Llandovery conodonts from the Oslo Region, Norway

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Conodont faunas are described from the middle and upper part of the Llandovery sequence in the central Oslo Region. Stratigraphically important species include *Distomodus staurognathoides*, *Pterospathodus amorphognathoides*, *P. celloni*, *P. pennatus*, *Carniodus carnulus*, and *Apsidognathus walmsleyi*. These species allow recognition of the *celloni* and *amorphognathoides* Zones, as established in Austria and present in Britain. Using faunas described herein, and previously documented collections, a conodont zonation for the Llandovery of the Oslo Region is presented. The paleoecological implications of the conodont distributions are briefly discussed.

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The marine Silurian succession in the Oslo Region has been thoroughly described, notably by Kiær (1908) and more recently by Worsley (1982) and Worsley et al. (1983). Culminating with the IUGS Silurian Field Meeting 1982, major syntheses of biostratigraphy and sedimentology have been presented in recent years (Worsley 1982). A general overview on conodonts was included in the latter publication (Aldridge & Mohamed 1982), and the present work deals with more detailed sampling, concentrating on the two uppermost Llandovery formations; the Rytteråker Formation as defined at Lemonstangen (NM 691591) and Vik Formation as defined near Rytteråker farm (NM 695596), both localities in the Ringerike district 45 km WSW of Oslo (Worsley et al. 1983). As no new taxa are introduced, a systematic paleontologic section is omitted. Remarks on some taxa and on the existing biostratigraphy are included in the text. Previous work on Silurian conodonts from the Oslo Region has also been utilized, including that of Aldridge (1974), describing an *amorphognathoides* Zone conodont fauna from the Ringerike district, and the contributions of Aldridge & Mohamed (1982), Aldridge (1984) and Idris (1984) on regional faunas, conodont colour alteration and conodont paleoecology respectively. Sample localities are in the central Oslo Region (Malmøya and Malmøykalven), Sandvika (20 km SSW of Oslo) and Ringerike (50 km WSW), as shown on the map (Fig. 1). Sample code abbreviations (as used in the Figs.): MKR = Malmøykalven, Rytteråker Formation, MKV = Malmøykalven, Vik Formation and KPV = Sandvika (Kampebråten), Vik Formation. Standard conodont techniques (acetic acid and tri-brome-methane) were used. The 'light' fraction was not examined. Photographs were made using a 'JEOL' Scanning Electron Microscope. Numbered slides are housed at Paleontologisk Museum, University of Oslo, Oslo. Sample weights and number of conodont elements are shown in Table 1.

Stratigraphy

The stratigraphy is well documented by Worsley et al. (1983). Brachiopods including *Borealis* and *Pentamerus* suggest a mid-Aeronian to mid-Te-

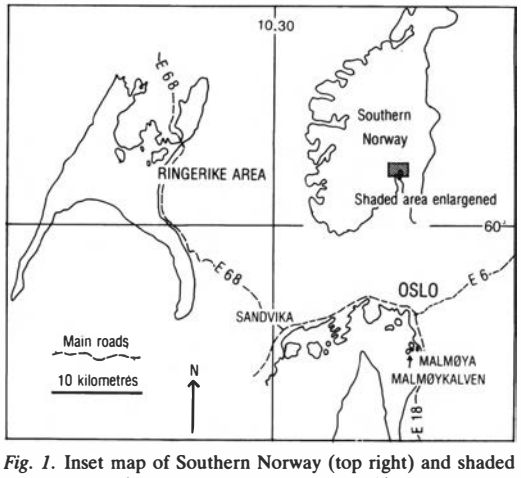


Fig. 1. Inset map of Southern Norway (top right) and shaded sampling area (enlarged; right bottom and left).

Table 1. Numbers of conodont elements per sample from Malmøykalven, Rytteråker Fm (MKR). Malmøykalven, Vik Fm (MKV) and Sandvika, Kampebråten, Vik Fm (KPV). Sample numbers and stratigraphic position over base of formation are equivalent; sample weight in kilograms, eg. 44.0/4.0 = sample 44.0, 44.0 m over formational base / 4.0 kilos.

sample / weight / taxa	MKR									MKV												KPV								
	44.0/4.0	-2.0/3.7	1.3/2.5	9.6/2.9	14.7/2.6	19.9/2.4	24.1/2.5	26.7/2.5	31.7/1.4	36.3/4.7	37.9/2.5	39.8/6.0	42.5/3.2	43.3/5.4	45.2/4.8	46.2/3.1	47.0/1.0	48.7/2.5	-7.0/2.2	1.4/3.0	5.1/3.0	22.5/3.7	45.5/3.7	51.5/3.0	63.0/2.8	69.0/4.0	73.0/3.0	79.1/2.5
Apsidognathus walmsleyi Pa																								6			1	
Pb																								3				
Aulacognathus bullatus								5				1	1															
Belodella silurica								16				10														11		
Carniodus carnulus Pb									1			4	4	3		5		1	1					4		3		
M																									2			
Sa									1				1	2		1		1	1									
Sb												3		3		3	2	1	1							1		
Sc												1		2		4	3	1						8	2			
Dapsilodus obliquicostatus				1				6													7	1			8			
Decoriconus fragilis								6			1					1												
Distomodus staurognathoides Pa						1		10	1							2					2			1		1		1
Pb							1	3																				
M							1																	1				
Sa				1			1		1							1			2					1		2		
Sb							2																					
Sc				3		1	1	1																		2		
Johnognathus huddlei								5																				
Johnognathus sp.																		1						3				
Oulodus? fluegeli Pa								2													1							
M								2	1												1	1						
Sa																					1							
Sb								2														1						
indiff.					1								1	2		1		7	1		4	3	3	5	6			
Oulodus petila Pa																		1						2				
M																		1						1				
Sc																		1						1				
Oulodus sp. indiff.								8		1						1	1									7		
Ozarkodina polinclinata Pb											2		1															
Sc									1		1																	
Ozarkodina sp. nov. A			1																									
Ozarkodina sp. indiff.									2	1								1										
Panderodus recurvatus						2		5										1			14	1		10	10	17	6	
Panderodus unicostatus	1		10	61			12	290	4		7		3			6	2		2	2	90	7	3	10	40	35	9	2
Panderodus sp.	1	3	7	4	10	15	2	149	6	5	9	30	3	24	10	7		45						135	10	56		8
Pseudooneotodus bicornis									2				4	2				8							2			
Pseudooneotodus tricornis									9				3				2	2	2									
Pterospathodus amorphognathoides Pa															2	39	2	3	6							4	2	4
Pb															2	28	2	2	3							2		2
M																8	2	3	2									
S																12		1								1		
P.celloni Pa									4			3	5	5								2	3	6	4			
Pb									2				12											9				
M									1															8				
S													3											16				
P. pennatus Pa									1	2	2	7	5	5	1			3						16	5	2	2	1
Pb											3	8																
M										2	1	2																
S												4																
Walliserodus sp.								17	2			1									7			2	10	2		

