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SYDNEY 1991

University of Sydney
Sydney, Australia
July 15-19, 1991

SIXTH INTERNATIONAL SYMPOSIUM ON THE ORDOVICIAN SYSTEM

RECORD 1991 / 47

ABSTRACTS

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Edited by: John R. Laurie[1], Barry D. Webby[2], Robert S. Nicoll[1] and John H. Shergold[1].

[1]Onshore Sedimentary and Petroleum Geology Branch, Bureau of Mineral Resources, Geology and Geophysics.
[2]Department of Geology and Geophysics, University of Sydney.

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WELCOME

Greetings and welcome to our Ordovician friends attending the Sixth International Symposium on the Ordovician System. This is the first time that leading international Ordovician geoscientists have met together in the Southern Hemisphere (in the tropical part of Ordovician Gondwana).

Although it is only three years since the Fifth International Symposium in Newfoundland, the wide range of research papers on offer at this (Sixth) Symposium testifies to the rapid rate of progress on aspects of current global Ordovician research. As in previous International Ordovician meetings at Birmingham, Columbus, Oslo and St. John's there will also be opportunities to have workshop discussions of the IUGS Subcommission on Ordovician Stratigraphy, and the Cambrian-Ordovician Boundary Working Group. These discussions will continue our efforts to find internationally accepted inter- and intra-system boundaries.

Our field trips are aimed to show the best exposed Ordovician rocks in Australia. We also hope our visiting colleagues will be able to take part in various cultural and social events arranged on these excursions and during their visit to Sydney.

We are particularly conscious of the efforts most of our overseas colleagues have made to attend this meeting. Members of the Organising Committee hope you will all have an enjoyable stay, and gain considerable scientific benefit from attending. Please do not hesitate to contact one of us if you need assistance during your visit.

Barry Webby
Chairman

ACKNOWLEDGEMENTS

The organising committee of the Sixth International Symposium on the Ordovician System wishes to thank the following organisations for their support of the Symposium:

International Union of Geological Sciences
International Commission on Stratigraphy
Subcommission on Ordovician Stratigraphy
Earth Resources Foundation
University of Sydney
Bureau of Mineral Resources
Esso (Australia) Ltd
Australian Tourist Commission
New South Wales Department of Minerals and Energy
Geological Survey of Victoria
University of Queensland

SYMPOSIUM VENUE

The symposium activities will be centred on the Edgeworth David Building, home of the Department of Geology and Geophysics and at Women's College, University of Sydney.

Technical Sessions will be held in the Main Lecture Theatre of the Edgeworth David Building.

REGISTRATION

The registration desk will be located in Women's College from 1600 to 2000 on Sunday 14 July, so that all participants attending the opening Welcome Buffet may complete their registration as early as possible

On each subsequent day of technical sessions, 15-16 July and 18-19 July, the registration desk will be located in the foyer of the Edgeworth David Building and will be open from 0800 to 1300.

ACCOMPANYING PERSONS

No formal program has been arranged for accompanying persons, but organisers will be available to advise any persons needing assistance.

SOCIAL EVENTS

The Welcome Buffet, including snacks, drinks and a hot meal (until 8pm), will be provided for all participants from 1830 to 2230 in the Main Common Room of Women's College on Sunday, July 14.

The Symposium Dinner will be held on a modern, spacious, twin-hulled cruiser, the *Matilda II* on Sydney Harbour on Thursday evening from 1930 to 2330.

End of session drinks, cheese and biscuits has been arranged in the Edgeworth David Building from 1440 on Friday, July 19. It is hoped that the final scheduled workshop can be concluded by 1800 so all participants can attend the Closing Banquet. Details will be provided at the registration desk.

ABSTRACTS

Note: Abstracts are listed alphabetically by authors' names

THE GENUS *JUJUYASPIS* AS A WORLD REFERENCE FOSSIL FOR THE CAMBRIAN-ORDOVICIAN BOUNDARY

ACEÑOLAZA, F.G. and ACEÑOLAZA, G., Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucuman, Miguel Lillo 205, Ar-4000 Tucuman, Argentina

The genus *Jujuyaspis*, originally described from the Province of Jujuy, NW Argentina, is a pelagic trilobite with a worldwide distribution. This, coupled with the fact that it occurs close to the Cambrian-Ordovician boundary, indicates that it is an excellent guide fossil for that stratigraphic interval. Apart from in Argentina, it has been found in southern Bolivia, Colombia, USA (Texas and Utah), Scandinavia and the Soviet Union.

Jujuyaspis in Jujuy is found in the black shale facies, in its upper levels associated with *Neoparabolina frequens* (= *Parabolina argentina*), immediately below the Black Mountain Eustatic Event (BMEE). Also present at this level are *Cordylodus proavus* and *Dictyonema flabelliforme sociale.*

WHITHER THE ASHGILL SERIES?

BARNES, Christopher R., School of Earth and Ocean Sciences, University of Victoria, PO Box 3055, Victoria, BC V8W 3P6, Canada.

The Ashgill Series is the highest series in the British Standard Section of the Ordovician System. It is divided into four stages: Pusgillian, Cautleyan, Rawtheyan and Hirnantian based on sections in Wales and northern England in a largely clastic facies bearing shelly fossils but few graptolites or conodonts. The stages are difficult to correlate globally due largely to endemism in the shelly faunas. Recent geochronologic studies have shown the Ashgill Series to be of brief duration — possibly only about 4 million years, or a small fraction of the Ordovician Period. The Ashgill has proven to be a useful term in encompassing the various events related to the terminal Ordovician glaciation, although the most severe phase was largely restricted to the Hirnantian (Gamachian). The Ashgill Boundary Working Group has had difficulty in proposing a suitable definition for the base of the Ashgill Series. There is no major bioevent near the traditional level. Suitable stratotype sections are rare or lacking. Possible defining biozones based on graptolites or conodonts could include the Dicellograptus complanatus or Pleurograptus linearis and Amorphognathus ordovicicus zones, respectively; no zones closely coincide near this level. An alternative approach in resolving this part of the internal Ordovician chronostratigraphic probelms is to include the Ashgill interval within the Caradoc (or equivalent upper Ordovician series). This interval may be best represented by two stages, yet to be defined, within the upper part of a redefined Caradoc (or equivalent) series. Although long established, it may be appropriate to allow the Ashgill to whither and be replaced by chronostratigraphic units of more suitable rank.

STRATIGRAPHIC EVENTS OF THE ORDOVICIAN SYSTEM

BARNES, Christopher R., School of Earth and Ocean Sciences, University of Victoria, PO Box 3055, Victoria, BC V8W 3P6, Canada.

The many stratigraphic correlation charts produced by the Subcommission on Ordovician Stratigraphy have provided a moderately complete global database but their format does not readily reveal important stratigraphic events during the Period. However, when combined with recent studies of tectonics, eustacy, paleoceanography, and isotope geochemistry, some broad event patterns in the stratigraphic record are beginning to emerge. Significant eustatic events have been documented close to most Series boundaries; glacial controls are now well constrained through most of the Ashgill, particularly at their climax in the Hirnantian, but their influence during the early Tremadoc remains speculative. Events near the base of the Llanvirn deserve more attention when a marked shift in strontium isotope ratios (decrease in $^{87}Sr/^{86}Sr$ ratio) has been demonstrated close to a time of initial closure of the Iapetus Ocean and other significant tectonic events. Extensive anoxic events characterize the Llanvirn and Caradoc and the latter interval is characterized particularly by transgressive events that were probably the most extensive in the entire Phanerozoic. The paper will review the major stratigraphic events in the Ordovician, especially those of global extent.

ORDOVICIAN CYCLES AND SEA LEVEL FLUCTUATION, IN THE PRECORDILLERA TERRANE, WESTERN ARGENTINA

BERESI, Matilde S., Cricyt, C. Correo 131, 5500 Mendoza, Argentina.

The Ordovician facies development in the Precordillera terrane, show changes in response to relative sea-level fluctuation. The Precordillera is located in the west of Argentina, in the Andean Arc.

The Ordovician sequences comprise three cycles: (I) A Carbonatic cycle developed from the Upper Cambrian to the beginning of the Middle Ordovician (Lower Llanvirnian). This cycle starts with cyclic peritidal carbonates (thrombolites and stromatolites). The deposition extended from shallow subtidal lagoons to supratidal flats and to a terrestrial environment. Their arrangement in shallowing-upward cycles is part of a superimposed regressive-transgressive sequence. They grade upward into subtidal carbonates. Continuous subsidence resulted in a transgression on a stable shelf, probably the western passive continental margin of Gondwana. The limestones are normally thinly bedded wackestone containing a diverse warm water biota. The conodont zones are represented by *Prioniodus elegans* at the base, to *Amorphognathus variabilis* - *Eoplacognathus pseudoplanus* at the top. The cycle culminates in a pelitic clastic unit. The graptolitiferous shales (*Paraglossograptus tentaculatus* Zone) represent the maximum transgression during a highstand.

A Clastic cycle (II) developed from the Middle Llanvirnian to the Middle Caradoc and overlies Cycle I with erosive unconformity. Cycle II corresponds to slope sequences deposited by turbidite flows. The lowstand siliciclastic facies are deposits of an outer and inner submarine fan environment, basin plain facies, associated with magmatic activity. The graptolite assemblages correspond to *Paraglossograptus etheridgei* - *Nemagraptus gracilis* to *Dicellograptus divaricatus salopiensis* Zones.

There are no palaeontological records from the Upper Caradocian to Early Upper Ashgillian. There is stratigraphic evidence of a glacial-eustatic event related to the Gondwana glaciation in the clastic sequences of Cycle III. The glacial deposits are pebbly mudstones produced by debris flow processes. These deposits are associated with channels containing an *Hirnantia* fauna.

The Clastic Cycle III was developed from the Hirnantian to the Llandovery. The intra-Ashgillian erosive unconformity separates the later cycle from underlying fine turbidites, and corresponds to a sea level change related to climatic variation during the Gondwana glaciation. The highstand sequence begins with a clastic shallow platform facies containing *Hirnantia* and *Dalmanitina*. This unit continues with oolitic sandstones containing acritarchs and chitinozoa microplankton and graptolitic shales with *Glyptograptus persculptus* at the top, as the typical lower Silurian assemblage.

ON THE INTERNATIONAL SERIES CLASSIFICATION OF THE ORDOVICIAN SYSTEM: FOUR STRATIGRAPHIC LEVELS IN THE MIDDLE ORDOVICIAN WITH GLOBAL CORRELATION POTENTIAL

BERGSTRÖM, S. M., Department of Geological Sciences, The Ohio State University, Columbus, OH 43210, USA.

The "First Report of the Caradoc Working Group", which was distributed in November, 1990 to Voting and Corresponding Members of the Subcommission on Ordovician Stratigraphy, reviewed some advantages and disadvantages of seven stratigraphic levels in the Middle Ordovician that appear to have potential to be identifiable over large parts of the world. Up to now, reactions to that report have not been numerous but the written opinions received, as well as informal discussions with Ordovician workers in North America and Europe, suggest considerable difference in opinion concerning the most useful level(s). Some workers in North America and China prefer the base of the N. gracilis Graptolite Zone as a series boundary although that level is not easily recognizable in cratonic successions except in Baltoscandia. Among the other possible levels listed in the "First Report", two seem superior to the others although neither is ideal. One of these is the base of the P. anserinus Conodont Zone, which can be recognized with high precision virtually globally in both "mixed" and shaly facies. However, this level is difficult to pick in most cratonic successions, and it does not coincide with a graptolite zone boundary. The other level is the base of the D. multidens Zone, which is at the base of the North American Mohawkian Series; at the base of the B. gerdae Graptolite Zone; at the base of the Midcontinent Aculeata Conodont Zone; and at a horizon in the lower Gi2 in the Australian graptolite succession. Another, previously not considered,level, which could be used as the base of an Upper Ordovician series, is the base of the Undatus Conodont Zone. This level is at the base of the North American Trentonian (Barneveldian) Stage; is very near the base of the C. americanus Graptolite Zone; in the uppermost part of the D. multidens Graptolite Zone and the A. tvaerensis Conodont Zone; at the base of the Chinese Xiaoxita Stage; and about at the base of Ea1 in Australia. Furthermore, the extremely widespread main K-bentonite beds occur at this level in eastern North America and northwestern Europe.

THE ORDOVICIAN K-BENTONITE PROJECT, PART II: DISTRIBUTION AND SIGNIFICANCE IN NORTHWESTERN EUROPE

BERGSTRÖM, S. M., Dept. Geol. Sci., The Ohio State University, Columbus, OH 43210; HUFF, W. D., Dept. of Geol., University of Cincinnati, Cincinnati, OH 43221; KOLATA, D. R., Illinois State Geol. Surv., Champaign, IL 61820; BAUERT, H. and KALJO, D., Inst. of Geol., Estonian Acad. Sci., Tallinn, USSR

Ordovician K-bentonites are widely distributed in northwestern Europe, where the principal occurrences are in the British Isles, Scandinavia, Poland, and western USSR. The largest number of beds by far (more than 150) is recorded from southern Sweden (Scania) but numerous beds are present also in some sections elsewhere in Sweden, and in southeastern Norway and western Estonia. Far fewer beds occur in the Ordovician of the British Isles and Poland. In Baltoscandia, there are only a few beds in the Arenigian through the Llandeilian, many in the Caradocian, and very few in the Ashgillian. In Britain, relatively few beds are known from the Llanvirnian through the Caradocian but several occur in the Ashgillian (especially in Scotland). Detailed study of more than 30 sections in Baltoscandia makes it possible to trace several biostratigraphically well-dated beds, or thin complexes of beds, for more than 1000 km (from eastern Estonia to southeastern Norway; and from central Sweden to Poland). Some of these beds, particularly the so-called "Big Bentonite", are highly significant event-stratigraphic markers regionally in the Baltoscandian middle Caradocian (upper D. multidens Zone; upper A. tvaerensis Zone), and they may represent the same eruptions as the coeval prominent K-bentonites (the Deicke and the Millbrig) in eastern North America.

The Ordovician K-bentonites in Baltoscandia and in the British Isles differ significantly in patterns of stratigraphic distribution, and correlation of individual beds between these regions has not yet been possible. This difference may be taken as an indication that the K-bentonites in these regions had different source areas. This possibility is not unexpected in view of the fact that based on recent plate-tectonic reconstructions, most of the British Isles occupied a position at considerably higher latitudes than Baltoscandia during Middle Ordovician time.

