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Aller au sommaire du numéro

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ABSTRACTS

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J. Tuzo Wilson
On The 25th Anniversary Of The Discovery Of The Avalon Peninsula's Roots

E.R.W. Neale

Dr. John Tuzo Wilson, arguably the pre-eminent Canadian scientist of the century, and long recognized as one of the world's great geoscientists, is most remarkable for the way in which he has shared his knowledge, wit and wisdom with his fellow citizens. His openness and cordiality have made him an unofficial ambassador of goodwill in the hundred countries that he has visited; his concern has led him to offer advice on topics perceived as far removed from science; his generosity has involved him in free and frank exchanges which have inspired colleagues. One such exchange, and the paper that followed it on the closing and re-opening of the Atlantic, provided a logical explanation of the "symmetry" of Newfoundland geology that had been recognized by Harold Williams. It served as a catalyst to the extraordinary development of Newfoundland geoscience over the past quarter century. As we celebrate the anniversary of this particular conceptual gemstone, it is appropriate that we briefly review Tuzo Wilson's career which, not surprisingly, sparkles with several such gems.

Born in Ottawa in 1908 of Scots and Huguenot ancestry, his childhood was privileged in that it involved much travel and the opportunity to meet some of the most interesting explorers and pioneers of the era. During vacations, he worked in remote areas as a field assistant for some of these people. In 1930, he was the first to graduate from a new physics and geology program at the University of Toronto. This was followed by two years as a Massey Fellow at Cambridge with Sir Harold Jeffreys and the young Edward Bullard. Finally, he obtained a doctorate from Princeton, where he worked with the young Harry Hess, Maurice Ewing (at nearby Lehigh) and the fabled Professor Richard M. Field, one of the first to recognize the importance of the oceans for understanding Earth history.

Tuzo joined the Geological Survey of Canada in 1936 and mapped in Nova Scotia, Quebec and the Northwest Territories. During World War II, he spent 1940-43 overseas with the Army before ending up as a colonel in charge of operational research. Following the war, Colonel Wilson was Deputy Director of Operation Muskox, an exercise which attracted much public attention and introduced snowmobiles to Arctic travel. Upon leaving the Army, he was asked to head up the geophysics group at the University of Toronto where he remained as professor and, later, as Principal of Erindale College until he retired in 1974. Then he assumed a major post, Director General of the Ontario Science Centre, from 1974-85, followed by the less onerous chancellorship of York University, from 1984-87. For the last few years, he has been Professor Emeritus at Toronto, attending meetings, giving talks and writing papers. What did he do during all those years in and (mainly) out of Toronto?

Tuzo Wilson's first fireball tossed into geoscience thinking circles was a subdivision of the Canadian Shield into provinces which appeared in a CIM Bulletin of 1949. It was based on structural trends, partly taken from early airphotos, and on a handful of radiometric dates. Together with a somewhat similar structural division of the Shield by J.E. Gill, it was ignored by most Precambrian workers for over 15 years, until it miraculously reappeared as the keystone of our present, widely accepted subdivision of the Canadian Shield. At the other end of the time scale, he compiled (under GAC auspices) the first Pleistocene map of Canada in 1958. Tuzo was a "Fixist" in his early days, creating models of stable, continental nuclei from which continents grew by accretion. Later, he compiled information on island arcs and championed contracting Earth theories. Then he reinterpreted these data in terms of an expanding Earth hypothesis. Finally, he unabashedly abandoned both views to accept the evidence of Hess (1962) and Dietz (1961) for a mobile Earth. On a sabbatical at Cambridge in 1965, with some of the young Turks who linked seafloor spreading with geomagnetic reversals, he proposed the concept of transform faults and laid the groundwork for much of plate tectonics. In 1966, he applied this new theory of plates to continental geology by pointing out evidence for the successive closing and opening of ocean basins (now called the Wilson Cycle). That now-classic reinterpretation of Atlantic and Appalachian history, which recognized the Afro-European parenthood of the Avalon Peninsula, is being celebrated at this symposium. Another landmark paper, in 1968, first used the "suspect terrane" concept in analyzing the Cordilleran orogenic belt.

