ON THE SERIES OF THE ORDOVICIAN SYSTEM

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ABSTRACT

Attention is drawn to the confusion that has resulted from indiscriminate use of terms Lower, Middle, and Upper Ordovician. Different recent definitions of these terms are reviewed. A reasonably exact world-wide subdivision of the system is considered to be scarcely possible at present, the correlation of the levels of the boundaries being too vague even in the graptolitic facies. It is found preferable at the time being to stress the existence of a profound palaeozoogeographical differentation, especially during the early part of the Ordovician Period, by using separate subdivisions of the series category for each major palaeozoogeographical province.

For avoiding confusion the use of the terms Lower, Middle, and Upper Ordovician is discouraged, and it is suggested, following North American practice, to apply regional names for these series. In the classification of the Ordovician of Baltoscandia the subdivision proposed by Raymond (1916) is followed and the boundaries drawn according to his suggestions. The correct terms for the series so defined are, in descending order, the Harjuan, Viruan, and Oelandian Series (Kaljo, Rõõmusoks, and Männil, 1958). The boundary between the Harjuan and Viruan Series is defined as that between the zones of *Dicranograptus clingani* and *Pleurograptus linearis*, and the boundary between the Viruan and Oelandian Series provisionally as that between the zones of *Didymograptus bifidus* and *D. murchisoni* (Jaanusson, 1960a).

INTRODUCTION

THE classification of the Ordovician System at the series level is, especially in Europe, in a state of confusion. There exist several, in part widely different, classifications, and the matter is further confused by the frequent use of identical terms, such as Middle Ordovician, for different parts of the system.

The series is a chrono-stratigraphic unit which normally (except where subsystems may be recognized) is ranked next below a system. In the Ordovician System a bipartite (Lower and Upper Ord.) or tripartite (Lower, Middle, and Upper Ord.) subdivision is commonly applied. Occasionally also Tremadocian is ranked as a separate series, and the remaining Ordovician subdivided into three series resulting in a quadripartite subdivision of the system. In addition also five or six of the British Ordovician subdivisions (including Tremadocian) are often termed series or treated as subdivisions of the bipartite or tripartite classification of the system.

There exists an astonishingly large number of different definitions of the terms Lower, Middle, and Upper Ordovician. Indeed the confusion is so great that it is sometimes difficult to know exactly what part of the Ordovician is meant. Most, but certainly not all, of the various definitions of the Ordovician series in Europe are given in the Table I. In that table the deliminations of the series of different regions or by different writers are given by reference to the British standard graptolite zones (ELLES & WOOD 1914, p. 526), and according to the current correlation. The latter is not always exact, since several boundaries have not been defined in terms of the graptolite zones.

The Ordovician Period, especially its early part, is characterized by an extensive palaeozoogeographical differentiation. The fauna of the North American and Arctic Canadian Series differs profoundly from that of the contemporaneous beds of European limestone as well as mudstone facies. Considerable differences exist also between the Australo-North American and British-Scandinavian successions of graptolite faunas. For this reason intercontinental correlations of the Ordovician System are at present not reliable enough for a classification that could be recognized and put to practical use all over the world. In this contribution the classification of the European sequence of the system is considered in the first hand.

An examination of Table I suggests that for the prevention of misunderstandings the use of the terms like Upper, Middle, and Lower Ordovician should be avoided, and regional names applied for these series in different major palaeozoogeographical provinces. Tremadocian is an unambiguous term, as is Canadian. But a formation or fauna which is stated to be of an early Upper Ordovician age may be early Middle Ordovician in some other classification.