THE BALTOSCANDIC ORDOVICIAN CONODONT FAUNAL SUCCESSION: A NEW COMPOSITE STANDARD BASED ON SECTIONS IN CENTRAL SWEDEN

BERGSTRÖM, S. M., Department of Geological Sciences, The Ohio State University, Columbus, OH 43210, USA; and LÖFGREN, A., Institute of Palaeontology, Lund University, S-223 62 Lund, Sweden.

The Ordovician conodont zone succession used virtually globally for high-latitude (Atlantic Faunal Region) and cold-water faunas is based mainly on Swedish sections, in which diverse conodont species assemblages can be obtained through virtually the entire system. The Lower Ordovician (Oelandian) faunas have been subjected to several modern taxonomic and biostratigraphic studies and are now reasonably well known. However, recent investigations have produced interesting new data of more than local significance. A large amount of information about the taxonomy and distribution of many of the Middle (Viruan) and Upper Ordovician (Harjuan) key species has been published during the last two decades but the distribution patterns of the many other species present have not been documented from Swedish sections previously. Our recent studies of classical and new sections in the Siljan area, central Sweden, have made it possible to present, for the first time, the detailed vertical ranges of many dozen conodont species in a stratigraphically well-controlled composite succession ranging from the lower Arenigian to the Hirnantian. No new major zonal units are proposed but there are several biostratigraphic refinements, also including clarification of the relations between conodont zonal units and units in the graptolite and trilobite zonal successions. Recent finds of conodont species best known from North America, such as Histiodella holodentata, H. kristinae, and species of Polonodus, provide new evidence useful for trans-Atlantic correlation with the North American Midcontinent conodont zone succession. A comparison is also made with conodont successions in Poland, Great Britain, and China.

LATE MIDDLE AND EARLY LATE ORDOVICIAN GRAPTOLITE BIOSTRATIGRAPHY, BIOGEOGRAPHY, AND PALEOECOLOGY IN NORTH AMERICA

BERGSTRÖM, S. M., Dept. of Geological Sciences, The Ohio State University, Columbus, OH 43210, USA; and MITCHELL, C. E., Dept. of Geology, State University of New York at Buffalo, Buffalo, NY 14260, USA.

Complete, or virtually complete, late Middle (late Mohawkian) and early Late Ordovician (early Cincinnatian) graptolite zone successions in North America are known from New York State-Quebec; the Cincinnati region in Ohio, Kentucky, and Indiana; and the Arbuckle Mountains and adjacent area in Oklahoma. At least part of this interval may also be present in graptolitic facies in the Great Basin (Idaho), the Canadian Cordillera, and the central Appalachians. The composition of the New York-Quebec faunas is closely similar to those of the Cincinnati and Oklahoma regions but there are some differences in stratigraphic ranges, the most significant one being that of the zonal index Climacograptus (D.) spiniferus. Nevertheless, the New York State-Quebec zone succession is the most detailed and regionally useful one recognized anywhere in North America. The succession in Texas, and probably also those in the Great Basin and the Canadian Cordillera, have a significant break in the upper Mohawkian and/or lower Cincinnatian graptolite succession. Both graptolite and conodont evidence support the idea that at least in some areas this represents a depositional break rather than an effect of ecological factors. Comparisons between the faunas of the relatively complete successions show some regional distribution patterns that may be due to migrations and/or ecological differentiation. Autecological studies of about 20 graptolite species in the Cincinnati region in transects from shallow-water high-energy carbonate-rich environments to deeper-water low-energy siliciclastic environments reveal distributional differences that may have been caused by a combination of depth-stratification and water mass specificity. Not only at the generic level, but also at the specific level, the North American faunas studied exhibit obvious similarity to coeval faunas elsewhere in the Pacific Faunal Region, but these faunas differ markedly at the species level from coeval faunas of the Atlantic Faunal Region in northwestern Europe.

ORDOVICIAN PLATE TECTONICS OF CHINA AND NEIGHBOURING REGIONS

CHEN Xu and RONG Jia-yu, Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Academia Sinica, Chi-Ming-Ssu, Nanjing, 210008, China

Seven Ordovician plates are recognised in China and its neibouring regions. In addition to the Tarim, Qaidam, Sino-Korean, South China and Tibet Palaeoplates, NE Xinjiang, the northernmost part of Inner Mongolia and Heilongjiang belong to the southernmost part of the Siberian Palaeoplate and the Junggar Basin and western margin to the eastern part of the Kazakhstan Palaeoplate.

Each of the palaeoplates usually includes two parts, a craton or platform (stable area) and a mobile belt or marginal basin (active area) which developed around or within the craton. Ophiolite zones are usually defined as an important indicator of suture lines between palaeoplates. All of the Ordovician plates in China are continental plates. Related faunas developed in Tarim, west Sino-Korean and South China Palaeoplates may indicate thet they were not separated from each other by large ocean basins. The Taconic and succeeding Caledonian movements may have affected all these palaeoplates except Tibet. Effects were not as well developed as on either side of the Iapetus.

Lithofacies and biofacies, volcanic and tectonic activity and the border or suture zones for each palaeoplate are summarised and among them, the South China Palaeoplate is studied in greater detail. It consists of three parts, the Yangtze Platform, the Zhujiang Basin and Cathaysialand. The Yangtze and Zhujiang basin were not separated by the Bangxi ocean as has been suggested by some workers.

ION PROBE ZIRCON AGES FOR THE BRITISH ORDOVICIAN AND SILURIAN STRATOTYPES

COMPSTON, William, FANNING, C. Mark and WILLIAMS, Ian S., Research School of Earth Sciences, Australian National University, GPO Box 4, Canberra, ACT 2601

The most direct and reliable method of dating sediments is through the ages of interbedded volcanics. The British Ordovician and Silurian stratotypes are blessed with an abundance of such rocks, and Ross et al. (1982) used fission-track dating of volcanic zircon and apatite to produce numerical ages for four Ordovician and three Silurian horizons whose biostratigraphy was well-established. The precision for the fission-track ages was between 2 and 3%(σ) and limited by counting statistics. Fission-track ages from other horizons were interpreted as too young due to track-annealing. Zircons from the same mineral separates were dated recently by Tucker et al. (1990) by mass spectrometric isotope dilution (MSID), with precision improved by an order of magnitude, and interpretation aided through the two independent ages per analysis that arise from the two U isotopes. The accuracy of age-determinations, as distinct from their high precision, is controlled by technical factors such as calibration of tracer solutions, uncertainty in U decay constants, and bias in isotopic ratio measurement. There are also geological factors such as the presence of detrital or xenocrystic zircon and small amounts of Pb loss, both of which were reported by Tucker et al.

We have recently reanalysed zircons from the Ross et al. mineral separates with the SHRIMP ion probe. The advantage of the ion probe compared with MSID is its high spatial resolution which allows analysis of very small single grains and the selection of inclusion-free areas within each grain. This gives very sensitive detection of any inherited zircon that might otherwise be mixed with magmatic grains in the MSID dissolution. Its disadvantages are the need for simultaneous comparison with a known reference zircon, and its lower precision per analysis owing to the much smaller amounts of sample used (2×10^{-9}g zircon per analysis). The latter means that ^{207}Pb cannot be measured well enough to obtain an independent $^{207}Pb/^{235}U$ age for zircons as young as early Palaeozoic, so that the ion probe ages are based solely on $^{206}Pb/^{238}U$.

Comparison of the ion probe and MSID results will be given for four horizons from the Ordovician and Silurian, and ion probe results reported for a horizon within the Arenig. Some significant differences are found between ion probe and MSID results at the 3% level, and between the fission-track and ion probe ages for the Arenig. We will also describe new ion probe results for volcanic horizons within the Cambrian which bear on the Rb-Sr dating of illite and whole-rock samples of shales, a method recently used for dating the base of the Ordovician (Yang et al. 1986).

TIME CALIBRATION OF ORDOVICIAN ZONES AND STAGES

COOPER, Roger A., DSIR GEO, PO Box 30368, Lower Hutt, New Zealand

A precise correlation of Early Ordovician graptolite sequences from around the world has been undertaken by using the ranges of individual taxa, rather than by correlating by zones. The scheme is tested by a non-parametric graphic correlation. A composite standard sequence of 66 successive bioevents spans an interval of approximately 50 Ma, giving an average event spacing of 0.7 - 0.8 Ma. The sequence can be calibrated against the radiometric timescale and the duration of event intervals (and local biostratigraphic zones) estimated. This calibrated scale can be used to calculate species durations, extinctions and origination. The Australasian graptolite sequence, probably the best studied and documented, is taken as representative of the Pacific Province (low latitude) and analysed for graptolite faunal dynamics in this way.

DEPTH ZONATION OF ORDOVICIAN PLANKTON AND ITS IMPLICATIONS FOR OCEAN LAYERING

COOPER, Roger A., DSIR GEO, PO Box 30368, Lower Hutt, New Zealand; FORTEY, Richard A., Natural History Museum, London, United Kingdom; and LINDHOLM, Kristina, Department of Geology, Lund, Sweden.

A survey of graptolitic sequences in craton-to-ocean floor profiles on different continents representing a range of Ordovician palaeolatitudes reveals that graptolites lived in two main depth zones - an epipelagic, near-surface zone, and a mesopelagic, deepwater zone. Based on 80 species and species groups, the survey shows that depth exerts a stronger influence on graptolite distribution than latitude, and that most taxa were pandemic and lived in the epipelagic zone, making them ideal for long range correlation. The survey is an independent test of the Berry-Wilde model of Ordovician ocean diversity layering in which a subsurface biotope favourable for graptolites was postulated, based on analogy with the present day oxygen-minimum zone in the tropical eastern Pacific.

BIOSTRATIGRAPHY AND BIOGEOGRAPHIC AFFINITIES OF LATEST ORDOVICIAN-EARLIEST SILURIAN CORALS IN THE EAST-CENTRAL UNITED STATES

ELIAS, Robert J., and YOUNG, Graham A., Department of Geological Sciences, The University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada.

Uppermost Ordovician (Gamachian) to lowermost Silurian (lowermost Llandovery) strata in the east-central United States contain a distinctive association of rugose and tabulate corals, the Edgewood Assemblage. These corals occur in: Keel Fm. and oldest beds of the overlying Cochrane Fm. in south-central Oklahoma; Cason Shale of western north-central Arkansas; Leemon Fm. of southern Illinois and southeastern Missouri; Noix Limestone and overlying Bryant Knob Fm., and the laterally equivalent Cyrene Fm., of northeastern Missouri; Wilhelmi Fm. of northeastern Illinois; and the lower Mosalem Fm. of northwestern Illinois and eastern Iowa. The Gamachian strata mark a regressive phase corresponding to the latest Ordovician glacial maximum, but may have been deposited during minor transgressions if sea level fluctuated during that time interval. Lowermost Llandovery strata were deposited during the major transgression associated with deglaciation in the earliest Silurian.

The Edgewood Assemblage is dominated by solitary Rugosa representing Streptelasma. Other Rugosa, including the solitary forms Keelophyllum, Grewingkia, and Bodophyllum, and the colonial forms Palaeophyllum and Pycnostylus?, are rare. The solitary Rugosa were evidently derived from species previously restricted to the North American continental margin, and are similar to those in the Dalmanitina Beds (Hirnantian) or possibly lowermost Llandovery beds of Östergötland, Sweden, and the Guanyinqiao Beds (Dalmanitina Beds; Hirnantian) of Guizhou Province, China. Among the Tabulata, Paleofavosites, Propora, and Halysites are most common. Catenipora, Rhabdotetradium, Protaraea, Acidolites, and ?auloporids are rare. Closest affinities are with Tabulata in the Ellis Bay Fm. (Gamachian) and Becscie Fm. (lowermost Llandovery) of Anticosti Island and the Grande Coupe beds (Ashgill) of the Matapédia Group near Percé, Quêbec. There are similarities with forms in the Ashgill and Llandovery of Baltoscandia. The Edgewood Assemblage includes the youngest North American tetradiids and the oldest North American Halysites.

MICROPALAEOGEOGRAPHY, FACIES AND STRATIGRAPHY OF PRE-VARISCAN PERI-GONDWANA CENTRAL EUROPE AND SPECIFICALLY OF ORDOVICIAN GERMANY.

ERDTMANN, Bernd-D., Institute of Geology and Palaeontology, Technical University Berlin, D-1000 Berlin, Germany.

Post-Cadomian and pre-Caledonian Palaeo-Europe was an integral northern extension of the African portion of the Panafrican-consolidated Gondwana megaplate. As the East European (Baltic) craton became "docked" and sutured to this northern rampart of "European Africa" along the transcurrent Tornquist Lineament during the Late Silurian Caledonides, the "Rheic Rift" in South Germany sagged and opened causing the English Midland to Thuringian and Lausitz microplates to secede from "Africa" (which continued to include pre-Alpide southern Europe) and to turn them into "outboard" terranes which became annexed to the Caledonide-consolidated Laurentian-East European macroplate. This "Rheic Rift" developed into the "Variscan Ocean" in the Devonian.

During the "African connection phase" (Riphaean to Early Silurian) the Ordovician of "Palaeo-Germany" is characterized by cold-water shallow to deeper marine clastics containing an "impoverished" fossil record of acritarchs, brachiopods, graptolites, Neseuretus-type trilobites and ostracods. A thick succession of Early Ordovician (Hunneberg to early Arenig) fine clastic shelf deposits marks a major transgression in Thuringia, whereas equivalents of the "Grés Armoricain" covered the northern margins of the North Saxonian-Lusatian Platform. North Atlantic province type conodonts are found in association with cyclically recurring oolitic chamosites and thin "lag deposits" denoting global regressive events during mid- and latest Arenig, late Llandeilo and early Ashgill intervals. Continuous Llanvirn to Llandeilo (and possibly early Caradoc) silty shale and chloritic argillite deposition including bentonites is observed in the Westfalian Ebbe Anticline, an eastern extension of the Brabant Massif. The Hirnantian episode is well represented by diamictic "Lederschiefer" and distinctly regressive Döbra and Eichberg Sandstones (of allochthonous "Bavarian" facies) with D. bohemicus and G. persculptus at the top. The strong development of rift volcanism and rift deposition of the Vendian-Cambrian is not continued into the Ordovician.

GLOBAL EUSTATIC EVENTS, BIO-EVENTS, BIOFACIES - AND "BIAS" - AS DEMONSTRATED FOR THE TREMADOC-ARENIG TRANSITION.

ERDTMANN, Bernd-D. Institute of Geology and Palaeontology, Technical University Berlin, D-1000 Berlin, Germany.

