetic Zone) — Paleontology, biostratigraphy. *Univ. Granada, Thesis Doctoral* 184, 1–758 (in Spanish).
- Oppel A. 1865: Die Tithonische Etage. *Z. Deut. Geol. Gesell.* 17, 535–558.
- Pavia G. & Cresta S. (Eds.) 2002: Revision of Jurassic ammonites of the Gemmellaro collections. *Quad. Museo G.G. Gemmellaro, Palermo* 6, 1–408.
- Pavlov A.P. 1914: Les cephalopodes du Jura et du Crétacé inférieur de la Sibirie septentrionale. *Mém. Acad. Impériale Sci. St.-Petersbourg, Ser. 8 — classe physico-mathématique*, XXI, 4, 1–68, 18 pls. (in Russian).
- Pillet L. & de Fromentel E. 1875: Description géologique et paléontologique de la Colline de Lémenc sur Chambéry. *Chatelain*, Chambéry, 1–135, 15 pls.
- Price G.D. & Mutterlose J. 2004: Isotopic signals from late Jurassic–early Cretaceous (Volgian–Valanginian) sub-Arctic belemnites, Yatria River, Western Siberia. *J. Geol. Soc. London* 161, 959–968.
- Price G.D. & Rogov M.A. 2009: An isotopic appraisal of the Late Jurassic greenhouse phase in the Russian Platform. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 273, 41–49.
- Price G.D., Wilkinson D., Hart M.B., Page K.N. & Grimes S.T. 2009: Isotopic analysis of co-existing late Jurassic fish otoliths

- and molluscs: implications for upper ocean water temperature estimates. *Geology* 37, 215–218.
- Retowski O. 1894: Die tithonischen Ablagerungen von Theodosia. Ein Beitrag zur Paläontologie der Krim. *Bull. Soc. Imperiale Naturalist. Moscou* 7, 206–301.
- Riboulleau A., Baudin F., Daux V., Hantzpergue P., Renard M. & Zakharov V. 1998: Évolution de la paléotempérature de eaux de la plate-forme russe au cours du Jurassique supérieur. *Comptes Rendus de l'Académie des Sciences Série II*, 326, 239–246.
- Riegraf W. 1981: Revision der Belemniten des Schwäbischen Jura. Teil 8. *Palaeontographica (A)* 173, 64–139, 5 pls.
- Roman F. 1897: Recherches stratigraphiques et paléontologiques dans le Bas-Languedoc (Thèse). *Ann. Univ. Lyon* 34, 1–345, 9 pls, 1 map.
- Sarti C. 1984: Ammonite fauna and biostratigraphy of the central Trentino region (Kimmeridgian-Tithonian), Northern Italy. *Boll. Soc. Paleont. Ital.* 233, 473–514 (in Italian, English abstract).
- Sarti C. 1993: Ammonite Fauna and biostratigraphy of the Venetian Alp Kimmeridgian. *Mem. Mus. Civi. Storia Naturale Verona*, 1–145 (in Italian, English abstract).
- Scherzinger A., Fözy I. & Parent H. 2010: *Virgatosimoceras* (Ammonoidea, Simoceratidae) from the Lower Tithonian (Upper Jurassic) — revision and value for correlation. *Neu. Jb. Paläont., Abh.* 256, 2, 195–212.
- Schiller W. 1904: Geologische Untersuchungen im östlichen Unterengadin. I. Lischannagruppe. *Ber. Naturforsch. Gesell. Freiberg im Breisgau* 14, 107–180, 5 pls.
- Schweigert G. 1999: Erhaltung und Einbettung von Belemniten im Nusplinger Plattenkalk (Ober-Kimmeridgium, Beckeri-Zone, Schwäbische Alb). *Stuttgarter Beitr. Naturkunde (B; Geologie und Paläontologie)* 273, 1–35.
- Shackleton N.J. & Kennett J.P. 1975: Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: Oxygen and carbon isotope analyses in DSDP sites 277, 279 and 281. In: Kennett J.P. & Houtz R.E. et al. (Eds.): Initial Reports of the Deep Sea Drilling Project, 29. *US Government Printing Office*, Washington, 743–756.
- Sokolov V.D. 1889: Materials for the geology of the Crim. The Tithonian of the Crim. *Material for the Geology of Russia*, XIII, 97–139, pl. II–IV (in Russian).
- Stolley E. 1919: Die Systematik der Belemniten. *Jahresbericht des Niedersächsischen Geologischen Vereins* 11 (for 1918), 1–59.
- Tavera J.M. 1985: Upper Tithonian–Berriasian ammonites of the Subbetic Zone (Betic Cordillera). *Tesis Doctoral, Universidad de Granada*, 1–381 (in Spanish).
- Toucas A. 1890: Étude de la faune des couches tithonique de l'Ardèche. *Bull. Soc. Géol. France, Sér. 3* 18, 560–630, 6 pls.
- Veizer J. 1983: Chemical diagenesis of carbonates: Theory and application of trace element technique. In: Arthur M.A., Anderson T.F., Kaplan I.R., Veizer J. & Land L.S. (Eds.): Stable isotopes in sedimentary geology. *Soc. Econ. Paleont. Mineralogist, Short Course Notes* 10, 3.1–3.100.
- Vetters H. 1905: Die Fauna der Juraklippen zwischen Donau und Thaya. *Beitr. Paläont. Österr.-Ungarns* 17, 4 (for 1904), 223–259.
- Vigh G. 1984: Die biostratigraphische Auswertung einiger Ammoniten-Faunen aus dem Tithon des Bakonygebirges sowie aus dem Tithon-Berrias des Gerecsgebirges. *Ann. Hung. Geol. Inst.* 67, 1–210.
- Weissert H. & Channell J.E.T. 1989: Tethyan carbonate carbon isotope stratigraphy across the Jurassic-Cretaceous boundary: an indicator of decelerated global carbon cycling? *Paleoceanography* 4, 483–494.
- Weissert H. & Mohr H. 1996: Late Jurassic climate and its impact on carbon cycling. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 122, 27–43.
- Zittel K.A. von 1868: Die Cephalopoden der Stramberger Schichten. Belemniten. In: Palaeontologische Studien über die Grenzsichten der Jura- und Kreide-Formation im Gebiete der Karpathen, Alpen und Apenninen. *Palaent. Mitt. Mus. Koeniglichen Bayerischen Staates* 2, 1, 33–38, 1 pl.
- Zittel K.A. von 1870: Die Fauna der aeltern Cephalopoden führenden Tithonbildungen. *Palaeontographica, Suppl.* 2, 2, 1–192, 15 pls.