HISTORICAL SURVEY OF THE SERIES CONCEPT IN THE ORDOVICIAN OF EUROPE

When proposing the Ordovician System LAPWORTH (1879a, p. 15) pointed out that it might preferably be subdivided into a Lower and an Upper Ordovician, but did not define these subdivisions. The definition of these terms was given in a subsequent paper (1880, pp. 192–199) after a careful and thorough discussion of the Ordovician stratigraphy in general and of the international zonal classification of the graptolitic facies in particular. He (1880, p. 192) found that "the Ordovician falls most naturally into two main divisions—a Lower or Arenig division, and an Upper or Bala division—the line of demarcation between them passing through the middle of the so-called Llandeilo formation [as defined by HICKS 1875]". The boundary was drawn at a level, where one of the most marked changes in the graptolite faunas takes place, manifested by the sudden and almost complete disappearance of the "*Didymograpta*" and by the appearance of "*Dicellograpta*" and *Nemagraptus*. In modern terms this boundary coincides with that between the zones of *Didymograptus murchisoni* and *Glyptograptus teretiusculus*.

Subsequent British (inofficial) practice has been to draw the boundary between the Lower and Upper Ordovician at the base of the zone of *Nemagraptus gracilis*. The reason for this deviation from LAPWORTH's original concept is not evident from the literature. However, these terms have been little used in the British literature, and as far as I can see, after LAPWORTH never properly defined. ALICHOVA (1957, p. 103) reports that the recent British practice includes Llanvirn and Llandeilo in the Middle Ordovician, but, to the best of my knowledge, the term Middle Ordovician has never been used by British writers with reference to the British sequence. Likewise, in the British Isles the lower boundary of the Upper Ordovician has (against KELLER's statement, 1954, p. 9) never been drawn at the base of the Ashgillian.

A subdivision of the Ordovician System, which closely corresponds to that of LAPWORTH, was used for a long time for the South Australian (particularly Victorian) graptolitic sequence (T. S. HALL 1899, and subsequent writers). This classification was modified by HARRIS & THOMAS (1938) who introduced the term Middle Ordovician into the Australian standard section for the *Diplograptus* Series as distinguished

by HARRIS (1935). The Middle Ordovician was defined as the beds between the zone of *Cardiograptus* and the zone of *Nemagraptus gracilis*. In this sense the Middle Ordovician roughly corresponds to that currently used by the French writers, but differs considerably from the usage of this term in most other regions of the world. It should be noted here that the proper term for the units called series by Australian and New Zealandian writers is evidently stage.

No effort has been made to trace the origin of the current French classification of the Ordovician System (cf. e.g. PHILIPPOT 1950). The Middle Ordovician is usually defined by French writers as including the Llanvirnian and Llandeilian (z. of *Glyptograptus teretiusculus*) of the modern British standard section.

The concept of Middle Ordovician Series was introduced into Europe by RAYMOND (1916). He drew the lower boundary of this series between beds corresponding to, in modern terms, the Kunda and Aseri Stages of the limestone sequence and the zones of *Didymograptus bifidus* and *D. murchisoni* of the graptolitic succession. The upper boundary was defined as that between the *Macrourus* beds and *Trinucleus* (= *Tretaspis*) shale (4bδ and 4cα of the Oslo region), later shown by THORSLUND (1940, 1948) to coincide with the boundary between the zones of *Dicranograptus clingani* and *Pleurograptus linearis*.

The term Upper Ordovician has been, and is, used in RAYMOND's sense in all Baltoscandian countries (e.g. Norway, Sweden, Estonia, and Lithuania), Poland (KIELAN 1956), and in the USSR (e.g. SOKOLOV 1953; ALICHOVA 1953, 1957; ALICHOVA *et al.* 1958; KELLER 1954). In order to distinguish the Upper Ordovician Series so defined from the other existing definitions of the Upper Ordovician, the term Harju Series (ÖPIK MS; LUHA 1940; KALJO, RÕÕMUSOKS, & MÄNNIL 1958) is a convenient, and the only available designation. The name is derived from the province of Harjumaa in Estonia where a reasonably complete and richly fossiliferous sequence of this series is exposed. The Harju Series seems to correspond fairly closely to the Cincinnatian Series of North America, but as the lower boundary of the latter series is not yet defined in terms of graptolite zones, an exact comparison is not possible.