The Tremadoc-Arenig hiatus in the type area of N. Wales represents a major missing time interval. In terms of graptolite succession this hiatus spans the "Kiaerograptus" quasimodo to "Didymograptus" simulans time equivalent, which in Scandinavia would be represented by the Hunneberg Stage graptolite zones of Kiaerograptus supremus, Araneograptus murrayi, Eotetragraptus approximatus and the basal "D." balticus zone. In terms of conodont zonation this corresponds to the top of the Paltodus deltifer, Paroistodus proteus, and to the base of the Prioniodus elegans zones. Whereas this hiatus is of its maximum extent in N. Wales, it is of a much less dimension in the Oslo-Scania confacies belt, where only the A. murrayi zone is generally missing (except in westernmost Scania). This hiatus is depositionally not expressed in many deeper water shelf marginal successions, or only by intercalation of oxygen advection-induced distinctive red shales, e.g. above La2 graptolite beds in the Cow Head Group of W. Newfoundland and in the top of the Yinchupu Formation along the southern margin of the Yangzi Platform, or in the top Yeli beds of the Hunjiang-Dayangcha region of the Sino-Korea Platform in China, however, there is no fossil control within these continuous sequences. By graptolite correlation of the Green Point, W. Newfoundland succession with the La2 of Victoria, Australia and coeval strata at Aorangi Mine and Preservation Inlet, New Zealand and with the Scandinavian Hunneberg graptolite sequence, apparently part of the La2 belongs to Tremadoc equivalents ("K." quasimodo - "K." taylori = Paradelograptus pritchardi), whereas Araneograptus pulchellus, Paradelograptus antiquus, the bulk of the La2 clonograptids, "Temnograptus" magnificus and other "dichograptoids" are of distinct Hunnebergian affinity, all occurring well below the FADs of E. approximatus or of "D." deflexus, the cold water earliest "Arenig" representative of peri-Gondwana. Thus, the only potential stratotype for a graptolite based GSSP for a revised Tremadoc-Arenig (or -Hunneberg) transition would be within the 12-20 m of (not yet measured) graptolitic black shale sections of the La2 in Victoria or in New Zealand.

WHITEROCKIAN GRAPTOLITES AND CONODONTS FROM THE VININI FORMATION, NEVADA: BIOSTRATIGRAPHIC IMPLICATIONS

FINNEY, Stanley C., Geological Sciences Dept., California State University, Long Beach, California 90840, USA and ETHINGTON, Raymond L., Geology Dept., University of Missouri, Columbia, Missouri 65211, USA

Large collections of beautifully preserved graptolites representing the Pacific province Isograptus fauna were collected from the Lower Member of the Vinini Formation in the Roberts Mountains. These beds also yielded large collections of lowest Whiterockian conodonts, suggesting that the base of the Whiterock Series correlates with the base of the Isograptus Zone. From this, one must conclude that the base of the Whiterock Series correlates with a level close to the base of the Australian Castlemanian Stage and with the middle of the British Arenig Series.

The graptolite fauna includes Tetragraptus (4 species), Didymograptus bifidus, D. paraindentus, D. extensus, Xiphograptus svalbardensis, X. declinatus, Isograptus caduceus australis, I. cf. primulus, I. subtilis, I. victoriae victoriae, I. v. divergens, Pseudisograptus dumosus, P. gracilis, P. hastatus, P. manubriatus koi, Oncograptus upsilon biangulatus, Cardiograptus morsus, Undulograptus austrodentatus americanus, and Pseudotrigonograptus ensiformis. All collections from the Vinini are difficult to correlate with either the classical Australian zonation or the recently developed Newfoundland zonation because of inconsistencies in the ranges and co-occurrences of key zonal species. However, correlation of the biostratigraphically lowest collections to the Australian zonation must be at least as low as the I. v. victoriae Zone or the underlying I. v. lunatus Zone.

The beds with the graptolites yielded large collections of conodonts. The fauna is of Midcontinent affinity with some North Atlantic elements and is correlative with the Histiodella altifrons Zone. Most importantly, the conodont fauna is virtually identical to that of the lowest Whiterock Series at its type section in Whiterock Canyon in the Monitor Range. Besides indicating that the base of the Whiterock Series is as low as the Middle Arenig, the Vinini collections provide an important tie between the graptolite and Midcontinent conodont zonations.

FAUNAL EVIDENCE IN THE ORDOVICIAN PALAEOGEOGRAHY OF THE NORTH ATLANTIC REGION

FORTEY, Richard A., The Natural History Museum, Cromwell Road, London SW7 5BD, England; HARPER, David A.T., Dept. of Geology, University College, Galway, Ireland; OWEN, Alan W., Dept of Geology and Applied Geology, The University, Glasgow G12 8QQ, Scotland.

It is generally agreed that the Ordovician was a critical time in the history of those palaeocontinents which today comprise the North Atlantic region. However, there is no general consensus on: (a) how many palaeocontinents there were, (b) the time of appearance or disappearance of the oceanic tracts that separated them e.g. along the 'Rheic line', (c) the position and palaeogeographic signature of marginal 'islands'. Faunal evidence has been invoked to support a variety of different reconstructions and timings. We examine cases in which the evidence has not been appraised in a critical way, or where faunas have been asked to carry more diagnostic weight than they should. The evidence is reviewed using new computer methods, such as biogeographic cladistics and seriation. 'Island' faunas for the most part align in positions marginal to former continents: there are a few 'mid-oceanic' candidates. Different groups of fossils show differing palaeobiogeographic sensitivity; trilobites are often the most diagnostic. Evidence for the existence of Tornquist's Sea in the Early Ordovician is good. However, the timing of geographical changes that occurred later in the Ordovician is open to several interpretations depending on the kind of data that are used. This will be examined using new faunal analyses from the Llandeilo to the Ashgill.

RE-EVALUATION OF THE UPPER ORDOVICIAN GRAPTOLITE BIOSTRATIGRAPHY OF THE ZONE 13 REFERENCE SECTION IN THE MARATHON REGION, WEST TEXAS.

GOLDMAN, DANIEL, Dept. of Geology, State University of New York at Buffalo, NY 14260, and BERGSTRÖM, STIG, M., Dept. of Geological Sciences, The Ohio State University, 125 South Oval Mall, Columbus, OH 43210.

There has been considerable debate whether or not a major hiatus occurs between the Woods Hollow and Maravillas formations in the Marathon graptolite zone reference standard. New collections from the lower Maravillas in the key section at the Picnic Grounds southwest of Marathon contains diagnostic Upper Ordovician graptolites that confirm the existence of a large stratigraphic gap below the Maravillas. Collections at 0.5 meters above the base of the Maravillas Formation contained only <u>Climacograptus</u> <u>nevadensis</u> (Carter); those from 4.5m contained <u>C</u>. <u>nevadensis</u> and <u>Orthograptus</u> <u>fastigtus</u>; those from 12.2m had <u>O</u>. <u>fastigatus</u>, <u>O</u>. <u>thorsteinssoni</u> Melchin, <u>Climacograptus</u> <u>tubuliferus</u>, and <u>Orthoretiograptus</u> sp; and those from 14.4m contained <u>C</u>. <u>tubuliferus</u>, <u>Orthoretiograptus</u> sp., and <u>Dicellograptus</u> <u>ornatus</u>. None of the species reported by Berry (1960) from Zone 13 at this locality occur in our collections.

Our data suggest that the basal Maravillas (Zone 13) correlates with the <u>D</u>. <u>gravis</u> Zone in the Victorian graptolite sequence; with the <u>C</u>. <u>tubuliferus</u> Zone at Trail Creek, Idaho; and with the upper part of the <u>O.</u> <u>quadrimucronatus</u> Zone in the Canadian Cordillera. Graptolites from the top of the Woods Hollow Formation represent the <u>C</u>. <u>bicornis</u> Zone indicating the hiatus between the Woods Hollow and Maravillas spans at least Ea1-Ea3 of the Australian sequence and most of, if not all, of the British Caradoc. There may be a similar, but smaller, hiatus in Idaho and the Canadian Cordillera. The uppermost Woods Hollow belongs to the <u>P</u>. <u>anserinus</u> conodont Zone and the basal Maravillas to the <u>A</u>. <u>ordovicicus</u> Zone which agrees with the graptolite evidence. In Baltoscandia, the <u>A</u>. <u>superbus</u> - <u>A</u>. <u>ordovicicus</u> Zone boundary is in the upper <u>P</u>. <u>linearis</u> Zone. The latter zone is correlated with the American <u>A</u>. <u>manitoulinensis</u> Zone, the lower part of which contains <u>A</u>. <u>superbus</u>. Hence the presence of <u>A</u>. <u>ordovicicus</u> in the basal Maravillas suggests a level well up in the <u>A</u>. <u>manitoulinensis</u> Zone, and an age no older than late Maysvillian. Our new data have far reaching regional implications in that they show that the scope of Zone 13 as commonly used by structural geologists in dating the Taconic orogenic phase in eastern North America is largely older, biostratigraphically, than the typical Zone 13 in the Marathon area.

DISTRIBUTION OF ORDOVICIAN PETROLEUM IN AUSTRALIA IN RELATION TO EUSTASY

GORTER, John D., Petroz N.L., 77 St George's Terrace, Perth, Western Australia, 6000

Ordovician sedimentary basins are widespread in Australia. In the Amadeus Basin the commercial oil and gas discoveries have been sourced and reservoired in the Early Ordovician sediments. Significant non-commercial gas discoveries have been made in Ordovician rocks in the Canning, Georgina and Warburton Basins. Oil and gas shows have been seen in the Arafura Basin. Other underexplored basins with oil and gas potential include the Wiso and Officer and the Tasman Geosyncline.

The localisation of source and reservoir rocks in those basins with production and significant shows is contrasted with published eustatic curves for the Ordovician. A model linking the development of the source and reservoir facies is proposed.

ORDOVICIAN OF THE PRAGUE BASIN (BARRANDIAN AREA, CZECHOSLOVAKIA)

HAVLÍČEK, Vladimír and FATKA, Oldřich, Ústřední ústav geologický, 118 21 Praha 1, Malostranské nám. 19, Czechoslovakia.

Prague Basin, bearing richly fossiliferous Ordovician sequences, is confined to Perunica microcontinent inhabited mostly by Baltic faunas in the Tremadoc; Baltic affinity, however, decreased gradually towards middle Ordovician; Dobrotivá and Beroun Series are dominated by Mediterranean - type faunas with no Baltic elements, whereas in the Kralodvor and Kosov the migration routes re-appeared. Ordovician of the Prague Basin is subdivided into the Tremadoc, Arenig, Llanvirn, Dobrotivá, Beroun, Kralodvor, and Kosov Series, each of them characterized by an influx of new fauna; moreover, bases of the Tremadoc, Arenig and Llanvirn coincide with transgressions that succeded regression events. Kosov Series reflects both the glacio-eustatic and tectono - eustatic movements.

THE ORDOVICIAN SYSTEM IN SOUTH AFRICA - A REVIEW

HILLER, Norton, Department of Geology, Rhodes University, Grahamstown, South Africa, 6140.

The Ordovician System is represented in South Africa by rocks belonging to the lower part of the clastic Table Mountain Group. The sequence rests unconformably on an eroded and peneplained surface cut across late Proterozoic metasedimentary rocks and associated granitic intrusives that give radiometric ages in the range 632-517 Ma. The Ordovician succession, which has been best studied at the western end of the outcrop area, has been divided into five formations. The Piekenierskloof, Graafwater and Peninsula formations, have been interpreted as having been deposited in an extensive coastal braidplain system that was periodically transgressed by the sea as evidenced by intervals of intense bioturbation. The Pakhuis Formation, consists of glaciogenic diamictites, arenites and argillites resulting from the late Ordovician glaciation that affected large areas of Gondwana. The overlying shaly Cedarberg Formation represents the fine-grained outwash material from the retreating ice sheets. It was initially deposited in peripheral glacial lakes and shallow marine embayments during the first stages of a post-glacial transgression.

In the eastern part of the outcrop belt only three formations are recognised; the Sardinia Bay Formation, has been attributed to deposition in a shallow tidal shelf setting, but uncertainty exists about the origin of the overlying Peninsula Formation. It is thought to represent a shallow marine shelf but problems with such an interpretation are recognised. The third formation is the lateral extension of the Cedarberg Formation but at its base it may include very thin equivalents of the preceding Pakhuis Formation.

For much of its thickness the sequence is unfossiliferous apart from trace fossils but the Cedarberg Formation, at the western end of its extent, has yielded a number of invertebrate remains including brachiopods, trilobites, conodonts and chitinozoans. The fauna is now accepted as indicating a late Rawtheyan to Hirnantian age.

THE ORDOVICIAN K-BENTONITE PROJECT, PART III: TRANS-IAPETUS STRATIGRAPHIC AND TECTONOMAGMATIC SIGNIFICANCE

HUFF, Warren D., Dept. of Geol., Univ. of Cincinnati, Cincinnati, OH 45221-0013 USA;
BERGSTRÖM, Stig M., Dept. of Geol. Sci., The Ohio State Univ., Columbus, OH 43210 USA; &
KOLATA, Dennis R., Illinois State Geol. Survey, Champaign, IL 61820 USA

Middle Ordovician (Caradocian) K-bentonites are widely distributed in Baltoscandia and North America. The Deicke and Millbrig K-bentonites in North America and the "Big Bentonite" in Baltoscandia are particularly thick and can be traced over several thousand square kilometers. Biostratigraphic, geochemical,and petrographic data have been compiled to test the hypotheses that 1) the "Big Bentonite" and Millbrig are the same age, and that 2) they originated from a common source. The Millbrig and Deicke are Rocklandian in age throughout the eastern Midcontinent of North America and both beds occur within the upper half of the *P. undatus* conodont zone. In Sweden the "Big Bentonite" occurs in the *D. multidens* graptolite zone and the *A. tvaerensis* Atlantic conodont zone. Graphic correlation methods (Bergström, 1989) indicate the K-bentonite portion of these zones are equivalent in North America and Europe.

Published ^{40}Ar-^{39}Ar (Kunk & Sutter, 1984) and U-Pb (Samson et al., 1989) age determinations of phenocrysts from the "Big Bentonite" and the Millbrig indicate age equivalence within analytical error. Microprobe analyses of primary plagioclase from the "Big Bentonite" typically show mole percent An between 30-50, in agreement with the andesine reported by Haynes (1987) for the Millbrig. Magmatic discrimination diagrams based on Nb/Y, Zr/TiO2, Hf, Th Ta and REE show the K-bentonites in both Baltoscandia and North America belong to a calc-alkaline suite ranging from andesites to rhyolite and are characteristic of destructive plate margin volcanism. Th-enrichment indicates a highly evolved magmatic system gave rise to the ashes on both sides of Iapetus. Available evidence suggests that the "Big Bentonite" of Baltoscandia and the Millbrig of North America are coeval and originated from the same tectonic setting and with the same magmatic parent. If our continued work bears this out we will have documented a Caradocian event-stratigraphic horizon extending from the American midwest to the western Soviet Union. The rock-equivalent volume of ash produced by this single ultraplinian eruption would have been in excess of 2000 cubic km, making it one of the largest known ash-falls in the stratigraphic record. The Millbrig and "Big Bentonite" are thickest near the Iapetus margin and thin toward their respective plate interiors, suggesting the eruption had sufficient height and velocity to overcome prevailing troposphere winds. The distribution pattern of K-bentonites on the two plates can be reconciled with current reconstructions of Ordovician plate tectonics.