lychian age for the Rytteråker Formation in the studied areas. Brachiopods from the Vik Formation include *Pentamerus, Pentameroides,* and *Costistricklandia,* indicating a Telychian (C4-C6) age. The top of the Vik formation is somewhat diachronous as noted by Bassett & Rickards (1971), being slightly older in Sandvika than on Malmøykalven. Graptolites from the overlying Skinnerbukta Formation on Malmøya include species of *Monograptus, Monoclimacis,* and *Cyrtograptus,* suggesting a Wenlock age for this formation (Bassett & Rickards 1971).

Lithology

The transition from the Solvik Formation (lowermost Llandovery) to the Rytteråker Formation is defined by a limestone dominance *contra* siliciclastic silt and mudstone. The carbonate content increases and texture coarsens upwards. Reef developments are observed near the top of the Rytteråker Formation in Ringerike. The Rytteråker Formation has a composite thickness of more than 70 m at Malmøykalven, thinning out in a northern/westwards direction.

The base of the Vik Formation is defined by an abrupt siliciclastic input producing several shale horizons. The first few metres show intercalating shales and calcareous mudstone beds. Upwards the carbonates are developed as fine nodular limestones in a marly mudstone matrix, with packstone and grainstone lenses occasionally developed. An intraformational breccia or conglomerate is observed 40 m above the formational base. In Sandvika, the top of the Vik Formation also contains thin bentonitic horizons. The top of the Vik Formation is marked by the greyish black graptolite shales of the overlying Skinnerbukta Formation. The Vik Formation has a composite thickness of more than 55 m at Malmøykalven, and approximately 80 m in Sandvika.

The regional Permian volcanic activity (Ramberg & Larsen 1978) has metamorphosed the sedimentary rocks of the Oslo Graben. This can be read from the Colour Alteration Index (Epstein, Epstein & Harris 1977) of the conodont elements. The conodonts in the present investigation are generally black, with a C. A. I. of 5, corresponding to more than 300°C. Collections made close to intrusive bodies have yielded bluish or white opaque conodonts. A comparative study on C. A. I. in the Oslo Region was presented by Aldrige (1984).

Depositional environments

The Rytteråker Formation shows an increasing number of coarse bioclastic limestones from the base upwards. These are thought to represent periods of higher water energy. Fossils include pentamerid brachiopods, stromatoporoids and abundant rugose and tabulate corals, typical of Benthic Assemblage 3 of Boucot (1975). Algae, observed in thin sections (N. Möller, in prep.) near the top of the formation at Malmøykalven, may indicate an environment in the photic zone.

The base of the Vik Formation is marked by a sudden input of a considerable amount of fine siliciclastic material resulting in several shale beds. At this level, no coarse bioclastic limestone is observed. Brachiopods comprise species of a *Clorinda* Community fauna (cf. Ziegler et al. 1968). This indicates a sudden deepening following the rather shallow environment facies at the top of the underlying Rytteråker Formation. Twenty metres above the base of the formation, *Pentameroides* occurs in life position, indicating a somewhat shallower setting. The Vik Formation fauna is dominated by corals and stromatoporoids in the lower part, with an increasing number of crinoids in the upper part. The presence of numerous, but rather thin bioclastic limestone lenses in the upper part of the formation may be the result of higher energy episodes.

The conodont fauna

Conodonts from the Vik Formation, Malmøykalven (NM 976378)

18 samples, totalling 55 kg of mixed shales- and carbonate rock (nodules, lenses and rubbly beds) were collected. The lowermost samples contain the stratigraphically important species *Distomodus staurognathoides* (Walliser) (Fig. 8a,b). Coniform conodonts dominate the samples at this level. The frequency of coniforms ranges from almost 100% in the lowermost samples to 30%–40% near the top of the formation (Fig. 2).

The fauna is richer and more diverse in the middle part of the formation. Sample MKV-26.7 is remarkably rich. Twelve taxa represented by a 530 elements were extracted from this 2.5 kilo sample. This is the most diverse and rich sample found anywhere in the present work. Otherwise, the average number of elements is between 20 and 30 per kg rock through the Vik Formation. Species appearing near this level include *Aula-*

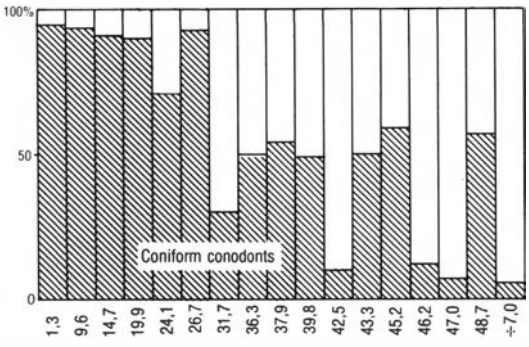


Fig. 2. Percentage coniform conodont distribution (shaded) plotted in relation to ramiform conodont distribution (open) from the Vik Formation, Malmøykalven/Malmøya. Sample codes are explained in the text.

cognathus bullatus (Nicoll & Rexroad) (Fig. 8g,i,j), *Johnognathus huddlei* Mashkova (Fig. 6k), *Oulodus? fluegeli* (Walliser) (Fig. 7b,e,i,h) and *Distomodus staurognathoides*. The coniform fauna includes *Panderodus unicostatus* (Branson & Mehl) (Fig. 7j), *Decoriconus fragilis* (Branson & Mehl). *Dapsilodus obliquicostatus* (Branson & Mehl), *Belodella silurica* Barrick and *Walliserodus* sp. All the stratigraphically diagnostic species indicate that the samples are high above the *Distomodus staurognathoides* Datum Plane proposed by Cooper (1980).