Different opinions as to the most suitable level for the lower boundary of the Middle Ordovician Series in Baltoscandia have been discussed by JAANUSSON (1960a). Three different boundaries between the graptolite zones have recently been used to define this boundary, those between the zones of *Glyptograptus teretiusculus* and *Didymograptus murchisoni* (LAPWORTH's boundary between Lower and Upper Ordovician; JAANUSSON & STRACHAN 1954), *Didymograptus murchisoni* and *D. bifidus* (RAYMOND's original boundary), and between the zones of *D. bifidus* and *D. hirundo*. The exact correlation of all these boundaries with the shelly sequence has previously offered difficulties, and caused some misunderstandings. For details, reference should be made to JAANUSSON's paper of 1960a.

One reason for the use of the lower boundary of the zone of *Didymograptus bifidus* for defining the base of the Middle Ordovician has been the postulated close correspondance of this level to the boundary between the Canadian and Champlainian Series of North America (WHITTINGTON 1954; KINDLE & WHITTINGTON 1958). Recent evidence indicates, however, that the level of the boundary between the latter series is lower down in the British standard graptolite section than suggested by WHITTINGTON (JAANUSSON 1960a). The association of European and Australian species in certain regions of China now makes possible a fairly exact correlation of

the Yapeenian Stage and the lower "Middle Ordovician" of Victoria with the European graptolitic sequence. MU & LEE (1958) have shown that the correlation between the British and Australian graptolite zones suggested by HARRIS & THOMAS (1938) is essentially correct. The Victorian Yapeen Stage is comparable to the lower part of *D. hirundo* zone. *Cardiograptus* occurs in Newfoundland in shales overlying the Table Head Limestone (DUNBAR 1954, p. 255; KINDLE & WHITTINGTON 1958, p. 338) which is considered to be of Whiterockian age (COOPER 1956). KINDLE & WHITTINGTON considered the shales to be of upper Yapeen age. But the species of *Cardiograptus* listed by them is *C. crawfordi* which in Victoria is indicative of the "Middle Ordovician" zones of *Diplograptus decoratus* and *Didymograptus nodosus,* i.e. of beds comparable to the *Didymograptus bifidus* zone. If the correlations of the shelly sequence of Newfoundland by COOPER (1956, Table Head Group) and KINDLE & WHITTINGTON (1958, Cow Head Group) with that of the other districts of North America are correct, the Whiterock Stage is evidently earlier than the main part of the (European) zone of *Didymograptus bifidus* (for details, see JAANUSSON 1960a). The correlation of the level of the boundary between the Canadian and Champlainian Series with the British-Scandinavian graptolitic sequence is still vague, the correlation of the Australian and Scandinavian graptolite zones below the *D. hirundo* zone not yet being exact. The above shows that evidence drawn from the correlation of the Canadian-Champlainian boundary cannot be used as an argument for defining the position of the boundary between the Lower and Middle Ordovician Series of Europe. The correlation is too uncertain. It is better to admit the existence of a profoundly different faunal development during this part of the Ordovician Period on both sides of the Atlantic by using separate subdivisions of, and separate names for, these series. This would prevent misunderstandings.

BULMAN (1958) suggested that the lower boundary of the zone of *Didymograptus bifidus* should coincide with an important change in the graptolite faunas, more exactly with that from the dichograptid fauna to the diplograptid fauna as defined by him. This gives according to him some support to the choice of this boundary as representing the lower boundary of Middle Ordovician. However, the appearance of diplograptids (other than *Glyptograptus dentatus*) does not seem to be as contemporaneous as asserted by BULMAN. MU & LEE (958) have shown a diversified diplograptid fauna to occur in China already in the upper part of the zone of *Didymograptus hirundo,* and the lower zone of the "Middle Ordovician" of Victoria, as indicated already by HARRIS & THOMAS (1938), to be comparable to the upper part of the *D. hirundo* zone. The correlative value of the lower boundary of the *D. bifidus* zone does not seem to be greater than that of the other zones used for defining the Middle Ordovician.