DO HIATUSES IN LOWER ORDOVICIAN LIMESTONES OF SWEDEN INDICATE EUSTATIC SEA-LEVEL CHANGES?

HUTTEL, Peter, Institut für Geologie Paläontologie, Technische Universität Berlin, Sekr. EB 10, Ernst-Reuter-Platz 1, 1000 Berlin 10, Germany

Hiatuses in Upper Cambrian and Lower Ordovician strata which seem to occur at the same time worldwide are interpreted as the effect of major regression events. It is supposed that during regressions major parts of the shelfs were emerged and eroded. However, the exact correlation of these regressive events has not yet been completed satisfactorily and is still a matter of discussion. Sedimentological aspects of these hiatuses have never been studied in detail. Thus, the sedimentological model "hiatus indicates regression and emergence" may work, but it may also be a wrong simplification as in the case of Lower Ordovician limestones of Sweden.

Lower Ordovician limestone sequences in Sweden are condensed and interspersed with hardgrounds. In most outcrops a big stratigraphic gap is found below their base. The oldest limestones are rich in glauconite suggesting subtidal environment and very low sedimentation rates. Sliding, slumping and pull-apart structures are common features of these rocks. Obvious ly sliding is of major importance in causing hiatuses. In the locality "Stenbrottet" a 50 cm thick carbonate sequence comprising the zones of Plesiomegalaspis armata to Plesiomegalaspis planilimbata thins out to nothing within a distance of 30 m due to sliding. Because sediments are so extremely condensed, also minor slides may account for major stratigraphic gaps.

Sliding of limestones was probably triggered by high fluid pressures resulting from dewatering of underlying Upper Cambrian and Tremadocian black shales. High fluid pressures could be achieved because early diagenetic lithification made limestones almost impermeable to water squeezed out from the shales.

THE ORDOVICIAN K-BENTONITE PROJECT, PART I: DISTRIBUTION AND SIGNIFICANCE IN EASTERN NORTH AMERICA

KOLATA, Dennis R., Illinois State Geological Survey, Champaign, Il 61820 USA; HUFF, Warren D., Dept of Geol., Univ. of Cincinnati, Cincinnati OH 45221-0013; and BERGSTRÖM, Stig M., Dept of Geol. Sci., The Ohio State Univ., Columbus, OH 43210 USA.

Outcrop and subsurface investigations indicate that approximately 50 volcanic ash beds (K-bentonites) occur in Ordovician rocks of eastern North America. The majority of beds occur within the *Amorphognathus tvaerensis* conodont zone in the early part of the Mohawkian Series (early Caradocian). Together they cover approximately 1.3 million square km, in an area that extends from northwestern Iowa to northern Alabama to Maritime Canada. Some beds can be correlated on a regional scale across major facies boundaries.

The Deicke and Millbrig K-bentonite Beds (Rocklandian Stage) are the thickest and most widespread beds in North America. They have been correlated by chemical fingerprinting and traced through outcrops and on wireline logs from their type sections in the Mississippi Valley to the southern and central Appalachian Mountains, a distance of about 1300 km. Both beds increase in thickness and grain size toward the southeast indicating a volcanic source area that was probably east of the present Appalachian Mountains. No trace of the volcanic system, however, is known. Trace element analyses indicate the parent magma was generally calc-alkaline in composition and the tectonic setting was that of an actively subducting back-arc system with a continental rather than oceanic basement. The subduction was a consequence of the Taconic orogeny. The volume of both beds suggests they rank among the largest air-fall ash deposits documented in the stratigraphic record. The Deicke, which is somewhat more extensive than the Millbrig, is the most widespread chronostratigraphic marker in the Ordovician of eastern North America.

ORDOVICIAN OIL SHALE OF ESTONIA - ORIGIN, PALAEOBIOLOGICAL CHARACTERISTICS AND USAGE.

KÕRTS, Aile, Institute of Geology, Estonia pst. 7, Tallinn 200101, Estonia.

The main accumulation of organic matter forming oilshale - kukersite, took place on a subtidal shallow shelf of the Baltic Basin during the late Llandeilo - early Caradoc regression. However, the oldest Kukersite kerogens in Estonia are of Arenig and the youngest of Wenlock age.

The Kerogen of kukersite (kukersine) is formed mostly of algal lumps (d = 50-500μm) named kuckers. The distribution of their different morphotypes (single globules or aggregates) in kukersite beds reflects the accumulation pattern. Accordingly, these morphotypes might be considered to be of facial (sedimentational) rather than of algal colonial nature. Kuckers contain blue-green algal (*Gloeocapsomorpha*), spore-like, mostly dyad remains that are also found singly or forming clusters in kukersite, particularly in alternating limestone beds. Abundant algal remains of restricted spatial distribution considering the size of the Ordovician Baltic Basin, indicates the possible algal mat origin of kukersine, derived from tidal flats.

The general distribution pattern of ostracodes in kukersite beds follows facies belts but the areas of organic matter accumulation do not. Although the thickest kukersite beds are remarkable for the abundance of particular ostracode species, they are accompanied by concentrations of other fossils (bryozoans, brachiopods, pelmatozoan debris).

The total output of oil shale from Estonian deposits exceeds 770 million tonnes. The commercial seam comprises several kukersite beds (10-30cm) and is 3m thick.

DISCOVERY OF THE FIRST LATE CAMBRIAN TO EARLY ORDOVICIAN CONODONTS FROM THE MONTAGNE NOIRE, SOUTHERN FRANCE

KUPPERS, Andreas N., Dtsches. Inst. für Japanstudien, Nissei Kojimachi Bldg, 3-3-6 Kudan-Minami Chiyoda-Ku Tokyo 102, Japan; and POHLER, Susanne M.L., School of Earth and Ocean Sciences, University of Victoria, Victoria, BC V8W 2Y2 Canada.

During regional mapping a small collection of conodonts has been recovered from Cambro-Ordovician meta-sediments in the Montagne Noire. This is the first documentation of conodonts of this age in southern France. The conodont faunas have been recovered from the Calcaire de la Val d'Hom. These limestones occur as lenticular bodies in the clastic series of the Cambro-Ordovician Clamoux Sandstone which is considered to be a flyschoid deposit.

Tha fauna of more than 100 specimens has a CAI of 5 and is composed entirely of simple cone genera such as *Teridontus, Fryxellodontus, Drepanodus, Acodus?* and *Semiacontiodus*. Species of *Drepanodus* dominate the fauna. This genus is only known from Ordovician deposits and the co-occurrence with *Teridontus* suggests an Early Ordovician age. The fauna lacks *Cordylodus* and also advanced components such as oistodontiform elements. Very few collections are known to date from Early Paleozoic rocks in Europe. Arenigian faunas described from Thuringia (Sannemann, 1955) are also characterized by simple cone genera as are early Arenig faunas from the Seydesehir Formation in Turkey (Barnes in Dean, 1973)

THE HUNNEBERGIAN

LINDHOLM, Kristina and LÖFGREN, Anita, Dept. of Historical Geology and Palaeontology, University of Lund, S-223 62 Lund, Sweden.

The Hunnebergian forms part of the Early Ordovician of Scandinavia, the original definition of its stratigraphic content approximately corresponding to the La2-Be3 interval in the Australasian zonal succession. It encompasses the *Paroistodus proteus* (with four subzones) and *Prioniodus elegans* conodont zones, and the *Kiaerograptus supremus*, *Araneograptus murrayi*, *Hunnegraptus copiosus*, *Tetragraptus phyllograptoides* and *Didymograptus balticus* graptolite zones. The base of the *Kiaerograptus supremus* Zone is as yet undefined and is probably situated in the uppermost Tremadoc. The Hunnebergian is subdivided into an Early and a Late part, the Early Hunnebergian consisting of the earliest two subzones of the *P. proteus* conodont zone and the graptolite zones below that of *T. phyllograptoides*.

Clastic and carbonate rocks from several areas in southern Scandinavia have been investigated for conodonts and graptolites. Graptolites predominate in the westerly shale successions (in Scania, Västergötland and the Oslo region). Conodonts co-occur with the graptolites to some extent, especially at Mt. Hunneberg in Västergötland, and are found abundantly in the limestone areas of Västergötland, Dalarna, Närke and the island of Öland.

The subdivison of the *P. proteus* Zone has improved the accuracy of correlation between conodont and graptolite zones, and between western and eastern Scandinavia. Internationally, the time span and stratigraphic position of the Hunnebergian suggests its insertion as a Series between the Tremadoc and the Arenig (beds of a corresponding age are virtually unknown in Wales). The boundary alternatives for international correlation within Hunnebergian time, and correlation with specific areas, e.g. Newfoundland, will be discussed.

SEDIMENTOLOGY OF THE COLLMBERG-QUARTZITE (SAXONY) AND ITS SIGNIFICANCE FOR THE PALAEOGEOGRAPHY OF THE ORDOVICIAN IN GERMANY

LINNEMANN, U., Institute of Soil and Site Science attached to Dresden University of Technology, Pienner Str. 8, O-8223 Tharandt, Germany

The Saxo-Thuringian Ordovician in Germany consists mainly of clastics. The Thuringian section of the Schwarzburg Anticline is the standard Ordovician section of Germany. This sequence has a thickness of 3,000m, an hiatus in the Llandeilo and Caradoc and is characterised by a eustatically controlled shelf development (Lutzner, Ellenberg & Falk, 1986; Knupfer, 1967; Fuchs, 1990). The section is underlain by clastic Cambrian (Goldisthal Group) with a thickness of 240m. In North Saxony the Ordovician is represented only by Tremadocian quartzites (Collmberg- and Dubrau-Quartzites), which overlay the Cadomian consolidated Lusatian Microplate. The basal conglomerates contain assorted Vendian sediments, e.g. cherts and quartzites. Pebbles of Cambrian age are unknown. The Ordovician quartzites directly overlay Vendian greywackes. The Thuringian and the North Saxonian Ordovician show a different facies which can be traced back to several consolidation periods of the basement.

ORDOVICIAN TO PERMIAN EVOLUTION OF SOUTHEAST ASIAN TERRANES: NW AUSTRALIAN GONDWANA CONNECTIONS

METCALFE, I., Department of Geology & Geophysics, University of New England, Armidale, NSW 2351.

Southeast Asia is a complex assembly of allochthonous continental terranes. Palaeontological, stratigraphical and palaeomagnetic data indicate thaat all of these terranes were derived directly or indirectly from Gondwana. Assembly of the terranes took place between the Late Palaeozoic and Cenozoic but the precise sites of original attachment, and timings of rifting from Gondwana and of amalgamation and accretion are still contentious. The continental "core" of the region comprises four principal terranes, South China, Sibumasu, Indochina and East Malaya. Early Palaeozoic, and in particular Ordovician, faunas of South China and Sibumasu show strong affinities with N and NW Australia and Tasmania and include forms otherwias endemic to Australia and Gondwana. Middle and Late Palaeozoic faunas of Sibumasu also show NW Australian affinities and the presence of Late Carboniferous-Early Permian glacial-marine diamictites with associated cool-water faunas suggest attachment to NW Australia at this time. The affinities of Early Palaeozoic faunas of Indochina and East Malaya are not yet known but Late Palaeozoic and younger faunas and floras do not appear to be relaated to Gondwana.

Biogeographic, stratigraphic and palaeomagnetic data suggest that South China and Sibumasu, along with the Norrth China, Tarim, Tsaidam, Lhasa, Changtang and possibly Indochina and East Malaya blocks formed part of the NE Gondwana margin in the Ordovician. Specific sites of attachment are indicated by stratigraphic and biogeographic evidence together with palaeomagnetic data. North China is placed near North Australia, Sibumasu adjacent to NW Australia and the South China, Indochina, Tarim, Tsaidam, Lhasa and Changtang blocks as forming part of the North India-Iran margin of Gondwana. Palaeobiogeographical and palaeomagnetic data suggest that South and North China (possibly along with Tarim, Indochina and Tsaidam) rifted from Gondwana in the Silurian. South China appears to have been isolated from other continental masses during the Devonian as evidenced by its high degree of faunal and floral endemism, but appears to have amalgamated with Indochina to form "Cathaysialand" by the Early Carboniferous.

An elongate continental sliver, the "Cimmerian Continent", including the Lhasa, Changtang and Sibumasu blocks, rifted from Gondwana in the Early-Middle Permian and travelled rapidly northwards across the Tethys, fragmenting on its journey. Amalgamation of Sibumasu and Cathaysialand occurred in Late Permian-Early Triassic times along the Uttaradit-Nan and Bentong-Raub sutures.

THE LANGE RANCH EUSTATIC EVENT: A REGRESSIVE-TRANSGRESSIVE COUPLET NEAR THE BASE OF THE ORDOVICIAN SYSTEM

MILLER, James F., Geosciences Department, Southwest Missouri State University, Springfield, Missouri, USA 65804-0089

The Lange Ranch Event is one of several Upper Cambrian-Lower Ordovician regressive-transgressive events; it includes 15 to 100 m of carbonates in the USA. The interval coincides with the Cordylodus proavus Zone of Miller (1988) and spans the North American Cambrian-Ordovician boundary, but it is of pre-Tremadoc age. The maximum regression was just above the base of the Fryxellodontus inornatus Subzone. The event is manifested differently in various depositional environments. In slope strata the event may start with massive debris slides, marking collapse of the platform margin; here the event may be mostly represented by debris slides, and the regressive phase may be much thicker than in shallower areas. In carbonate platforms the base of the event is marked by a shift from deep to shallow subtidal strata, followed by a shallowing-upward sequence. In shallow environments there may be a stromatolite bed or an unconformity (or both) at the maximum regression. The transgressive phase may consist of a deepening-upward sequence or may be entirely shallow-water strata, such as 60 m of stromatolites in parts of Utah. In shallow depositional environments, some or all of the regressive phase may be absent from erosion during the maximum regression; the lower part of the transgressive phase may be missing also in such environments.