The appearance of *Pterospathodus celloni* (Walliser) (Fig. 6a) in MKV-31.7 permits a more detailed assignment. Furthermore, occurrences of *Pterospathodus pennatus* (Walliser) (Fig. 6h) and of *Carniodus carnulus* Walliser (Fig. 61, 7c) indicate a high *celloni* Zone age (Walliser 1964). *P. celloni* is abundant in samples up to and including MKV-43.3. The succeeding sample (MKV-45.2) displays good specimens of *P. amorphognathoides* Walliser (Fig. 6a-g,i) defining the base of the *amorphognathoides* Zone (Walliser 1964). *P. celloni* and *P. amorphognathoides* have not been found together in any sample. Thus, a co-occurence of these species (Schönlaub 1971; Cooper 1980) has not been observed in the present work.

There seems to be a difference between Pa elements of *P. amorphognathoides* from the lower part of the *amorphognathoides* Zone and those from the upper part. Specimens from the lower part exhibit a narrower platform margin, and the denticles are better developed and spaced, but in smaller numbers (Fig. 6g). Upwards in the *amorphognathoides* Zone, the platform becomes broader, the number of denticles increases, and the denticles become more fused (Fig. 6d). The Pb elements show smaller variations, notably the cusp being erect or being slightly inclined in the different specimens. This variation is not believed to have any stratigraphical significance (Fig. 6b,i). Very few new species are introduced in the lower part of the *amorphognathoides* Zone (10 to 20 m below the top of the Vik Formation) – only *Oulodus petila* (Nicoll & Rexroad) (Fig. 8h) (MKV-31,7) and *Ozarkodina polinclinata* Nicoll & Rexroad (MKV-37.9) were recognized as additional. The base of the *amorphognathoides* Zone (Walliser 1964), equivalent to the *Pterospathodus amorphognathoides* Datum Plane of Cooper (1980), lies within the top of the Vik Formation, 45.2 m above the formational base at Malmøykalven. Species of *Pterospathodus* are abundant in all the uppermost samples, indicating that the *Pterospathodus* Extinction Plane (Cooper 1980) should be found in an overlying Wenlock horizon. A conodont range chart and a simplified lithological outline from Malmøykalven/Malmøya are presented in Fig. 3.

Conodonts from the Vik Formation, Sandvika (NM 846403)

To investigate a possible lateral variation in conodont faunas, nine samples were collected from Sandvika (13 km SSW of Oslo). The *Pterospathodus amorphognathoides* Datum Plane (Cooper 1980) was found in the upper part of the formation on Malmøykalven, thus the sampling in Sandvika was concentrated on the upper part of the Vik Formation.

The number of conodont elements/sample is very similar to the observations at Malmøykalven, 24 as against 22 per kg of carbonate rock. The number of taxa seems to be slightly lower, ranging from three to ten in each sample. *Distomodus staurognathoides* occurs throughout the section, *Oulodus? fluegeli* is restricted to the *celloni* Zone here, and *Pterospathodus pennatus* is found in the upper part of the *celloni* Zone extending into the *amorphognathoides* Zone. *Pterospathodus amorphognathoides* is first found in sample KPV-69.0 and the *Pterospathodus amorphognathoides* Datum Plane (Cooper 1980) is proposed in Sandvika at this level. Although the fauna in Sandvika resembles the fauna at Malmøykalven, *Decoriconus fragilis* is absent and *Apsidognathus walmsleyi* Aldridge (Fig. 8c-f) is the only additional species in the Sandvika samples. Well preserved Pa and Pb elements occur,