He went on to other aspects of plate theory and showed the potential usefulness of linear chains of oceanic volcanic islands as the fossil tracks of hot spots which record the motions of lithospheric plates. He continues today, intrigued by the new methods of seismic tomography and a continuing curiosity about the behaviour of the Earth's mantle. Tuzo Wilson, the scientist, received in 1978 the Vetlesen Prize - the earth science equivalent of the Nobel. Earlier, he had been elected Fellow of the Royal Society (of London) and made a Companion of the Order of Canada. He has been awarded a plethora of medals including the Alfred Wegener, the Logan, the Wollaston, the Penrose and (believe it or not) the J.T. Wilson! He has been granted innumerable honorary degrees from great bastions of learning such as Yale and, of course, Memorial.

Tuzo the scientist has also been a leader of science. He was president of the International Union of Geodesy and Geophysics (1957-60) during the momentous International Geophysical Year, the year of the two moons. He first visited China during this period and achieved a Norman Bethune-like aura within its scientific circles. He has also served as President of the American Geophysical Union (1980-82) and of the Royal Society of Canada (1972-73). In the latter role, he strove to make that Society the national academy that

Canada lacked - he firmly planted the seed, although it took nearly two decades and another earth scientist hoeing the intellectual garden before it came about.

Tuzo Wilson's example and leadership have inspired two or more generations of earth scientists to look beyond their laboratory benches and map-areas to contemplate the significance of their work in its broadest contexts. But, on another front, where again he has set a superb example, he was for a long time less successful in attracting followers. This is the realm of public awareness of science. Since 1946, when events from Operation Muskox made daily front page news across the land, he has maintained exceedingly close relationships with the press and the public. His 1958 visit to China resulted in three popular books, the first of which, "One Chinese Moon", was a best seller in Canada, which was then starved for news of the world's most populous country. During the plate tectonic revolution, many intelligent laypersons were better informed and more abreast of progress, thanks to Tuzo's popular articles and TV appearances, than were many of his fellow scientists. At normal retirement age, he leapt at the opportunity to head up the Ontario Science Centre, which rapidly became a model of effective science communication for Canada and other places in the world. Visits and exchanges with China resumed, and many of the 117 science centres developed in that country bear the imprint of OSC and its itinerant director-general. As the first winner (1968) of the Royal Society of Canada's Bancroft Award for public communication of science, Tuzo's example over the last half century has finally convinced many other scientists that they can tell about the excitement of their work without losing face or arousing the suspicions of their peers!

If talking about science to the masses requires resolve, venturing public opinions on non-scientific issues requires courage verging on foolhardiness. A case in point was the Memorial University convocation of 1968 when the honorary graduate, instead of talking about moving plates, had the temerity to discuss the physical care and intellectual feeding of undergraduates. Many faculty members were deeply offended by this unsolicited advice from the upstart, newly appointed principal of Erindale College. The wiser ones slowly came around to following his guidelines - 10 or 15 years later (the average incubation time for a new Tuzo Wilson idea!). He has also been free with his advice in the pages of magazines, such as "Macleans", and in public broadcasts such as the CBC Massey Lecture series. Subjects have included energy and conservation, economics and economists, the nuclear threat, the global population problem, the need for government agencies to seek unpaid outside advice, and many, many more. His views have not always pleased industrial tycoons, civil service mandarins, economists and religious zealots, but newspaper editorial writers and thoughtful members of the public have welcomed his fresh perspectives.

Tuzo Wilson, our best known scientist, has made vast contributions to our understanding of the Earth and made many informed suggestions on how mankind can live in harmony with it. In the course of advancing knowledge, he has fearlessly discarded hypotheses in the face of new facts concerning this mobile planet and the people upon it. But in one regard he remains a Fixist; his devoted wife is the same Isabel Dickson whom he married in 1938, who accompanied him to China, who has shared in his several visits to Newfoundland and who is again present at this nostalgic 25th Anniversary. We hope to see them back here many times before the 50th Anniversary arrives.