This event can be recognized in the USA, Canada, Scandinavia, Kazakhstan, North China, Australia, and probably Antarctica and Greenland. Precise conodont correlation permits recognition of isochronous events in these areas, leading to the interpretation that the Lange Ranch Event is a true worldwide eustatic event.

EVOLUTION OF THE DIPLOGRAPTACEA AND THE INTERNATIONAL CORRELATION OF THE ARENIG-LLANVIRN BOUNDARY

MITCHELL, Charles E., Department of Geology, State University of New York at Buffalo, Buffalo, NY 14260, U.S.A.

From their appearance in the upper Yapeenian, diplograptacean graptolites underwent a rapid diversification. Despite substantial differences in nomenclature and true provincialism, preliminary comparative studies indicate that the sequence of evolutionary first appearances of several common species is similar in both the Pacific and Atlantic Province faunas. These evolutionary events provide a means to gauge the degree of diachronism of the first appearance of diplograptaceans across these regions. The late Yapeenian Undulograptus sinodentatus is known only from China, but earliest Darriwilian (early Da1) assemblages occur widely in the Pacific Province where they consist of U. austrodentatus, Undulograptus sp. A, (= U. austrodentatus of Williams and Stevens), and the spinose U. sinicus, together with Cardiograptus and Oncograptus. By mid-Da1 the last-named two Yapeenian holdovers became extinct while several diplograptaceans made their debut, including U. cumbrensis and U. formosus (with Pattern C astogenies), and "Climacograptus" pungens (Pattern A). The range of Eoglyptograptus dentatus (sensu Bulman) is not well known in the Pacific Province, but at least some early Da1 specimens referred to this species are U. cumbrensis. In its type area at Lévis, Quebec, E. dentatus occurs together with "C." pungens, above the first appearance of U. austrodentatus.

The first appearance of diplograptaceans in the Bogo Shale of the Trondheim region is marked by U. austrodentatus and U. sinicus, and in the upper D. hirundo Zone in Scania, by the latter plus U. cumbrensis. These assemblages, together with the other species present, suggest a Da1 age. The base of the D. artus Zone on Öland coincides with the first appearance of E. dentatus and the oldest Hustedograptus species. U. camptochilus, which closely resembles U. formosus, ranges upward from the D. hirundo Zone to overlap the range of these species. Upper Arenig assemblages from Shropshire and Wales yield U. austrodentatus and U. cumbrensis (including specimens identified as "G. dentatus"), whereas E. dentatus and Hustedograptus debut early in the Llanvirn D. artus Zone strata that still bear U. austrodentatus.

These relationships suggest that the base of the Llanvirn corresponds to a level in the Australian succession no older than mid Da1 and perhaps as young as the base of Da2. Conodont correlations among graptolite-bearing successions in Quebec, Newfoundland, Utah, and Nevada suggest that this level, in turn, falls within Zone N of the upper Whiterockian Series. The lower Kanosh Shale is probably pre-Da1.

PALEOGEOGRAPHIC SIGNIFICANCE OF ARENIG-LLANVIRN TOQUIMA-TABLE HEAD AND CELTIC BRACHIOPOD ASSEMBLAGES

NEUMAN, Robert B., Dept of Paleobiology, E-308 National Museum of Natural History, Smithsonian Institution, Washington DC 20560 USA and HARPER, David A.T., Department of Geology, University College, Galway, Ireland.

The Toquima-Table Head (TTH) and Celtic (CB) brachiopod assemblages are distinctive associations of brachiopod genera that occur in continental margin and peri-insular settings at various places throughout the world. Continental margin occurrences of TTH include type localities in western Nevada (Toquima Range), eastern California and the Canadian Rocky Mountains and in the northern Appalachians (Table Head, Newfoundland) and in similar settings in NE USSR, and perhaps in Kazakhstan and the Himalayas. Peri-insular settings include the volcanogenic rocks of the South Mayo Trough, western Ireland and the post-ophiolitic carbonates of the uppermost allochthon in west-central Norway (Holonda area, Lower Hovin Group). Continental margin occurrences of CB include its type localities on Anglesey, NW Wales and at Tagoat, SE Ireland, and perhaps the Oslo region, Norway and the Yichang area, central PRC. Peri-insular settings include volcanogenic rocks in the northern Appalachians (Maine, New Brunswick, Newfoundland, of both island-arc and mid-ocean ridge origin), east-central Ireland (Bellewstown volcaniclastics), central Norway (Otta Conglomerate, detritus from an eroding ophiolite), NE PRC (Xiao Hinggan Ling Mountains, Heilongjiang Province) and carbonates of the Precordillera of NW Argentina. On *Terra Mobilis* plate reconstruction maps (Scotese & Denham, 1988) for 450 Ma, TTH continental margin localities occur on trans-equatorial continents, and those offshore are inferred to have occupied sites in adjacent low-latitude waaters. CB localities, in contrast, lie on the margins of the circumpolar Gondwanan supercontinent, and on adjacent insular edifices.

EVOLUTION OF THE CONODONT GENUS *CORDYLODUS* AND THE CAMBRIAN - ORDOVICIAN BOUNDARY

NICOLL, Robert S., Bureau of Mineral Resources, PO Box 378, Canberra ACT, Australia

The conodont biostratigraphic scheme across the Cambrian-Ordovician boundary has been associated with the evolutionary lineage of the genus *Cordylodus*. Levels suggested for placement of the period boundary and conodont zonal boundaries have depended, at least in part, on the interpretation of speciation within this genus. However, problems of application of these conodont zones have arisen from differing interpretations of the various species and lineages of *Cordylodus*. New analysis of the key species of *Cordylodus* has sought to remove some of this ambiguity.

In *Cordylodus* a stem lineage and three primary branches can be recognised. The stem lineage consists of *C. primitivus, C. proavus* and *C. caboti*. The *lindstromi* branch, consists of the four species (*C. prolindstromi, C. lindstromi, C. prion* and *C.* sp. nov B) and all members have a dual tipped basal cavity. The *angulatus* branch consists of *C. drucei, C. angulatus* and possibly *C. horridus*. The *caseyi* branch consists of *C.* sp. nov. C, *C. pararotundatus, C. caseyi* and *C. ramosus*, all species that show the early stages of lateral process development.

Key morphologic events in the *Cordylodus* lineage are; 1) the development of denticulation with the evolution of *Eoconodontus notchpeakensis* to *Cordylodus primitivus*, 2) the development of the dual tipped basal cavity with the evolution of *C. caboti* to *C. prolindstromi* and 3) the beginnings of the development of lateral processes in *C. caseyi*.

PRELIMINARY CORRELATION OF PAYNTONIAN (LATEST CAMBRIAN) TO EARLIEST ARENIG (EARLY ORDOVICIAN) SEALEVEL EVENTS IN AUSTRALIA AND SCANDINAVIA

NICOLL, Robert S., Bureau of Mineral Resources, PO Box 378, Canberra ACT, Australia; NIELSEN, Arne T., Geological Museum, Oster Voldgade 5-7, DK-1350 Copenhagen, Denmark; LAURIE John R., and SHERGOLD, John H., Bureau of Mineral Resources.

In the Georgina and Amadeus Basins of central Australia a series of 7, possibly 9, eustatic events can be recognised in the interval extending from the base of the Payntonian (Late Cambrian) to the lower part of the Arenig (Early Ordovician). These include the previously identified Lange Ranch, Black Mountain, and Kelly Creek Eustatic Events; and an additional 6 events that are either un-named or have not previously been recognised in Australia. Improved biostratigraphic control of the intracratonic shelf sediments of the Georgina, Amadeus and Canning Basins now allows a trans-Australian tracing of transgressive and regressive sediment packages and the identification of these nine events.

The Lange Ranch Eustatic Event is identified as separating the Payntonian and Datsonian Stages, and is dated by the first appearance of the conodont genus *Cordylodus*. The *Acerocare* Regressive Event (ARE) is located at the Datsonian-Warendian (Cambrian - Ordovician) boundary and is dated by the first appearance of *Cordylodus lindstromi*. The Kelly Creek Eustatic Event (KCEE) is located at the top of the Warendian (?base of Hunneberg) and precedes the incoming of *Paroistodus proteus*. The Black Mountain Eustatic Event is dated by the incoming of *Cordylodus angulatus*, but this event is not as significant as the succeeding KCEE.

In Scandinavia no small scale Late Cambrian eustatic events can be identified, but the latest Cambrian *Acerocare* Zone most likely represents a lowstand period. The Black Mountain event is correlated with the faunal shift *Rhabdinopora*/*Adelograptus*, the Kelly Creek event is signalled by the *Ceratopyge* Limestone, and the Billingen transgression induced a pronounced faunal and depositional shift at the Hunneberg/Billingen transition.

Arenigian sea level changes - a basis for high resolution intercontinental ecostratigraphical correlation?

NIELSEN, Arne Thorshøj, Institute of Historical Geology and Palaeontology, University of Copenhagen, Øster Voldgade 10, DK-1350 Kbh. K, Denmark.

Detailed palaeoecological studies of the late Arenigian trilobite faunas in the Komstad Limestone and Huk Formations of southern Scandinavia have revealed a surprisingly high number of environmental oscillations, which appear traceable throughout Scandinavia and are believed to relate to sea level fluctuations. A correlation of the environmental shifts (ecostratigraphy), within the framework of a biostratigraphical zonation, enhances the local stratigraphy significantly. For example, 6 events can be established within the M. limbata Zone.

In order to determine if the inferred Scandinavian Arenigian sealevel changes are recognizable outside the North Atlantic Region, a detailed study of a section through the extremely fossiliferous Horn Valley Siltstone (Arenigian), Amadeus Basin, Central Australia, was undertaken in 1990. The project is still in progress, but the preliminary results are very encouraging, as it seems that the sequence of Scandinavian late Arenigian sealevel changes can be recognized in Central Australia in a surprizingly orderly fashion. To date, combined evidence from Scandinavia and central Australia indicates 13 middle to late Arenigian transgressive-regressive cycles.

It therefore appears, at the present stage of study, that an ecostratigraphical correlation of the sea level changes potentially can carry not only the Scandinavian trilobite zonal boundery events into Central Australia, but even allows for detailed intrazonal correlation subdividing each of the zones into 4-6 subunits.

THE GLOBAL STRATOTYPE FOR THE CAMBRIAN-ORDOVICIAN BOUNDARY THE SEARCH FOR PERFECTION

NORFORD, B. S., Geological Survey of Canada, Calgary, Canada,

Since 1974, the International Working Group on the Cambrian-Ordovician Boundary has coordinated global studies of the boundary interval. Extremely detailed knowledge of the rocks and faunas of the boundary interval has been achieved throughout the world. The most important schemes of biostratigraphic zonation have been correlated with each other with great precision; these are based on graptolites, on conodonts and on trilobites. Sedimentation studies have recognized changes of sea level on several continents that may be eustatic in origin. Paleomagnetic studies have begun and indicate that a reversal may occur near the boundary interval.

In 1985 it was decided that conodonts should be used as the prime group of fossils for selecting the base of the Ordovician System at a horizon close to, but below, the lowest occurrence of planktic graptolites within the global stratotype section. Search for the global stratotype section itself has concentrated on two localities, Dayangcha (northeastern China) and Green Point (eastern Canada), both sited in slope environments. Two sets of difficulties have arisen and polarization of opinion has developed within the Working Group. Conodont specialists have not yet been able to agree on the taxonomic limits of species within a lineage of *Cordylodus* that have been used for definition of the conodont zones in slope and deeper environments. Concerns have been raised about the potential for reworking of conodont and shelly fossils in slope environments and about the possibility of scouring being present locally and causing incomplete records of sedimentation.

There are alternative courses of action if agreement cannot be achieved on the *Cordylodus* lineage. A different lineage could be selected for intensive study and used as the key to conodont biostratigraphy. A different phylum could serve as the prime fossil group, but many trilobites are provincial at this level and planktic graptolites have no documented ancestors before their sudden appearance that is almost instantaneous globally. The preferred paleogeographic site for the global stratotype could be a deeper environment (with a condensed sequence and specialized lithologies) or a shallow platform (with potential for hiatuses and hardgrounds).

The Working Group is at a key stage and its expertise is at a peak. The prime components of its task have been achieved. All that remains are selection of the locality and precise horizon to document the Boundary and agreement on the specific fossils to be used to identify the level at which a bright metal spike will mark the Boundary within the global stratotype.

ORDOVICIAN STRATIGRAPHY AND GRAPTOLITE FAUNAS OF THE GLENOGLE FORMATION, SOUTHEASTERN BRITISH COLUMBIA, CANADA

Norford, B.S., Geological Survey of Canada, Calgary, Alberta; and Jackson, D.E., Amoco (U.K.) Exploration Company, London, England.

The Glenogle Formation was deposited in Arenig to very early Caradoc time in the White River Trough that extended between shallow water environments of the Purcell Arch to the west and the Bow Platform to the east. Basinal rocks of the Lower Member dominate the central and western parts of the Trough in Bendigonian to Darriwilian time (Arenig to mid-Llandeilo). Adjacent to the Bow Platform, influx of carbonate and siliceous material into the Trough permits division of the Lower Member into the Basal Unit, the Cherty Quartz Siltstone Unit, the Middle Unit and the Limestone Unit and allows relation to changes in sea level on the Bow Platform. In the western part of the Trough, debris flows from the Purcell Arch transported shallow carbonates into the Basal Unit. The Upper Member documents shallowing throughout the Trough, presumably corresponding to the Owen Creek Formation and the superjacent hiatus on the Bow Platform. It is dominated by quartz silt and sand, mixed with carbonate close to Bow Platform and with argillaceous material further west. The top of the formation is an unconformity below Upper Ordovician rocks. Thermal maturities are high in the Glenogle (Conodont Alteration Indices 4-5; Graptolite Maximum Reflectances 7.93-11.9%).

The *Tetragraptus fruticosus, Didymograptus bifidus, Isograptus victoriae maximus, Oncograptus, Cardiograptus, Paraglossograptus tentaculatus, ?Diplograptus decoratus, Glyptograptus euglyphus* and *Nemagraptus gracilis* zones can be correlated with precision with Australia, New Zealand, Newfoundland and Spitsbergen. The higher zones are known only locally because of the downcutting of the sub-Upper Ordovician unconformity and the basal zone was restricted to a small part of the Trough while deposition of McKay Group carbonates continued elsewhere. Local presence of shelly fossils and recovery of conodonts from one section allow correlation of the upper Ilbexian Stage of the North American craton with the Bendigonian and Chewtonian stages, the Valhallan with the Castlemanian and Yapeenaian, and the *Orthidiella* and *Anomalorthis* Zones of the Whiterockian (restricted) with the Darriwilian.