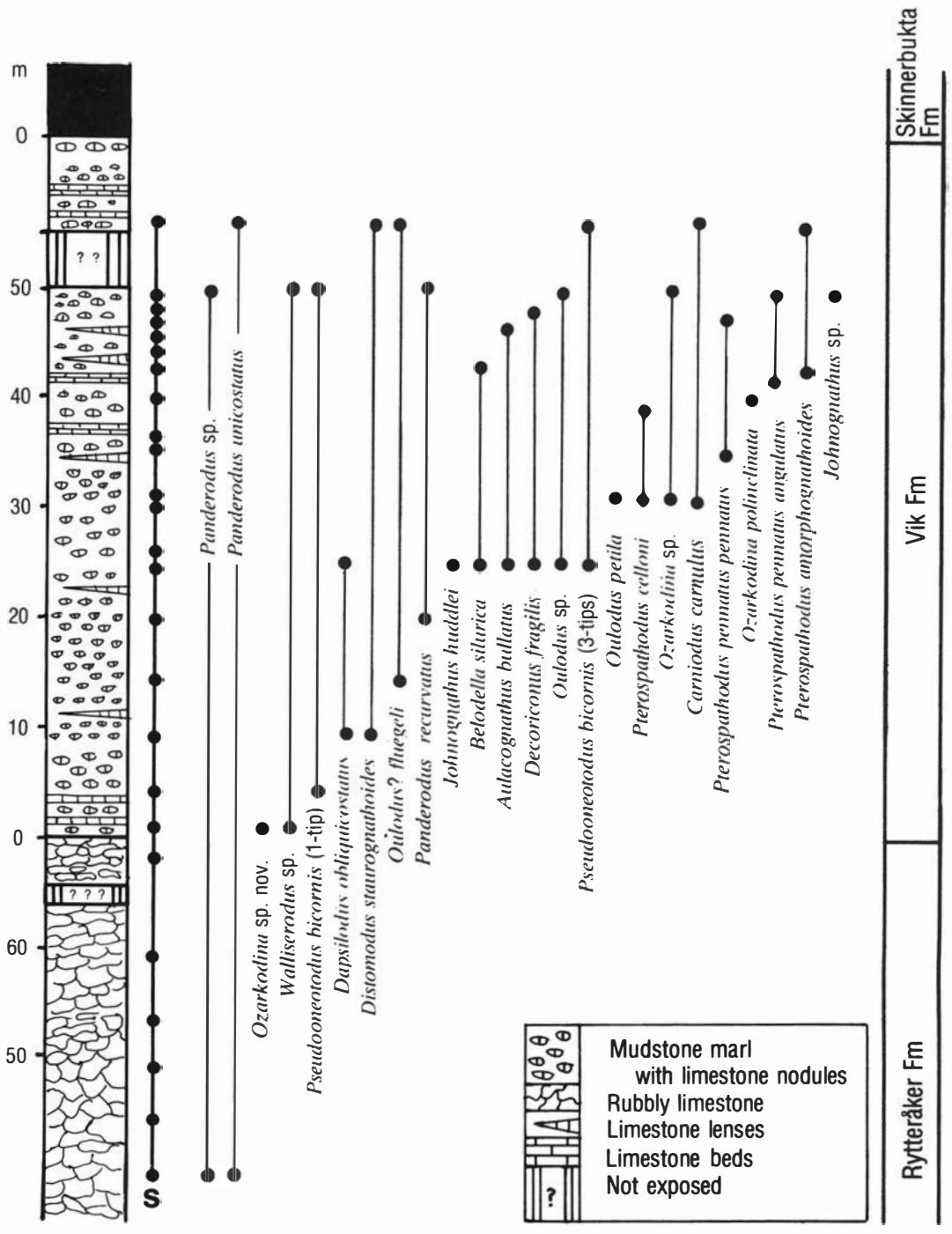


Fig. 3. Stratigraphical distribution of conodonts from Rytteråker and Vik formations in a composite section from Malmøya/Malmøykalven. Metre measurements are those taken from the base of the respective formations. S = sample points.

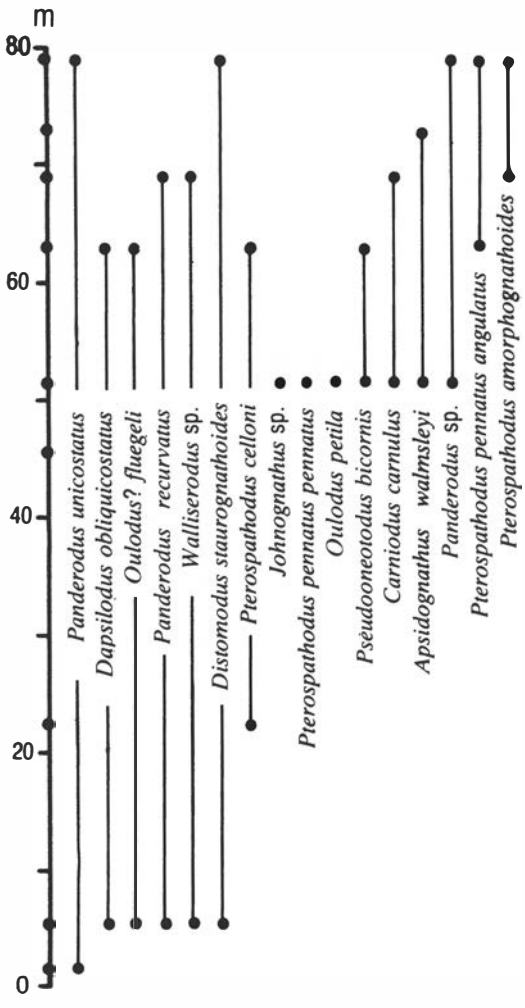


Fig. 4. Stratigraphical distribution of conodonts from the Vik Fm. at Sandvika. O m = base of formation.

notably in sample KPV-51.5. A conodont range chart from the Sandvika section is presented in Fig. 4.

Conodonts from the Rytteråker Formation, Malmøykalven

To trace the base of the *celloni* Zone, six samples of average weight 4.0 kg were collected from the uppermost 20 m of the Rytteråker Formation at Malmøykalven. The lithology is dominated by coarse bioclastic rubbly and nodular limestone and the fauna is dominated by corals, stromatoporoids and crinoids. All these samples were barren, except for one *Panderodus unicostatus* and four broken elements of *Panderodus* sp. Aldridge & Mohamed (1982) noted the sparsity of conodonts in the Rytteråker Formation throughout the Oslo Region. They report fragments of *Ozarkodina oldhamensis* (Rexroad) and *Pterospathodus? tenuis* (Aldridge) near the base of this formation at Malmøya (NM 976377) and *Pte-*