Did the Atlantic close and then re-open?: a commentary

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Tuzo Wilson's 1966 Nature paper entitled "Did the Atlantic close and then re-open?" is truly the major turning point in the history of ideas on the evolution of the Appalachian Orogen. For a hundred years the Appalachian Orogen was the type geosyncline, and Appalachian evolution was viewed in fixist models of geosynclinal development. Contrasting faunal realms were always enigmatic and never properly explained by notions of land barriers. Equally enigmatic was the symmetry and two-sided nature of the Newfoundland cross section that refuted the fixist idea that continents grew like trees by the outward addition of assymetric peripheral rings. The Wilson Cycle of closing a proto-Atlantic Ocean, then re-opening the Atlantic Ocean provided an elegant and simple solution to these enigmas.

Wilson realized that island arcs existed on the North American side of his proto-Atlantic, such as the present Notre Dame Subzone in Newfoundland, and that the major faunal boundary lay to the east of these volcanic rocks. He also realized that the early Paleozoic continents may have touched in the Middle Ordovician, "for thereafter the distinction between Atlantic and Pacific faunal realms ceases to be marked". One continent encroaching upon another in the middle and late Ordovician explained the former borderland concept of Charles Schuchert and Marshall Kay. Likewise, Kay's island arcs were most in evidence during the early Ordovician, the time of major proto-Atlantic closing.

Wilson also recognized irregularities in ocean closing, which occurs first at promontories, then at re-entrants, with resulting clastic wedges and an overall change from early Paleozoic marine conditions to middle and late Paleozoic terrestrial conditions. The Taconic allochthons were also part of his ocean closing scenario. The proto-Atlantic was completely closed by the end of the Paleozoic, and major spreading of the Atlantic began in the Cretaceous.

Wilson then went on to trace the former course of the proto-Atlantic along the length of the Appalachian-Caledonian chain from Spitzbergen to Florida. This is no small task. It is encouraging to see that the contemporary Newfoundland analysis supported his views, and that even Tuzo had trouble finding a suture along the New England segment of the system. Northwest Africa was accommodated with ease as a Hercynian orogenic belt, in some respects symmetrical to the southern Appalachians.

An important corollary of the Wilson Cycle is that the assembly and eventual breakup of Pangea must have been an event of major significance in world geology. This is certainly true in North America where major orogenesis and accretion in the Cordilleran Orogen on the Pacific margin corresponds to Atlantic opening.

Since the 1966 Wilson paper, we have emerged from fixist geosynclinal models that were entrenched in the literature for 100 years. Still, the Appalachian Orogen is full of surprises and there are many secrets yet to be revealed. As so aptly expressed by David Baird, how strange it is that the more we seem to find out, the horizon is still there, always inviting us to go closer. We have more problems now than our predecessors, before the advent of the Wilson Cycle. And where will the horizon be teasing us to approach in 25 or 50 or the next 100 years. Will we be then as far away from where we stand now as our present position is from the world of pre-Wilson Cycle practioners?

Petrography and diagenesis of reservoir sandstones, Hibernia oil field, Jeanne d'Arc Basin

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Reservoir sandstones of the Hibernia oil field (1600-5000 m subsurface depths) were investigated to establish paragenetic sequences of diagenetic events and to evaluate the effects of burial on reservoir porosity with increasing depth.

Major early to late diagenetic sequences in sandstones are summarized as: thin chlorite rims, siderite (δC^{13}-7.66PDB and δO^{18}-5.26PDB), quartz overgrowths, early pyrite, early ferroan calcite (δC^{13}-1.64 and δO^{18}-6.66), dissolution (dominantly of calcite) and generation of secondary porosity, late ferroan calcite (δC^{13}-10.92 and δO^{18}-8.85)/ late ferroan dolomite (δC^{13}-5.06 and δO^{18}-7.31), late quartz overgrowths, kaolinite, late pyrite, migration of hydrocarbons. Late ferroan dolomite with curved cleavages and sweeping extinction resembles saddle dolomite (common in carbonates) and has not previously been reported from sandstones.