GONDWANA GLACIATION IN THE LATE ORDOVICIAAN: EVIDENCE FROM PEBBLY MUDSTONES OF THE SAN JUAN PRECORDILLERA, ARGENTINA

PERALTA, Silvio H., National University of San Juan - CONICET, Argentina; CARTER, Charles H., The University of Akron, Ohio, USA and MARTINEZ, Ricardo, National University of San Juan, Argentina.

On the Villicum Range of the eastern Precordillera of San Juan Province, the lower part of the Don Braulio Formation is composed of pebbly mudstone deposits that contain scattered, oriented clasts with glacial features and channels filled with bioclastic detritus.

The stratigraphic association of these deposits containing *Hirnantia, Dalmanitina* and *G. persculptus* indicates a Late Ashgillian age, which is consistent with the Gondwanan Late Ordovician glaciation and global eustatic sea level change.

The occurrences of these glacial events was recorded on the geosynclinal peri-Gondwanan basins by the development of a widely distributed, marine stratigraphic pattern, recognized in most of the South American pericratonic areas. The depositional model includes: Diamictite deposits of Late Ordovician age unconformably overlying Middle to Upper Ordovician clastic sequences and continuing with concordant fossiliferous beds of Late Ashgillian or, in some areas, with Lower Llandoverian ferriferous series.

ORDOVICIAN BRACHIOPOD BIOSTRATIGRAPHY, CENTRAL WESTERN NEW SOUTH WALES, AUSTRALIA

PERCIVAL, Ian G., Esso Australia Ltd, GPO Box 4047, Sydney, N.S.W. 2001, Australia

Late Ordovician (Caradoc) formations of the Molong High and Parkes Platform in central western NSW contain 5 brachiopod zones. The earliest, Fauna A, is distributed through the Fossil Hill Limestone (Cliefden Caves Limestone Group), Ashton Member of Regans Creek Limestone, and Ranch and Bourimbla Limestone members of Daylesford Limestone, Bowan Park Group. Its characteristic assemblage includes Eodinobolus, Dinorthis, Plectorthis, Sowerbyites, Wiradjuriella, Anoptambonites, Rhynchotrema and Protozyga; Webbyspira principalis is diagnostic. Fauna AB is present in the lower Belubula limestone, and Gerybong Limestone Member (Daylesford Limestone). This zone is typified by abrupt appearance of several new diminutive genera together with rapidly evolving transitional forms. Brachiopod Fauna B (contemporaneous with coral-stromatoporoid Fauna II) is distributed through the upper Cliefden Caves Limestone Group, Regans Creek Limestone, and Quondong Limestone (Bowan Park Group). Genera restricted to Fauna B include Eridorthis, Phaceloorthis, Skenidioides, Trigrammaria and Molongcola. Abrupt faunal changeover at the end of Fauna B time coincided with cessation of carbonate deposition along the eastern Molong High and Parkes Platform. Graptolitic siltstones and spiculites at this level contain 6 brachiopod genera new to the succession, constituting Fauna C. Diagnostic genera include Anomaloglossa, Elliptoglossa, Durranella and Sericoidea. Higher levels in the Parkes Platform sequence contain Fauna D, dominated by Gunningblandella, Kassinella, Dulankarella?, Infurca, and Casquella.

Fauna A has an early to middle Caradoc age aspect (Wilderness time-equivalent in North America). Fauna AB is most likely of late Wilderness age, based on the presence of Didymelasma. Fauna B is probably contemporaneous with the Trenton Stage. Fauna C (associated with Dicranograptus hians zone graptolites) is correlated with the Trenton to Eden interval. Fauna D exhibits similarity to the Anderken and Dulankara Horizons of Kazakhstan (Eden to possibly Maysville time).

EARLY TO MIDDLE ORDOVICIAN CONODONT FAUNAS FROM THE MARGINS OF THE NORTH AMERICAN CRATON IN CANADA

POHLER, Susanne M.L., School of Earth and Ocean Sciences, University of Victoria, Victoria, B.C., V8W 2Y2, Canada.

Canada's Precambrian cratonic areas are bordered by younger orogens in which large segments of marginal marine deposits of Ordovician age are preserved. Large conodont collections have been accumulated from Early to early Middle Ordovician slope deposits of the Cow Head Group in western Newfoundland. Conodont samples have been collected from the proximal and distal slope as well as the shelf break with exceptionally good lateral control which enables correlation of the faunas. On a proximal to distal transect intervals of distinctive lateral segregation alternating with those of mixing with shelf-derived faunas can be related to margin morphology and sea level changes.

On the western side of the continent Ordovician conodont faunas from the greater Selwyn Basin have been studied. The Selwyn Basin is considered to be an inner miogeoclinal basin with graben-like embayments and troughs. Deep-water deposits of the Road River Group, and proximal and distal slope deposits of the Rabbitkettle and Haywire formations have been sampled for conodonts by several regional geologists. The faunas are characterized by different degrees of mixing between shallow and deep-water faunas. The faunal composition is probably to some degree due to structural complexity but also to margin configuration.

MIDDLE AND LATE ORDOVICIAN ORDOVICIAN BRACHIOPOD FAUNAS OF NORTH AMERICA

POTTER, A.W. and BOUCOT, A.J., Dept of Geosciences & Dept of Zoology, Oregon State University, Corvallis, Oregon 97331-5506 USA.

We have grouped North American Llandeilian to Ashgillian articulate brachiopods into informal "faunas". Some faunas are single palaeocommunities; however, most are based on composite faunal lists and are unresolvable mixtures of several paleocommunities. Faunas occupying the craton and shallower miogeocline mostly occurred in Benthic Assemblages (BA) 2-3 of Boucot (1975), ehere BA1 is intertidal and BA3 extends to the lower depth limit of prolific reef growth. Deeper water faunas of BA4-5 (5 is subphotic) were generally confined to outer ramp or outer shelf-to-slope miogeolinal areas. BA2-3 and 4-5 faunas both occurred locally at appropriate depths on suspect terranes. Maximum diversity in BA2-3 faunas was commonly <15 genera, rarely up to 20; that in BA4-5 faunas ranged up to about 25-30 genera. In Llandeilian-early Caradocian, BA4-5 faunas with such genera as *Skenidioides* and *Bimuria* are well documented in the Appalachians (Pratt Ferry, Edinburg & Rich Valley units) from Alabama to Newfoundland, but are rarely reported in western North America (unnamed units in Alaska & California, Copenhagen Formation in Nevada). In Late Caradocian-Ashgillian, these BA4-5 faunas are even less known outside the northern Appalachians, occurring in the Martinsburg Formation in Virginia and Pennsylvania, in Alaska, Northwest Territories and northern California. The rarity of these Ordovician BA4-5 faunas (compared to the distribution of Silurian analogues) is partly due to less common preservation of appropriate lithofacies and to inadequate sampling. However, in some better-sampled places (New York, Nevada, Idaho) anaerobic-dysaerobic conditions in the BA4-5 depth range prevented development of these faunas and caused anomalous onshore-offshore transects in which BA1-3 brachiopod faunas passed directly into trilobite/graptolite dominated assemblages. Thes transects have not previously been recognized as anomalous.

PRELIMINARY MAGNETIC POLARITY STRATIGRAPHY FROM BLACK MOUNTAIN, WESTERN QUEENSLAND, AUSTRALIA

RIPPERDAN, Robert L., Dept of Envir. Sci. and Energy Res., Weizmann Inst. of Sci., Rehovot 76100, Israel; and KIRSCHVINK, Joseph L., Div. of Geol. and Planet. Sci., California Inst. of Tech., Pasadena, California 91125, USA

The Cambro-Ordovician boundary section at Black Mountain, western Queensland, Australia, preserves one of the most rapidly deposited sequences spanning the boundary. CAI values about 1.5 indicate a low thermal maturity, raising the possibility that original magnetic signatures may be preserved.

Oriented block samples were collected from 115 levels, with emphasis on collecting fresh, finer grained limestone. All samples were measured using a cryogenic magnetometer and subjected to both alternating-field and thermal demagnetization. Most samples preserved two components. The first component was closely aligned with the present geomagnetic field direction in Australia, and was readily removed by low levels of alternating-field and thermal demagnetization; it is thought to be a viscous remanent magnetization (VRM). In about half of the samples, a second component was completely isolated by thermal demagnetization up to 580° C. Most of these samples displayed a west-trending, equatorial second component (Dec.=274°, Inc.= 11.6°, K=6.4, α_{95}=9°, N=47) with dual polarities that passed the reversal test. A preliminary (south) pole position of 1°N., 57°E. (δm = 5°, δp = 9°) from this component is comparable with other Late Cambrian-Early Ordovician poles from Australia. This second component is interpreted to be primary.

Other samples had west-trending demagnetization trajectories but failed to reach stable endpoints, indicating incomplete resolution of the second component. 15 of these samples were used to infer polarities. Those showing <30° angular difference between the lowest and highest demagnetization steps, or between the present day field direction and the highest demagnetization step, were excluded from polarity interpretation.

The geomagnetic field polarity was predominantly reversed during deposition of the Black Mountain section. Short periods of normal polarity occur at about 240m above section base (70m; 5 samples) in the Chatsworth Limestone, and at about 500m (10m; 3), 730m (10m; 2) and 790m (15m; 2) in the Ninmaroo Formation. A zone of mixed polarities may occur at the 580m level (45m; 4 samples). The normal zone beginning at 240m appears to correlate with *Proconodontus muelleri*-equivalent normal polarity zones in other sections. Correlation of the remaining normal polarity events is more difficult; it is suggested that they may be part of a mixed polarity "superzone" that has been found at the *Cordylodus proavus* level in other sections. Further study of the upper part of the Ninmaroo Formation will facilitate correlation of these polarity zones to other sections spanning the Cambrian-Ordovician boundary.

GASTROPODS AND BRACHIOPODS FROM THE ORDOVICIAN TELSITNA FORMATION, NORTHERN KUSKOKWIM MOUNTAINS, WEST-CENTRAL ALASKA

ROHR, David, Sul Ross State University, Alpine TX 79832; DUTRO, J. Thomas, Jr, U.S. Geological Survey, Washington DC 20560; and BLODGETT, Robert B., U.S. Geological Survey, Reston VA 22092.

The Telsitna Formation, a 2,000m thick carbonate sequence in the northeastern part of the Medfra quadrangle, ranges in age from late Early to early Late Ordovician (Arenigian through Maysvillian). Megafossils are not particularly abundant but several levels produce silicified shelly fossils that can be etched from the rock. Many of the gastropods and brachiopods are described. Corals, ostracodes and trilobites occur sparsely, and conodonts have been identified from all the critical parts of the sequence. *Maclurites*, a large, flatly coiled gastropod as much as 20cm in diameter, perhaps the most striking fossil, can be seen on many bedding surfaces throughout the sequence. It also has a distinctive, large, wedge-shaped operculum. At least five other kinds of gastropods and four brachiopods are present: *Barnesella?*, aff. *Teiichispira, Helicotoma, Lophospira, Scalites?* and *Paucicrura, Doleroides, Diparelasma* and *Strophomena?*. These fossils are part of the "Arctic Ordovician Fauna" found in Greenland, the Canadian Arctic and the northern American Cordillera, as well as several parts of Alaska. Palaeontological and lithostratigraphic evidence indicates that this palaeobiogeographic province was tropical to subtropical during the Ordovician.

ORDOVICIAN SEA LEVEL FLUCTUATIONS

ROSS, June R. P., Dept. Biology, Western Washington University, Bellingham, WA. 98225, U.S.A.; and ROSS, Charles A., Chevron U.S.A. Inc., P.O. Box 1635, Houston, Texas, 77251, U.S.A.

In the Early Ordovician (Ibexian), broad areas of the cratons were flooded and sea level was generally high, although there were at least five major regressions. On predominantly carbonate shelves, two major falls in sea level (second order cycle) are recognized within the middle Ibexian and three or four additional, less extensive sea level falls (third order cycle) are recognized near the top. Throughout these Early Ordovician carbonate successions, minor sea level cycles (fourth and fifth order cycles) of about one meter can usually be consistently identified. Toward the close of the Early Ordovician (during the Whiterockian), major falls in sea level resulted in extensive weathering and erosion of the carbonate platforms. The duration of this sea level draw down is difficult to estimate because of the lack of a good stratigraphic record on the cratons. There may have been minor transgressions but subsequent erosion and weathering removed most of the deposits.

The Late Ordovician (i.e., Mohawkian, Shermanian, Cincinnatian, and Gamachian) is characterized by a series of repeated, rapid transgressions (high stands) which progressively flooded further onto the cratons. These transgressions are punctuated by many sea level low stands, particularly during the early part of the Late Ordovician (Mohawkian). Throughout the middle part of the Late Ordovician (Shermanian and Cincinnatian), the cratons were more extensively flooded and characterized by well defined one meter cycles (fourth and fifth order cycles). In the latest Ordovician (Gamachian), a major sea level drop again caused widespread exposure of the cratons. One or two short sea level high stands may occur within this time of generally lowered sea level. The duration of this sea level low stand also is difficult to estimate. These events were followed by the general flooding of the cratons in the Early and Middle Silurian.

NORTH AMERICAN WHITEROCK SERIES SUITED FOR GLOBAL CORRELATION

ROSS, Reuben J., Jr, Department of Geology and Engineering Geology, Colorado School of Mines, Golden, Colorado 80401, USA; and ETHINGTON, Raymond L., Dept of Geology, University of Missouri, Columbia MO 65211, USA

The Whiterock Series of North America is an ideal chronostratigraphic unit. Its base is indicated by species of four different phyla (graptolites [*Isograptus victoriae* zone], conodonts [*Tropodus laevis* zone] and brachiopods and trilobites [Zone L of Ross, 1951; *O. subalata* zone of Hintze, 1952; *Orthidiella* zone of Cooper, 1956]), permitting global correlations from basin to slope, shelf and platform environments. Its upper limit is the base of the Mohawk Series (base of the conodont subzone of *Baltoniodus gerdae*). It records timing of orogenic events (Taconic Orogeny) and circumferential deposition around the North American continent during tectonic activity preceding the Tippecanoe Sequence of Sloss (1963). Similar correlative deposits are recognized in much of northern Europe and Soviet Asia which may be signalling fundamental paleotectonic events worthy of future research.