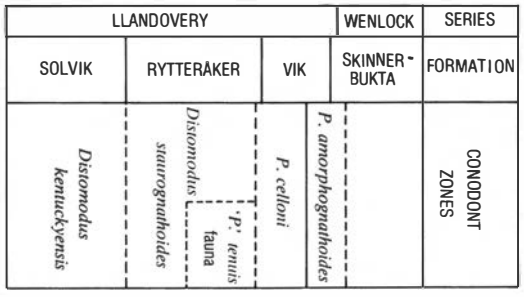
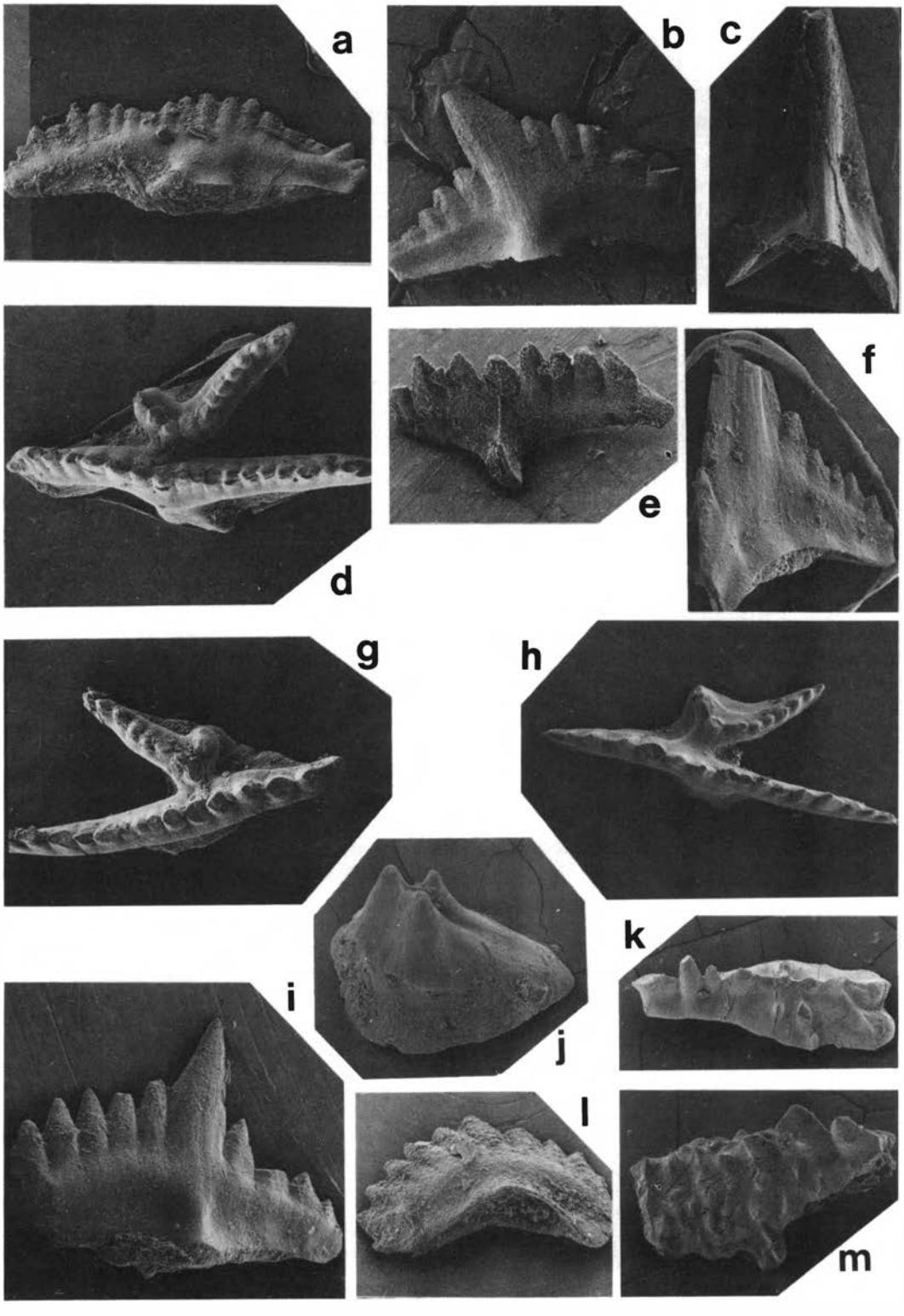


Fig. 5. Proposed conodont biozones for the Central Oslo Region. Dashed lines = estimated boundaries, solid line = observed boundary described herein. After Aldridge & Mohamed (1982), Idris (1984) and Nakrem (herein).

Fig. 6.
a, *Pterospathodus celloni,* PMO 111.196/1, Vik Fm 42.5 m, Malmøykalven, 40×.
b, *P. amorphognathoides* Pb, PMO 111.216/11, Vik Fm 79.0 m, Sandvika, 75×.
c, *P. amorphognathoides* M, PMO 111.199/26, Vik Fm 46.2 m, Malmøykalven, 75×.
d, *P. amorphognathoides* Pa, PMO 111.202/1, Vik Fm 7 m below top of profile, Malmøya, 55×.
e, *P.* sp., juvenile, PMO 111.201/6, Vik Fm 48.7 m, Malmøykalven, 70×.
f, *P. amorphognathoides* S, PMO 111.199/27, ;Vik Fm 46.2 m, Malmøykalven, 75×.
g, *P. amorphognathoides* Pa, PMO 111.199/6, Vik Fm 46.2 m, Malmøykalven, 55×
h, *P. pennatus pennatus* Pa, PMO 111.199/2, Vik Fm 46.2 m, Malmøykalven, 40×.
i, *P. amorphognathoides* Pb, PMO 111.199/11, Vik Fm 46.2 m, Malmøykalven, 40×.
j, *Pseudooneotodus tricornis,* PMO 111.201/60, Vik Fm 48.7 m, Malmøykalven, 50×.
k, *Johnognathus huddlei,* PMO 111.192/3, Vik Fm 26.7 m, Malmøykalven, 35×.
l, *Carniodus carnulus,* PMO 111.196/7, Vik Fm 42.5 m, Malmøykalven, 80×.
m, *Johnognathus* sp., PMO 111.201/10, Vik Fm 48.7 m, Malmøykalven, 40×.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rospathodus celloni in a sample from the uppermost Rytteråker Formation collected from the southernmost parts of the Oslo Region. Fragments of *Distomodus* aff. *staurognathoides* have been found near the base of the Rytteråker Formation in samples from Asker, 15 km SW of Sandvika (Aldridge & Mohamed 1982). This produces the framework for Fig. 5, where data from Aldridge & Mohamed (1982) are included.