Porosity in the fine-grained, loosely packed, diagenetically immature Barremian-Albian Avalon/Ben Nevis Sandstone is mainly primary. The fraction of the total porosity which is secondary in origin increases gradually with depth from 20% in the Avalon/Ben Nevis Sandstone to >80% in the diagenetically mature Tithonian-Berriasian Hibernia Sandstone. Aggressive pore fluids required for dissolution are inferred to have been provided by multiple complex reactions in organic-matter rich Kimmeridgian shales and shales interbedded in the reservoir sandstones of the Jeanne d'Arc Basin.

Newfoundland to Cape Breton Island: terrane correlations

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The geology of Cape Breton Island is interpreted as a continuation of the geology of Newfoundland across the Cabot Strait/Laurentian Channel. The Mira terrane of southeastern Cape Breton Island is composed of late Precambrian and Cambrian rocks like those of the "type" Avalon terrane of eastern Newfoundland. Gneiss, anorthosite, and ca. 1 Ga syenites of the Blair River Complex in northwestern Cape Breton Island are similar to units in the Indian Head and Steel Mountain terranes in the Humber Zone of western Newfoundland. Isotopic data from the Blair River Complex indicate North American (Laurentian) affinity.

The area between the Blair River Complex and the Mira terrane, like the corresponding area in Newfoundland, is less readily assigned to terranes or zones than was previously assumed when field relations, ages, and petrochemistry were only broadly constrained. Although some isotopic data suggest crustal similarity at depth with the Mira (Avalon) terrane, contrasts in igneous and metamorphic history make it difficult to assign the area to a single terrane, or even to a composite Avalon terrane. In contrast to Newfoundland, direct remnants of Iapetus Ocean-floor do not appear to be preserved in Cape Breton Island, and the "Iapetus suture" is best described as cryptic. The margins of the Blair River Complex, therefore, now mark the southeasternmost extent of Laurentia in the northern Appalachian Orogen.

An unusual Early Ordovician (Tremadoc) trilobite fauna of Gondwanan affinity in the Cow Head Group, western Newfoundland

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Most trilobites collected from the Cow Head Group to date are of Laurentian affinity, and have come from transported limestone boulders within the carbonate breccia beds. However, an unusual trilobite fauna of Gondwanan affinity has been recovered from *in situ* dolomitic siltstone beds also containing abundant graptolites. While the fauna is diverse, the constituent trilobites are minute, almost microscopic. The following taxa have provisionally been identified:

?*Angelina* sp. undet.
Apatokephalus sp. cf. *A. asarkus* Sdzuy, 1955
Asaphellus sp. cf. *A. homfrayi* (Salter, 1866)
Asaphoon sp. cf. *A. pithogastron* Hutchison and Ingham, 1967
Bienvillia sp. undet.
Hospes sp. undet.
Macropyge sp. undet.
Orometopus sp. undet.
Parabolinella sp. undet.
?*Proteuloma* sp. undet.
Pseudokainella sp. undet.
Shumardia sp. undet.

This assemblage is comparable to Early Ordovician (Tremadoc) faunas in Argentina, Mexico, Nova Scotia (Cape Breton Island), eastern Newfoundland (Random Island), the British Isles (England and Wales), France, Germany (Bavaria), Czechoslovakia (Bohemia), Scandinavia (Norway and Sweden) and Kazakhstan. It is interpreted to be a cold water fauna.