ORDOVICIAN HYDROCARBON DISTRIBUTION IN NORTH AMERICA AND ITS RELATIONSHIP TO EUSTATIC CYCLES

SCHUTTER, Stephen R., Exxon Production Research Company, PO Box 2189, Houston, Texas, 77252-2189, USA

The Ordovician rocks of North America are among the most prolific in terms of hydrocarbon production. Hydrocarbons are found in significant quantities in each of the Ordovician series and are produced in many of the cratonic basins. However, in most of these basins structuring is only weak to moderate, and reservoirs usually have low porosities and permeabilities. As a consequence, most fields have low rates of production, although their productive lives may be very long.

Distribution of hydrocarbons is strongly linked to Ordovician eustatic sea level cycles. Source rocks are organic-rich shales and carbonates deposited during periods of rapidly rising and early highstand sea level conditions. Phosphate deposits are often associated with some part of the cycle, along with occasional oolitic ironstones. Reservoir rocks are typically late highstand carbonates, often with porosity and permeability enhanced by dolomitisation or subaerial exposure. Reservoir sands do occur, and are commonly quartz arenites deposited during the early sea level rise. These facies may be arranged in a complete sandstone-shale-carbonate cycle, although usually one or more facies are reduced or absent.

Karstification of the top of the Lower Ordovician carbonate platform is widespread across North America; in some basins it forms an important hydrocarbon reservoir. Rather than a single exposure horizon, it is a composite of exposure surfaces at the end of severaal different cycles. Karstification occurs at other levels in the Ordovician as well.

Although Ordovician rocks have had a long exploration history, there is still a significant exploration potential. The deeper Ordovician rocks of west Texas, the Anadarko and Michigan basins are considered frontier areas. Hudson Bay and the Arctic Islands, as well as the Great Basin region of the western U.S. have most of the necessary qualities, but are virtually unexplored.

ORDOVICIAN GRAPTOLITES OF THE SALAIR (SOUTHWESTERN SIBERIA)

SENNIKOV, Nikolay V., Institute of Geology and Geophysics, Siberian Branch, USSR Academy of Science, Novosibirsk 630 090 USSR

A sequence of graptolite zones and associations was established in the Ordovician sections of the Salair. The Tremadoc association consisted of *Dendrograptus hallianus, D.* aff. *tenuissimus, Callograptus staufferi* and *Dictyonema* sp.. The Arenig includes the *densus* zone (*Phyllograptus densus densus, P. densus opulentus, P. anna anna, Expansograptus constrictus constrictus, Tetragraptus bigsbyi bigsbyi, Eotetragraptus harti, Didymograptus protobifidus, Corymbograptus v-fractus*); the *broeggeri* zone (*Expansograptus broeggeri, E. suecicus robustus*); *gibberulus* zone (*Isograptus gibberulus, I. paraboloides, I. hemicyclus, I. victoiae maximodivergens, I. forcipiformis tenuis, Pseudisograptus manubriatus, C. holubi, E. sparsus*). *E. extensus, E. suecicus suecicus, E. taimyrensis, P. anna longus, Tristichograptus ensiformis*, were transitional from the Arenig; The Llanvirn contained the *balhashensis-kirgisicus* zone (*E. balhashensis, E. kirgisicus, Didymograptus indentus*); the *jakovlevi* zone (*E. jakovlevi*). *Orthograptus calcaratus priscus* was a transitional Lanvirnian form. The Llandeilo comprises the *teretiusculus* zone (*Glyptograptus teretiusculus, G. euglyphus, O. calcaratus acutus, Climacograptus angustatus, Gymnograptus ?linnarssoni ejuncidus*). The Caradoc association consisted of *O.* ex gr. *truncatus* and *O.* ex gr. *quadrimucronatus*. The Ashgill association included *Ptilograptus glomeratus, Rhadinograptus* aff. *jurgensonae, Koremagraptus kozlowskii, Hedrograptus mirnyensis.*

REVISED CAMBRIAN-ORDOVICIAN BOUNDARY BIOSTRATIGRAPHY, BLACK MOUNTAIN, WESTERN QUEENSLAND

SHERGOLD, John H. and NICOLL, Robert S., Bureau of Mineral Resources, P.O. Box 378, Canberra, ACT, Australia.

Residual material from samples obtained in 1989-90 for magnetostratigraphic documentation of the Cambrian - Ordovician boundary interval at Black Mountain, western Queensland, has been acid etched for conodonts considered diagnostic for the definition of this Systemic boundary in the carbonate sequences of northern and central Australia. Preliminary results permit the recognition of 7 successive Late Cambrian conodont assemblage-zones based on the first occurrences of <u>Teridontus nakamurai</u>, <u>Hispidodontus resimus</u>, <u>H. appressus</u>, <u>H. discretus</u>, <u>Cordylodus proavus</u>, <u>Hirsutodontus simplex</u> and <u>Cordylodus prolindstromi</u>. The advent of the Payntonian Stage is relocated at the base of the <u>H. resimus</u> A.-Z. The FAD of <u>C. proavus</u> continues to define the base of the Datsonian Stage but is no longer correlated to the base of the European Tremadoc. It categorically does not overlap the late Payntonian Stage as earlier suggested by misidentified conodonts. Biostratigraphical conclusions based on revision of <u>C. lindstromi</u> and its restructured synonymy, now indicate coincidence of the FAD of <u>lindstromi</u> and the Warendian Stage at Black Mountain. This horizon, correlated to the base of the Tremadoc in Europe, is now recommended as the most satisfactory revised datum for the Cambrian-Ordovician boundary in Australian platformal carbonate sequences.

NEW DATA ON THE EARLIEST KNOWN VASCULAR PLANTS FROM THE MIDDLE ORDOVICIAN OF SOUTH KAZAKHSTAN.

SNIGIREVSKAYA, N. S., Botanic Institute, Leningrad, 197022; POPOV, L. Ye., VSEGEI,Srednij pr. 74, Leningrad, 199026; USSR; ZDEBSKA, D., Instytut Botaniki PAN, PL-31-512 Krakow, Poland.

A re-study of plant remains described previously by M. A. Senkevitch (1963) under the generic names Akdalaphyton and Sarytuma confirmes their assignment to the earliest known vascular plants. Stomata have been discovered both through light microscope and under SEM, in the most of studied specimens. Thus the evolutionary history of vascular plants is extended back to the Middle Ordovician. The well preserved remains of vascular plants have been discovered from the basal part of Anderken Formation (Caradoc) in Chu-Ili Range, South Kazakhstan. The lithology is represented by alternating cross-bedded and flat-lying sandstones and siltstones with marks of tidal currents. The associated fauna includes the lingulide Ectenoglossa sorbulakensis, the trilobite Isotelus romanovskii, as well as various bivalve molluscs and gastropods. This community may be refered to Bentic Assemblage Zone 1. The invasion of the earliest vascular plants in subaerial environments, in the Middle and Late Ordovician, led to the origin of new kinds of biotopes, and to significant changes of trophic relations in near-shore bentic assemblages.

ORDOVICIAN CONODONTS FROM THE TURBIDITE SEQUENCE OF THE LACHLAN FOLD BELT, SOUTH-EASTERN AUSTRALIA

STEWART, Ian R., Dept of Ecology and Evolutionary Biology, Monash University, Clayton, Victoria 3168, Australia.

Conodonts have been recovered from cherts and siliceous sediments throughout the vast expanse of Lower Ordovician turbidites in the south-eastern Lachlan Fold Belt. Correlation with faunas recovered with graptolites in the Bendigo-Ballarat zone and Mornington Peninsula has allowed precise age control throughout eastern Victoria Victoria and southern New South Wales.

Many of the rocks are highly deformed or weathered, rendering chemical extraction techniques unusable; consequently the conodonts are studied using rock sectioning techniques and latex replicas of prepared moulds.

Resolution of zonal indicators is restricted to species which can be positively identified, given the constraints imposed by the material.

Although faunas are sparse, the species found are indicative of a cold water faunal realm. Large numbers of natural assemblages of ramiform and coniform conodonts have been recovered.

CONODONT-GRAPTOLITE TIE LINES IN THE EARLY ORDOVICIAN OF VICTORIA

STEWART, I.R., Department of Ecology and Evolutionary Biology, Monash University, Clayton, Vic. 3168; and VANDENBERG, A.H.M., Geological Survey of Victoria, P.O. Box 173, East Melbourne, 3002.

The Lower Ordovician in Victoria contains six conodont assemblages, four of which occur with graptolites and hence are firmly tied to the "standard" Australasian graptolite zonation. The conodont assemblages are:
(1) *Cordylodus proavus* assemblage: this occurs in chert at Tabberabbera and is not accompanied by any graptolites.
(2) *Cordylodus* sp. at Howqua, accompanied by anisograptids (La1-La2).
(3) *Prioniodus elegans-Paracordylodus* assemblage: this occurs with *Tetragraptus approximatus* and *Pendeograptus fruticosus* (4-br.) at Tabberabbera, and is firmly tied to Zone Be1 (basal Bendigonian).
(4) *Oepikodus evae* assemblage (*O. evae, Bergstroemognathus extensus, Protoprioniodus aranda, Scolopodus rex*): this is very abundant in the Devilbend Quarry, Mornington Peninsula where it ranges from latest Bendigonian (Be4, *P. fruticosus* 3-br. Zone) to late Chewtonian age (Ch2, *Isograptus primulus* Zone). Less diverse faunas of the *O. evae* assemblage occur with Be3 graptolites (*P. fruticosus* 4-br. and 3-br.) at Daylesford.
(5) *Polonodus* assemblage (*Polonodus* sp., *Spinodus spinatus, 'Cordylodus' horridus, Periodon aculeatus, Histiodella* sp.): occurs with Darriwilian (Da3, *P. decoratus* Zone) graptolites at Surprise Gully near Romsey, and at Wellsford Rifle Range near Bendigo.
(6) *Pygodus* assemblage: Both *P. serra* and *P. anserinus* occur in Victoria, *P. serra* with latest Darriwilian, and *P. serra* plus *P. anserinus* with *N. gracilis* and other early Gisbornian graptolites.

CRINOIDS IN REGIONAL STRATIGRAPHIC STUDIES OF THE ORDOVICIAN OF THE USSR

STUKALINA, Galina A., All-Union Geological Research Institute, Sredny Prospekt 74, Leningrad 199026, USSR

Crinoids from the Ordovician of Kazakhstan, the southern Tien Shan, and the Siberian and Russian platforms have been analysed. Crinoid-based biostratigraphic units are deduced for each of these regions, based on associations that succeed one another in time, are not repeated in stratigraphic sections, and that have taxa that are rather distinctively linked genetically. Comparative analysis enables presentation of:
1. Diagnoses and characteristics of regional and stage units of the Ordovician of the USSR based on crinoids.
2. Characteristics of the general pattern of evolution of Ordovician crinoids through time.
3. An outline of the extent of tangible transformation that occurred through the succession of communities, as well as:
4. Designating the taxa of greatest importance for subdivision and correlation of stratigraphic units, and
5. Specifying palaeogeographic features of the Ordovician biota.

UPPERMOST CAMBRIAN AND LOWEST ORDOVICIAN BIOSTRATIGRAPHY IN THE CENTRAL APPALACHIANS

TAYLOR, John F., Geoscience Dept., Indiana University of Pennsylvania, Indiana, PA 15705 USA; REPETSKI, John E., and ORNDORFF, Randall C., U.S. Geological Survey, MS970, National Center, Reston VA 22092, USA

Trilobite faunas from the upper Conococheague Limestone and the overlying Stonehenge Limestone in the Appalachians near the Pennsylvania depocenter indicate that this interval spans the upper *Saukia* Zone to the middle *Bellefontia-Xenostegium* Zone. Conodonts are present throughout and document the presence of the *Eoconodontus* to *Rossodus manitouensis* Zones. There is no evidence of any major stratigraphic break of zonal magnitude, within this interval; it appears to be an essentially complete sequence representing continuous deposition during the early Tremadocian transgression. Species of *Symphysurina, Clelandia, Hystricurus* and *Bellefontia* allow recognition of some subzones used in western North America; the *Symphysurina bulbosa* and *S. woosteri* Subzones of the *Symphysurina* Zone and the *Bellefontia collieana* Subzone of the *Bellefontia-Xenostegium* Zone have been recognized so far. The recovery of *Praepatokephalus* sp. from strata low in the Stonehenge (above abundant *Symphysurina* and below grainstones with abundant *Bellefontia collieana* near the formation top) suggest that these strata represent the *Xenostegium franklinense* Subzone which, in western North America, extends upward from the lowest occurrence of *Praepatokephalus armatus* to the lowest occurrence of *B. collieana*. Chronocorrelation of these strata in the Stonehenge with the *Xenostegium franklinense* Subzone in western North America is tenuous because *Praepatokephalus* sp. displays (1) consistent morphological differences and may not be conspecific with *P. armatus* and (2) strong lithofacies control, occurring only in oolitic facies. The trilobite and conodont data suggest that the interval from which the important olenid trilobite *Jujuyaspis* has been reported (elsewhere in North America) lies within the uppermost part of the Conococheague Limestone, an interval that is poorly exposed through this region.

A REVIEW OF THE ORDOVICIAN PALAEOGEOGRAPHY OF AUSTRALIA

TOTTERDELL, Jennifer M., Onshore Sedimentary and Petroleum Geology Program, Bureau of Mineral Resources, Canberra, A.C.T., 2601, Australia; and COOK, Peter J., British Geological Survey, Keyworth, Nottingham NG12 5GG, United Kingdom.

The BMR-APIRA Phanerozoic Palaeogeographic Maps of Australia project has produced a series of maps illustrating the palaeogeographic evolution of Australia from the Cambrian to the Recent. Seventy time slices, including four in the Ordovician, were mapped. The results of the project are being published in the BMR Palaeogeographic Atlas of Australia series.

The accuracy of any palaeogeographic analysis of the Ordovician Period in Australia is hampered by relatively poor biostratigraphic control and the lack of a clear understanding of the tectonic setting of the eastern part of the continent (Tasman Fold Belt). The palaeogeographic reconstructions presented here are not palinspastic, therefore they may not be accurate in areas that have undergone considerable shortening and/or terrane movement; the palaeogeographic elements may be valid, but their relative positions may not be. The tectonic model used for compilation of these maps is that a relatively stable craton was flanked to the E by a convergent margin with a westerly dipping subduction zone. A marginal sea lay to the W of the volcanic arc, and a fore-arc basin and trench to the E. Arc volcanism and deep-water turbidite deposition occurred in the fold belt throughout the Ordovician, Late Ordovician volcanic rocks and turbidites being especially abundant. Gold and copper mineralisation is associated with the volcanics at several localities.