In the most recent papers on the Ordovician of Sweden (JAANUSSON 1960a), Estonia (MÄNNIL 1958) and the USSR (ALICHOVA 1957; BALASHOVA & BALASHOV 1959) the boundary between the Lower and Middle Ordovician is drawn according to RAYMOND's original suggestion at a level corresponding to the boundary between the zones of *Didymograptus bifidus* and *D. murchisoni*. The same level is regarded as the boundary between these series also in China (cf. e.g. GRABAU 1924; HSÜ 1934; the same classification is evidently applied in all recent literature on the Ordovician sequence of China). On account of the fact that in Europe this level is now more extensively used as the lower boundary of the Middle Ordovician than any of the

other levels, it is recommended here to define the boundary between the Lower and Middle Ordovician in Europe as that between the zones of *Didymograptus bifidus* and *D. murchisoni*. The correct, and the only available, name for the Middle Ordovician Series defined as above is Viru Series (Öpik Ms; Luha 1940; Jaanusson 1945; Kaljo, Rõõmusoks, & Männil 1958). The name is derived from the province of Virumaa in eastern Estonia, where the sequence of the series is excellently exposed.

The Lower Ordovician Series of Europe is thus defined as the sequence between the top of the Cambrian System and the base of the *Didymograptus murchisoni* zone, provided that the latter boundary attains general acceptance. The correct name for this series is Oeland Series (Kaljo, Rõõmusoks, & Männil 1958).

In Europe the Oelandian falls by tradition into two well-defined subdivisions, here considered as subseries. The lower subseries is generally termed the Tremadocian, whereas the correct name for the upper subseries would be Arenigian. However, the term Arenigian can only be used, if either the upper boundary of the Oelandian Series coincides with the lower boundary of Llanvirnian, or if the upper boundary of Arenigian is drawn according to the original definition of this unit in a chronostratigraphic sense (Hicks 1875), i.e. between the zones of *Didymograptus bifidus* and *D. murchisoni* (cf. also Elles 1937). In the latter sense this term was in general use until Llanvirnian (Hicks 1881) became incorporated into the British standard section chiefly under the influence of Elles' paper of 1922. Now the definition of Arenigian cannot be changed back to its original concept without an official British authorization, as confusion might otherwise arise from the simultaneous existence of two different definitions of this term. As long as the upper boundary of the Oelandian Series is defined as above (between the zones of *Didymograptus bifidus* and *D. murchisoni*), and the upper boundary of the Arenigian currently drawn below the zone of *Didymograptus bifidus*, it is best to use the term Ontikan (Kaljo, Rõõmusoks, & Männil 1958) for the upper subseries of Oelandian.

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Table I. Comparison of different classifications of the Ordovician System of Europe. Remarks:—It is uncertain, whether the zones of *Dicellograptus anceps* and *D. complanatus* can be distinguished or the corresponding beds should be included in one graptolite zone (cf. Jaanusson 1960b). For purposes of broad correlation the zones of *Climacograptus wilsoni* and *C. peltifer* can be included in one zone, termed the zone of *Diplograptus multidens* (cf. also Jaanusson & Strachan 1954). The zone of *Didymograptus extensus* includes several successive graptolite faunas, distinguished as subzones in Great Britain (cf. Elles 1933) and as separate zones in Scandinavia (Törnquist 1901, 1902; Monsen 1937; Hede 1951; Tjernvik 1956). The degree of faunal changes and the thicknesses of the Scandinavian zones are comparable to those of the zone of *Didymograptus hirundo* (Spjeldnæs 1953, p. 182) and of the superimposed zones. The use of the wide graptolite zone of *Didymograptus extensus* in the British standard classification has probably sometimes led to an underestimation of the diversity of successive faunas in the Arenigian and, in consequence, to an exaggeration of the relative importance of the Llanvirnian sequence. The existence of a separate zone of *Dichograptus* is highly uncertain (Bulman 1958). The Tremadocian graptolite zones are omitted.