The lack of conodonts in the Rytteråker Formation is enigmatic. Abundant conodont faunas are preserved both below and above this formation. A comparative study on lithology and conodont abundance was presented by Miller (1978). His 'Unit 2' (Wenlockian) massive dolostone is thought to represent very shallow or restricted environments, producing barren conodont samples. As mentioned in the introduction, the Rytteråker Formation is characterized by coarse, bioclastic limestones, infrequent dolomitization, a shallow water macrofauna and algae (observed in thin sections), suggesting that the sparsity of conodonts is connected with very shallow water. This does not necessarily mean 'nearshore', but more probably an offshore carbonate reefal crest. Samples from the underlying Sælabonn Formation (nearshore, sandy equivalent of the Solvik Formation) have provided reasonable conodont faunas (Aldridge & Mohamed 1982). An explanation for the lack of conodonts in the Rytteråker Fm. can be that the environmental conditions were too hostile for the conodont animal (e.g. too high water energy, too shallow water column), and the very few conodonts observed here might be transported in from deeper environments.

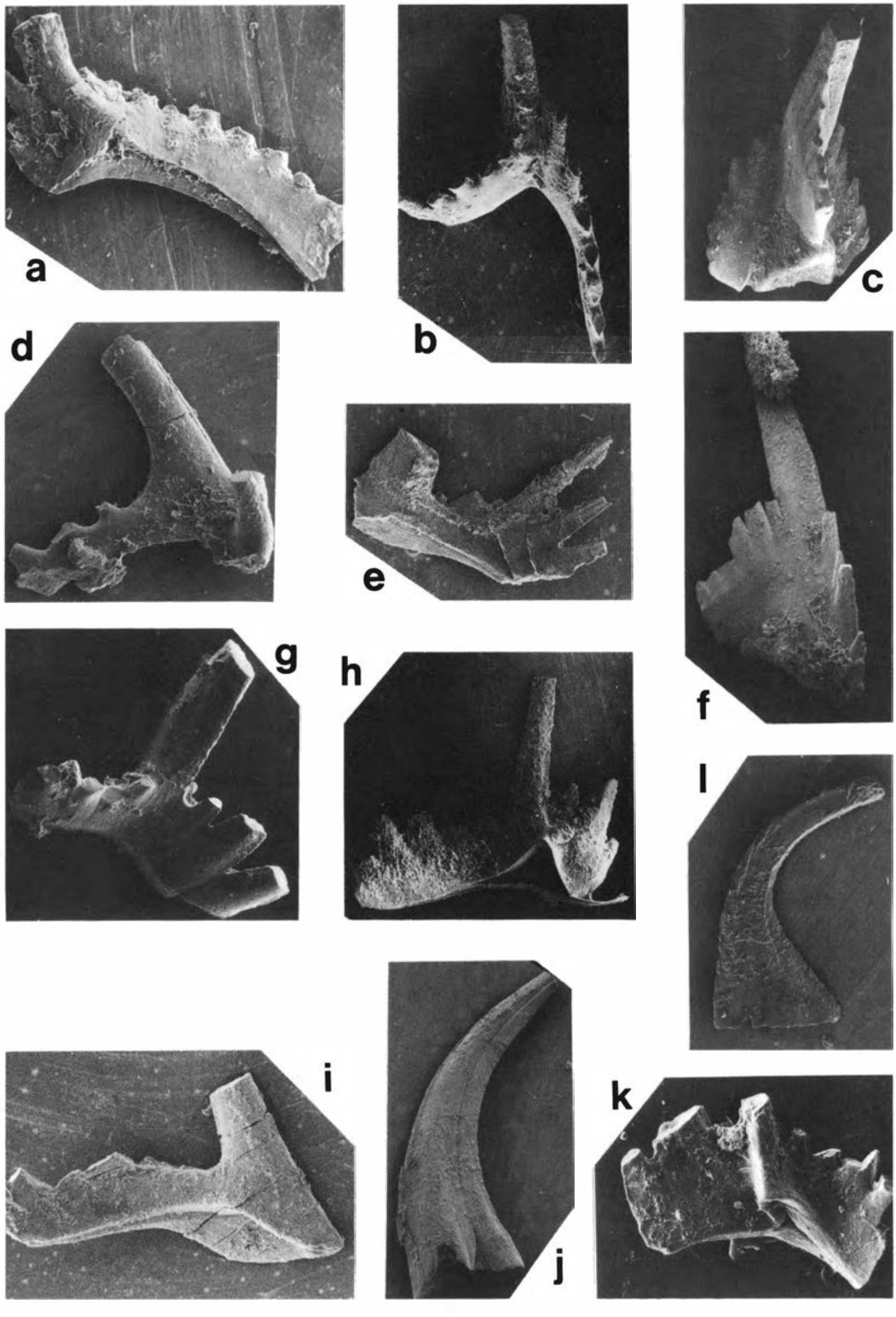
Conodont biostratigraphical conclusion

The lowermost *Distomodus kentuckyensis* Zone spans most of the Solvik Formation. The conodont fauna recovered by Aldridge & Mohamed (1982) and Mohamed (1984) is fairly rich, and important species from the Malmøykalven-Sandvika area include:

Distomodus kentuckyensis Branson & Branson
Icriodella discreta Pollock, Rexroad & Nicoll
I. deflecta Aldridge
Oulodus kentuckyensis (Branson & Branson)
Ou. cf. *nathani* McCracken & Barnes
Ozarkodina hassi (Pollock, Rexroad & Nicoll)
Oz. oldhamensis (Rexroad)
Oz. protexcavata Cooper

In Fig. 5 the base of the *Distomodus staurognathoides* Zone is placed just above the base of the Rytteråker Formation. Broken elements of *Distomodus* aff. *staurognathoides* have been found 0.8 m below the top of the Solvik Formation in Asker (near Sandvika) (Aldridge & Mohamed 1982). Further sampling may place the base of the *Distomodus staurognathoides* Zone more accurately near the Solvik/Rytteråker Formation boundary. Both the *D. kentuckyensis* Zone and the *Distomodus staurognathoides* Zone can be correlated with zonations in Great Britain (Aldridge 1972) and Anticosti Island (Uyeno & Barnes 1983) as well as other parts of the world. The Rytteråker Formation produces very few conodonts, but in the Ringerike area (Fig. 1), elements of an *Pterospathodus? tenuis* (= 'Amorphognathus' tenus Aldridge & Mohamed 1982) fauna were recovered near the formational base. The conodont fauna is generally too sparse and incomplete for detailed stratigraphical use.