Much of the SE part of the craton and parts of the fold belt were affected by the Late Cambrian-Early Ordovician Delamerian Orogeny. This period of folding, metamorphism and uplift was accompanied by the emplacement of mainly granitic intrusives. Coarse detritus was shed from the uplifted highlands in the SE corner of the craton; however, the effect on most cratonic basins appears to have been minor.

A striking palaeogeographic feature of the Early Ordovician was the development, as a result of sea level rise, of the transcratonic Larapintine Sea, linking the Canning and Amadeus Basins with the open ocean to the E and W. The seaway was the site of deposition of organic-rich shales (source rocks) and shallow marine sandstones (reservoirs), phosphorites and evaporites, and hence is of considerable economic importance. It reached its maximum extent in the Middle, but had disappeared by the Late Ordovician. Whether as a result of eustatic sea level fall, regional tectonics or both, a marked change in palaeogeography occurred in the Late Ordovician, with the marine environments that had prevailed in most cratonic basins being replaced by paralic and continental environments, or by the complete cessation of deposition.

THE ORDOVICIAN GRAPTOLITE SEQUENCE OF AUSTRALASIA

VANDENBERG, A.H.M., Geological Survey of Victoria, Department of Industry, P.O. Box 173, East Melbourne, 3002, Victoria; and COOPER, R.A. DSIR Geology and Geophysics, P.O. Box 30368, Lower Hutt, New Zealand.

The classical Ordovician graptolite succession of Victoria has long been taken as standard for the region and used for subdivision and correlation of Ordovician sequences widely around the world. We review the Victorian succession and incorporate other Australian and New Zealand graptolitic sequences into an Australasian set of zones and stages. Thirty zones are recognized and defined, of which one (Ca4, *Isograptus victoriae maximodivergens*) is new and two (La1, Da4) each comprise two subzones. Several zones are redefined, but the previous zone notation has been retained. Nine stages are recognized (as previously) and defined, six (Lancefieldian, Bendigonian, Chewtonian, Castlemainian, Yapeenian, Darriwilian) in the Early Ordovician and three (Gisbornian, Eastonian, Bolindian) in the Late Ordovician; reference sections for each are nominated. The Bolindian stage contains 5 zones, here designated Bo1 to 5. The Australasian stages are correlated internationally.

ORDOVICIAN CHRONOSTRATIGRAPHY - A CHINESE APPROACH .

WANG Xiaofeng, Yichang Institute of Geology and Mineral Resources, Yichang, Hubei Prov., P.R. China; and ERDTMANN, Bernd-D., Inst. Geology and Palaeontology, Technical University Berlin, D-1000 Berlin, Germany.

Facies considerations contributed to a dual chronostratigraphic scheme in China. These two schemes represent either graptolite or mixed graptolite-conodont-shelly facies. Ordovician subdivision schemes of international scope have been thoroughly discussed and applied by scores of Chinese geologists for several decades. The basal Ordovician stage will be the Hunjiangian (formerly Xinchangian) or Lianghekouan Stage depending on the adoption of a graptolite- or conodont-based Cambrian-Ordovician boundary GSSP. It is proposed to draw the base of a revised "Arenig" at the FAD of E. approximatus in graptolite facies or at the base of the P. proteus zone in conodont facies, although the latter is at a distinctly lower level than E. approximatus. Corresponding to the Baltic Hunneberg Stage the shelly Daobaowanian correlates with the P. proteus and O. communis zones, and the "Arenig" (of the type area) correlates with the mixed shelly Dawanian or the bulk of the graptolitic Ningkuoan Stage in China. The base of a revised "Llanvirn-Llandeilo" should be taken at the FADs of U. austrodentatus and the conodont E. variabilis, respectively. The ensuing stage corresponds to the topwards extended graptolitic "Ningkuoan" Stage or to the correspondingly extended conodont-shelly "Guniutanian". In China, as in many other parts of the world, the base of the N. gracilis zone marks the base of the Upper Ordovician Series and implicitly the base of the downwards extended "Caradoc". A graptolite zonal succession equivalent to "Caradoc" is well exposed in a new section at Qidong in southern Hunan Province. The Chinese "Caradoc" counterpart is the downwards extended graptolitic Hanjiangian or the corresponding upper Miaopoan and the complete Xiaoxitaan Stage (mixed facies). The lower boundary of the Wufengian Stage (approximate equivalent of "Ashgill") is drawn at the FAD of D. complexus or P. pacificus. Corresponding conodont FADs have not yet been fully established for the Upper Ordovician Series in China. A dual Series division of the Ordovician is preferred by most Chinese geologists.

GLOBAL BIOGEOGRAPHY OF ORDOVICIAN CORALS AND STROMATOPOROIDS

WEBBY, Barry D., Department of Geology and Geophysics, University of Sydney, N.S.W., 2006, Australia

Coral-stromatoporoid associations of the American-Siberian faunal realm, representing a warm-water, low-latitude aspect, and typified by labechiid and clathrodictyid stromatoporoids, compound rugosans (Favistina, Cyathophylloides, Palaeophyllum and Crenulites), the tetradiids and other tabulates (Saffordophyllum, Foerstephyllum, Billingsaria, Nyctopora and Calapoecia), occur in present major continental areas of North America, Greenland, Siberia, North China, and the Tasmanian sector of Gondwana. Similar assemblages are recorded from fold-belt remnants of continental shelf, microcontinent or island-arc affinities in eastern North America (including Alaska), Scotland, the Urals, Kazakhstan, Altai Sayan, Kolyma, NW and SE China, Mongolia, Shan Thai, central New South Wales and New Zealand.

A second association representing the Euroasiatic realm is of possible cooler, mid-latitude aspect, and is characterised by occurrences of solitary rugosans (including streptelasmatinids and calostylinids), halysitine and heliolitine corals, but no stromatoporoids. This is present on the East European and South China Platforms, and in fold belt regions of England, Wales, Eire, Brittany and Central Asia (Tadzhikstan). However, some solitary rugose-dominated associations also occur elsewhere, for example, in more offshore (deeper and cooler) waters of the near equatorial zone and, according to Elias, on the North American Platform adapted to higher than normal temperatures and salinities also in the equatorial zone.

Distributions were plotted on Scotese's Ordovician global map reconstructions, with addition of inferred ocean currents, and show the American-Siberian assemblages occupying a broad, band-like spread across the equator influenced by warm, westward-driven currents. Euroasiatic associations were more restricted, controlled by the cooler, eastward-driven currents of south temperate latitudes.

ARENIG AND LLANDOVERY GRAPTOLITES AND TRILOBITES FROM CENTRAL NEWFOUNDLAND, CANADA AND THE CLOSURE OF IAPETUS

WILLIAMS, S. Henry, Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, Canada A1B 3X5; COLMAN-SADD, Stephen P., O'BRIEN, Brian H. and BOYCE, W. Douglas, Geological Survey Branch, Newfoundland Department of Mines and Energy, P.O. Box 8700, St. John's, Newfoundland, Canada A1B 4J6

A newly discovered fossiliferous horizon within sediments of the Coy Pond Complex, belonging to the Exploits Subzone of the Dunnage Zone of central Newfoundland, yields U. shelvensis and the cyclopygid trilobite C. grandis brevirhachis of late Arenig age. This is the first record of a Lower Ordovician cyclopygid trilobite in North America, a group which was apparently restricted to the continents of Gondwana and Baltica until middle or late Ordovician times. The species have been recorded previously only from England and South Wales, suggesting that south-central Newfoundland lay on the northern oceanic margin of Eastern Avalonia in a peri-Gondwanan position during the Lower Ordovician. Shelly and graptolitic faunas from equivalent-age strata in the Notre Dame Subzone of central Newfoundland show marked North American affinities, suggesting that the main Iapetus suture or sutures occur in the vicinity of Red Indian Line, which now separates the two subzones.

Graptolites from a sequence of turbidites on Upper Black Island, north-central Newfoundland, include the first positively identified Silurian taxa from the province, and provide the first unequivocal evidence of Silurian oceanic sedimentation in the Dunnage Zone. The assemblage is similar to that found in sediments of similar age in the United Kingdom and Scandinavia, but unlike any known from elsewhere in North America. This suggests the presence of open oceanic conditions, or deep marginal basins with connections to European areas, during the Llandovery, and implies that at least part of the Iapetus Ocean was still open in central Newfoundland during early Silurian times.

STRATIGRAPHY AND GEOCHEMISTRY OF ORDOVICIAN VOLCANICS FROM CENTRAL NSW.

WYBORN, D., BMR Geology & Geophysics, PO Box 378 Canberra City ACT 2601, Australia.

The stratigraphy of Ordovician volcanic sequences in central New South Wales has been refined as a result of a new and ongoing assessment of the compositions and ages of units in different structural blocks. Units from different blocks are somewhat different from one another and previous correlations now appear untenable. More likely, individual thick sequences of lavas in single blocks probably define separate volcanic centres. A volcaniclastic unit consisting of chert, volcanic shale and greywacke, mafic sills and rare interbedded mafic lavas, is widespread above and below volcanic units and probably represents the archipelagic apron that surrounds the various main volcanic centres. Work to date indicates some differences in the mineralogy and chemistry of the volcanic centres, though all are dominated by porphyritic trachybasalts. Geochemically the differences are best expressed in the high field strength elements (Ti,Zr,Y,Nb). No significant differences can be resolved with the large ion lithophyle (LIL) elements as burial metamorphism up to lower greenschist facies has obviously redistributed many of the more mobile elements. LIL elements are highest in the least altered and least metamorphosed samples and a shoshonitic character is clear for all units. The challenge now is to determine the timing of volcanism from centre to centre, differences in eruptive products and consequent constraints on petrogenesis.

THE INTERNAL BOUNDARIES OF THE ORDOVICIAN IN SOUTH CHINA

YIN Gongzheng, Regional Geological Survey Team of Guizhou, Bagongli, Guiyang 550005, Guizou, People's Republic of China.

The Ordovician System in South China is well developed and includes various types of sedimentation and a variety of biotas, and the internal boundaries of the Ordovician may be defined using several groups.

The Lower-Middle Ordovician boundary in South China is drawn between the *Pterograptus elongans-Didymograptus murchisoni* Range Zone and the *Glyptograptus teretiusculus* Range Zone or *Glossograptus hincksii* Range Zone of graptolites; between the *Pygodus serrus* Range Zone and *Pygodus anserinus* Range Zone of conodonts; between the *Dideroceras wahlenbergi-Meitanoceras* Assemblage Zones and the *Lituites* Range Zone of nautiloids and between the *Zhenganites-Megalaspides zhenganensis* Assemblage Zone and the *Calymenesun tingi-Birmanites hupeiensis* Assemblage Zone of trilobites.

The Middle-Upper Ordovician boundary in South China is drawn between the *Dicranograptus clingani-Climacograptus spiniferus* Range Zone and the *Orthograptus quadrimucronatus* Range Zone of graptolites; between the *Hamarodus europaeus* Acme Zone and the *Protopanderodus insculptus* Range Zone of conodonts; at the top of the *Sinoceras chinense-Michelinoceras elogatum* Assemblage Zone of nautiloids and between the *Paraphillipsinella globosa-Hammatocnemis yangtzeensis* Assemblage Zone and the *Nankinolithus* Range Zone of trilobites.

NEW ORDOVICIAN MICROVERTEBRATE AGNATHANS (JAWLESS FISHES) FROM CENTRAL AUSTRALIA.

YOUNG, Gavin C., Bureau of Mineral Resources, PO Box 378, Canberra, A.C.T., Australia

Vertebrate fossils of Ordovician age were first recorded from the Harding Sandstone of Colorado by Walcott late last century, and since then many other localities have been reported from North America, and most recently (1986) from South America (Bolivia). Ordovician vertebrates were not recorded from outside of the Americas until Bockelie & Fortey described some Early Ordovician phosphatic fragments from Spitsbergen (the vertebrate affinity of these is still controversial).

The first Ordovician vertebrates from the Southern Hemisphere (two genera of primitive heterostracans; *Arandaspis* and *Porophoraspis*) were described by Ritchie & Gilbert-Tomlinson (1977; *Alcheringa 1*: 351-368) from the Stairway Sandstone of the Amadeus Basin, central Australia. These are the oldest vertebrates (about 465 million years) represented by intact remains so far known. Here I report new microvertebrate faunas from five horizons in the Amadeus Basin sequence, both older and younger than the *Arandaspis* fauna. A micro-vertebrate assemblage from the slightly younger Stokes Siltstone includes remains similar to the genus *Sacabambaspis* described recently from the Ordovician of Bolivia, and other scales possibly belong to an early gnathostome. Scales and bone fragments from the top of the Pacoota Sandstone and lower Horn Valley Siltstone may be the oldest confirmed vertebrate remains (about 485 million years, early Arenig). These assemblages have proved useful in dating marginal marine deposits in which conodonts are often rare or absent.

LATE ARRIVAL

THE ORDOVICIAN PALAEOGEOGRAPHY OF EUROPE AND THE CONSTRUCTION OF A PRELIMINARY ORDOVICIAN POLARITY TIMESCALE

TRENCH, Allan, Dept of Geology, University of W.A., Nedlands 6009, W.A.; and TORSVIK, Trond H., Geological Survey of Norway, PB 3006, Lade, Trondheim, N-7002, Norway

New palaeomagnetic data from Baltica and southern Britain have changed our perception of European Ordovician palaeogeography. In effect, Baltica has advanced from being a continent "without a Lower Palaeozoic polar wander path", to being perhaps the best constrained of the Iapetus-bordering continents. Also, the new palaeomagnetic constraints from Baltica complement deductions from biogeographic and palaeoclimatic indicators. In southern Britain, the recently acquired data reconcile a conflict between palaeomagnetic and biogeographic interpretations of the width of the Iapetus Ocean; they indicate that northern and southern Britain were separated by c.45° of latitude in Tremadoc-Arenig times, which was reduced to c.30° by end Llanvirn times.

The new Baltic palaeomagnetic data, recorded from Arenig to Caradoc limestones of the Swedish platform, are considered highly reliable given that a stratigraphically-linked magnetic polarity pattern is observed. Furthermore, the relatively low reversal frequency for Arenig-Caradoc times enables intercontinental comparisons to be made with previously sampled sections in Siberia.

Swedish and Siberian polarity data agree well using the available biostratigraphic constraints and point the way to the development of an Ordovician reversal timescale. Preliminary data indicates that Early Ordovician times were dominated by a reversed-polarity field. Rapid reversals then occurred during Llanvirn-Llandeilo times which were succeeded by a period of mostly normal polarity through Caradoc-Ashgill time. Palaeomagnetic studies from Britain, USA, Australia, China, France and Canada have been compiled to supplement the Swedish-Siberian correlation.

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