British standard graptolite zones	Lapworth, 1880	Some subsequent British writers	Philippot, 1950 and others	Raymond, 1916	Kiaer, 1920	Størmer, 1953	Jaanusson & Strachan, 1954	Alichova, 1957 and others	Kaljo, Rõõmusoks, & Männil, 1958
D. anceps	World-wide	British Isles	France	Balto-scandia	Norway	Norway	Scandinavia	USSR	Balto-scandia
D. complanatus	Upper Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Upper Ordovician	Harjuan Series (Upper Ordovician)
D. linearis									
D. clingani									
C. wilsoni									
C. peltifer									
N. gracilis									
G. teretiusculus									
D. murchisoni			Middle Ordovician	Middle Ordovician	Middle Ordovician	Middle Ordovician	Middle Ordovician	Middle Ordovician	Viruan Series (Middle Ordovician)
D. bifidus	Lower Ordovician	Lower Ordovician							
D. hirundo			Lower Ordovician	Lower Ordovician	Lower Ordovician	Lower Ordovician	Lower Ordovician	Lower Ordovician	Oelandian Series (Lower Ordovician)
D. extensus									
? Dichograptus									Trema-docian: Ontikan Subseries
Tremadocian	Upper Cambrian	Upper Cambrian							

Standard graptolite zones	Hicks, 1875 [Lapworth, 1880, p. 194]	Lapworth, 1879 b pp. 334, 338, 423, 427		Hicks, 1881	Lapworth, 1889	Marr, 1905, 1913
D. anceps	Caradoc Group	Bala Formation	Higher Bala or Caradoc – Bala	Bala Group	Caradoc	Ashgillian
D. complanatus						Caradocian
P. linearis						
D. clingani						
C. wilsoni						
C. peltifer			Lower Bala or Llandeilo-Bala		Llandeilo	
N. gracilis						Llandeilian
G. teretiusculus	Llandeilo Group	Llandeilo Formation		Llandeilo Group		
D. murchisoni						
D. bifidus	Arenig Group	Arenig Formation		Llanvirn Group	Arenig	Skiddavian
D. hirundo				Arenig Group		
D. extensus	Tremadoc Group					
? *Dichograptus*						
Tremadocian	[Hiatus in St. Davids district]	Cambrian		Cambrian	Cambrian	Cambrian

TABLE II. Comparison of different classifications of the British standard section of the Ordovician System. Remarks:—The arenaceous Abercastle and Port Gain beds of St. Davids district were included by HICKS (1875) and many subsequent writers in the Tremadoc group, but later shown to be of Arenigian age (cf. COX &

Elles & Wood, 1914 p. 526	Marr, 1905, according to Elles & Wood, 1914. Watts, 1917	Elles, 1922, 1925	Watts, 1929	O. T. Jones, 1936	Elles, 1937	Geological Survey, 1948
Caradocian	Ashgillian	Ashgillian	Ashgillian	Upper Bala	Ashgillian	Ashgillian
	Caradocian	Caradocian	Caradocian	Lower Bala	Caradocian	Caradocian
Llandeilian	Llandeilian	Llandeilian	Llandeilian		Passage beds	
				Llandeilo	Llandeilian	Llanvirnian
Llanvirnian		Llanvirnian	Llanvirn	Llanvirn		Llanvirnian
Arenigian	Skiddavian	Arenigian	Skiddavian	Arenig	Arenigian	Arenigian
Cambrian	Cambrian	Cambrian	Cambrian	Cambrian	Cambrian	Cambrian

PRINGLE 1930). The Upper Llandeilo of HICKS (1875, 1881) was later proved to be established upon beds of Llanvirnian age brought into this position by a powerful overthrust (COX & PRINGLE 1930); this is indicated in the table by the oblique line between the Llandeilo and Llanvirn Groups of HICKS 1881.

THE STATUS OF THE BRITISH STANDARD CLASSIFICATION OF THE ORDOVICIAN SYSTEM

During almost one hundred years attempts have been made to use the British Ordovician standard classification for the Ordovician sequences in the other regions of the world. For this reason a discussion of the status of the British classification is inevitable also in this connection.