Fig. 7.
a, *Oulodus* sp. Sb/Sc, PMO 111.211/12, Vik Fm 51.5 m, Sandvika (Kampebråten), 130×.
b, *Oulodus? fluegeli* Sb, PMO 111.192/21, Vik Fm 26.7 m, Malmøykalven, 80×.
c, *Carniodus carnulus* Sa, PMO 111.199/31, Vik Fm 46.2 m, Malmøykalven, 80×.
d, *Oulodus* sp. Sc, PMO 111.211/12, Vik Fm 51.5 m, Sandvika (Kampebråten), 65×.
e, *Oulodus? fluegeli* M, PMO 111.211/12, Vik Fm 51.5 m, Sandvika (Kampebråten) 80×.
f, *Carniodus carnulus* Sb, PMO 111.201/5, Vik Fm 48.7 m, Malmøykalven, 80×.
g, *Oulodus* sp. Sa, PMO 111.192/20, Vik Fm 26.7 m, Malmøykalven, 80×.
h, *Oulodus? fluegeli* Pa, PMO 111.192/20, Vik Fm 26.7 m, Malmøykalven, 80×.
i, *Oulodus? fluegeli* M?, PMO 111.211/12, Vik Fm 51.5 m, Sandvika (Kampebråten), 80×.
j, *Panderodus unicostatus,* PMO 111.192/76, Vik Fm 26.7 m, Malmøykalven, 65×.
k, *Oulodus* sp. Sc, PMO 111.192/29, Vik Fm 26.7 m, Malmøykalven, 130×.
l, *Dapsilodus obliquicostatus,* PMO 111.192/29, Vik Fm 26.7 m, Malmøykalven, 75×.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The base of the *Pterospathodus celloni* Zone lies within the top of the Rytteråker Formation. *P. celloni* is found close to the top of this formation in Skien (Aldridge & Mohamed 1982). Further sampling in deeper water environmental settings of the Rytteråker Formation may produce better faunas. The lower part of the *P. celloni* Zone is dominated by coniform conodont elements both in Sandvika and on Malmøykalven. In the upper part important additional species are:

Oulodus? fluegeli, Johnognathus huddlei, Aulacognathus bullatus, Oulodus petila, Apsidognathus walmsleyi, Carniodus carnulus, Pterospathodus pennatus pennatus, P. pennatus angulatus, Ozarkodina polinclinata.

The fauna is moderately to very rich. The base of the *P. amorphognathoides* Zone lies within the top of the Vik Formation, 45.2 and 69.0 metres above the base of the formation at Malmøykalven and Sandvika respectively. Within the *celloni* and *amorphognathoides* Zones some species are observed outside their previously designated zones. Among these are *Belodella silurica* Barrick and *Dapsilodus obliquicostatus* (Branson & Mehl), previously assigned to the Upper Silurian (Barrick 1977). *Decoriconus fragilis* (Branson & Mehl) and *Panderodus recurvatus* (Rhodes) are found in the *celloni* Zone as well as in the *amorphognathoides* Zone, though Barrick (1977) proposed only an *amorphognathoides* Zone distribution. Among the ramiform conodonts, *Johnognathus huddlei* Mashkova is also found in the *celloni* Zone, contrary to the distribution observed by Mashkova (1977). The observed extended ranges were also observed in the British Silurian (Mabillard & Aldridge 1985). The amorphognathoides Datum has been recognized from many parts of the world (Cooper 1980), and a valuable correlation with the Oslo Region is possible. Above the base of the amorphognathoides Zone, apart from *Pterospathodus amorphognathoides* Walliser, no new conodont taxa are introduced.

Conodont paleoecology

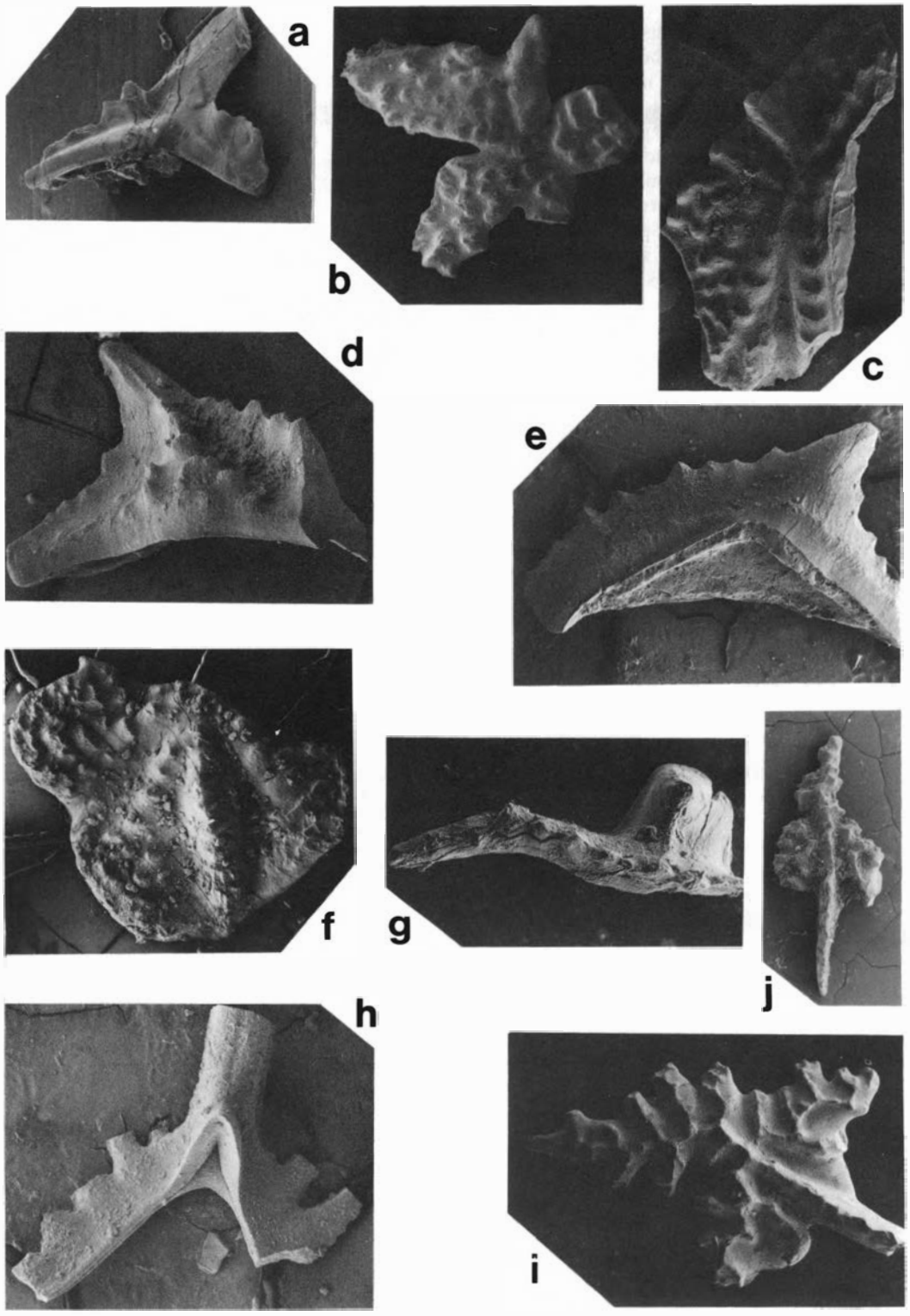
Species distributions and interactions from the *Distomodus kentuckyensis* Zone in the Oslo Region have previously been described by Idris (1984). In the *celloni-* and *amorphognathoides* Zones, a few additional remarks can be made:

1. The coniform *vs.* ramiform element distribution in Fig. 2 shows that coniforms dominate (90%) in the deepest settings of the lower part of the Vik Formation at Malmøykalven. The coniform percentage decreases irregularly upwards in the formation (30%). In the Sandvika section, coniforms dominate overall (50–70%) through the Vik Formation. The bathymetry from these areas described by Johnson & Worsley (1982) was based on brachiopod communities and indicated a deepening near the top of the formation. Winnowed bioclastic debris observed as packstone and grainstone lenses that may indicate episodes of higher energy, produced a high proportion of ramiform conodonts, probably representing transported concentrations.

2. Certain species occur in samples believed to represent well defined environmental settings. *Apsidognathus walmsleyi* is found only in Sandvika, and in reconnaissance samples from Ringerike. These samples have shown algae and dolomite crystals in thin sections, which in turn may indicate photic environment and shallower water.

Fig. 8.

a, *Distomodus staurognathoides* Sa, PMO 111.199/9, Vik Fm 46.2 m, Malmøykalven, 80×.
b, *Distomodus staurognathoides* Pa, PMO 111.192/10, Vik Fm 26.7 m Malmøykalven, 35×.
c, *Apsidognathus walmsleyi* Pa, PMO 111.211/9, Vik Fm 51.5 m, Sandvika (Kampebråten), 45×.
d, *A. walmsleyi* Pb, PMO 111.211/10, Vik Fm 51.1 m, Sandvika (Kampebråten), 80×.
e, *A. walmsleyi* Pb, PMO 111.211/10, Vik Fm 51.5 m, Sandvika (Kampebråten), 80×.
f, *A. walmsleyi* Pa, PMO 111.211/9, Vik Fm 51.5 m, Sandvika (Kampebråten), 45×.
g, *Aulacognathus bullatus* Pa, juvenile, PMO 111.206/3, Vik Fm, Ringerike, 50×.
h, *Oulodus petila* Sa, PMO 111.211/6, Vik Fm 51.5 m, Sandvika (Kampebråten), 80×.
i, *Aulacognathus bullatus* Pa, PMO 111.192/1, Vik Fm 26.7 m, Malmøykalven, 35×.
j, *Aulacognathus bullatus* Pa, juvenile, PMO 111.205/1, Vik Fm, Ringerike, 40×.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Apsidognathus ruginosis Mabillard & Aldridge 1983 (=*A.* sp. nov. Aldridge & Mabillard 1981) was originally believed to be a shallow water indicator although the case may need reconsideration (Aldridge, pers. comm.). Worsley et al. (1983) proposed a deepening of the Silurian shelf sea from Sandvika to Malmøykalven. In the present study, *A. walmsleyi* is only found in the Sandvika section and is therefore considered to be a shallow water dwelling species. *Decoriconus fragilis* on the other hand is only found in the deepest settings of the Vik Formation at Malmøykalven. This species has been described as preferring deep water conditions, documented from the Welsh Borderland (Aldridge & Mabillard 1981). *Pterospathodus celloni, P. pennatus* and *P. amorphognathoides* are most abundant in samples of fairly shallow water origin, but as noted previously, the shallowest settings (Rytteråker Formation at Malmøykalven) have a dramatically low conodont content.

The bathymetric implications assessed by coniform conodonts (Aldridge 1976, Aldridge & Mabillard 1981, Idris 1984) verify the bathymetry already proposed by Johnson & Worsley (1982) in the lower and middle Llandovery formations. In the Vik Formation at Malmøykalven, the conodonts indicate a shallowing rather than a deepening (cf. Johnson & Worsley 1982, fig. 2A). New discoveries of in situ pentamerids in the middle part of the Vik Formation support the conodont based bathymetry. In the *D. kentuckyensis* Zone, *Panderodus unicostatus* obviously preferred an off shore/deep water environment (Idris 1984). This tendency is also present in the *celloni* and *amorphognathoides* Zones, contrary to the observations in the Welsh Borderland (Aldridge & Mabillard 1981, fig. 1.3 and 1.4).

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