The British geologists, and LAPWORTH himself in his subsequent papers, did not follow LAPWORTH's (1880) intentions of a subdivision of the system on the series level based on the graptolitic sequence and defined by strictly faunal changes. They continued to use the regional rock units of Wales and the Welsh Border as the standard units of the Ordovician section, and largely defined the boundaries according to regional changes in lithology, important disconformities, or to a mixture of faunal, lithological, and correlative evidences. As most of the type sections of different standard divisions are situated in areas with preponderantly shelly sequence, these divisions could generally not be defined in terms of the graptolite zones by other means than by a, often tentative, correlation. Subsequently the names of the standard rock units were transferred by correlation to the graptolitic facies, defined by reference to the graptolite zones, and, so defined, used as standard Ordovician subdivisions also outside the British Isles. From time to time, when the correlations have been revised, or the concept of the basic rock unit has been changed, the definitions of the standard divisions in terms of the graptolite zones had to be altered. The correlation between the shelly sequence and the graptolite zones is still not always exact, and a disturbing circumstance is the occasional existence of two different definitions of the same term, one in terms of the graptolite zones and the other by reference to the shelly faunas. Ashgillian as defined in the shelly sequence (MARR 1905, 1907, or KING & WILLIAMS 1948) is not identical with Ashgillian as defined in the graptolite facies (ELLES & WOOD 1914; cf. JAANUSSON 1960b), and Caradocian of South Shropshire (DEAN 1958) is not equal to Caradocian in terms of the graptolite zones. Neither has it been proved that the Llandeilian of the Llandeilo district (WILLIAMS 1953) corresponds exactly to the zone of *Glyptograptus teretiusculus*, i.e. to the Llandeilian as now defined by reference to the graptolitic succession. All these circumstances make an unconditional use of most terms of the standard classification of the British Ordovician not advisable outside regions with the particular shelly fauna characteristic for these divisions.

The main different standard classifications of the British Ordovician are compared in Table II. The stratigraphic meaning of the term Ashgillian has lately been discussed by JAANUSSON (1960b). Ashgillian is considered as a unit of stage category, and usable outside the British Isles only, when defined in terms of graptolite zones. It may be a useful term as a subdivision of the Harju Series. The correlation of the type Caradocian with the graptolitic succession is still so vague that it does not seem to be advisable to apply this term outside the distribution of the particular shelly fauna characteristic for this division. Bala is a term of series category, and available for those who prefer to draw the lower boundary of the Upper Ordovician at the base of Bala Series. Llandeilian can be considered as a stage, but as long as its exact correspondence with the zone of *Glyptograptus teretiusculus* has not been conclusively proved the name can scarcely be applied in regions, where the shelly fauna distinctive for the type

Llandeilo is not developed. It is difficult to determine the value of Llanvirnian (HICKS 1881) in terms of chrono-stratigraphic categories. It is a well defined unit, but seems to be too large to constitute a stage, and too small to be of series category. When referring to the Baltoscandian sequence I have difficulties in finding a practical use for this unit. Arenigian and Tremadocian are well-established terms of series category, and have been considered above. Skiddavian (MARR 1905) is a synonym of Arenigian (HICKS 1875).

CONCLUSIONS

(1) Series ought to be defined in terms of the graptolitic sequence (JAANUSSON & STRACHAN 1954), since otherwise their boundaries can not be recognized internationally, nor even within a continent.

(2) Owing to an extensive palaeozoogeographical differentiation during the Ordovician Period the intercontinental correlations are at present not reliable enough for a subdivision on the series level that could be recognized and put to practical use all over the world.

(3) For the prevention of misunderstandings the use of terms like Upper, Middle, and Lower Ordovician should be avoided, and regional names applied for these series in different major palaeozoogeographical provinces.

(4) For the Ordovician sequence of Europe the following classification on the series level is recommended:

Harju Series (Upper Ordovician).—Top of the Ordovician System to base of the *Pleurograptus linearis* zone.

Viru Series (Middle Ordovician).—Top of the zone of *Dicranograptus clingani* to base of the zone of *Didymograptus murchisoni*.

Oeland Series (Lower Ordovician).—Top of the zone of *Didymograptus bifidus* to base of the Ordovician System.

The boundaries between the above graptolite zones are defined according to the current practice in Scania and on Bornholm.

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