Stratigraphy and biostratigraphy of Cretaceous and Paleocene strata on the northeast coast of Baffin Island: economic implications for an early and protracted rift history

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The Quqaluit and Cape Searle formations in half-grabens below the Cape Dyer basalts on the northeast coast of Baffin Island show a long history of rifting and sedimentation in Baffin Bay. Quqaluit Formation deposits of tectonically controlled braided and meandering rivers contain spores (*Appendicisporites* and *Trilobosporites*) and pollen (*Tricolpites* and *Retitricolpites*) which indicate an Aptian through early Cenomanian age. Cape Searle rocks are mixed debris flows and volcanic ash. Pollen in these rocks (*Trivestibulopollenites* and *Quercoidites*) indicate an early Paleocene age. The catastrophic deposition of Cape Searle rocks by volcanically induced floods is confined to valleys which formed before the onset of upper Paleocene basalt volcanism.

Valley-fill deposits of early Cretaceous age are widely recognised along the northeast coast of Baffin Island. In the north, these rocks are covered with upper Cretaceous marine strata which have excellent source rock potential. In the south, the lower Cretaceous sandstones are covered with Tertiary volcanic flows. Deeply buried rocks of presumably similar origin lie farther offshore in Davis Strait. If a Cretaceous marine source rock can be found below the Tertiary volcanics in southern Baffin Bay, the potential for hydrocarbons in this area remains good. Half-grabens exposed onshore are likely candidates for exploration models offshore; the hydrocarbon fields on the Labrador shelf are formed in a similar manner.

The geological development of the Humber and Western Dunnage zones: the Wilson Cycle and much more

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The Humber and Dunnage Zones provide a spectacular record of the Wilson Cycle, involving Late Precambrian to early Paleozoic opening and closing of the proto-Atlantic or Iapetus Ocean. The Humber Zone constitutes the ancient western continental margin to the ocean. The evolution of the zone involved initial rifting of its Grenvillian basement during the latest Precambrian with associated rift-facies sedimentation and volcanism, followed in the Early Cambrian by the establishment of a passive continental-margin shelf, slope and basin sequence. Passive continental-margin sedimentation was terminated at the end of the Early Ordovician by the emplacement of an imbricate thrust stack (Taconian allochthons) over the shelf. This event caused drowning of the shelf and the establishment of a deep-water foreland basin which was infilled by sediment derived from the advancing thrust sheets. The lower slices of the thrust stack consist of rocks from the nearby continental margin. The highest slices of the allochthons consist of ophiolite suites and represent fragments of the Dunnage Zone which have been thrust over the miogeocline.

The Dunnage Zone has traditionally been viewed as vestiges of the Iapetus Ocean accreted onto the North American margin during the Taconian orogeny. Ophiolites, interpreted as fragments of the Iapetus mid-ocean ridge crust and mantle, were considered to represent the oldest rock units in the zone, and associated volcanic and sedimentary sequences were inferred to represent younger island arc assemblages developed on the Iapetus crust. Recent geochemical and geochronological data indicate a more complex history in which the ophiolites invariably formed in a supra-subduction zone environment associated with older island arc sequences.

Although the Wilson model has proved remarkably durable in explaining the early Paleozoic character and evolution of the Newfoundland Appalachians, major problems remain in understanding the mid-Paleozoic and later history of the orogen. For example: the timing, character and distribution of the Silurian Salinic versus the Devonian Acadian orogenic events in the Humber and the western Dunnage Zones remain unresolved; and did the driving mechanism for the mid-Paleozoic rock units and associated orogenic events evolve in an environment of continued oceanic subduction or continental collision (Iapetus open or closed)?

Geologic history of the Gander Zone and the Exploits Subzone in Newfoundland during the Early Paleozoic: a review

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During the Cambrian and Early Ordovician, the Gander Zone and the Exploits Subzone of the Dunnage Zone formed continental margin and oceanic terranes, respectively. These lay adjacent to the continent of Gondwana, which is represented in North America by the Avalon Zone. Evidence for their separation from Laurentia and the oceanic terranes of the Notre Dame Subzone is provided principally by faunal provinciality. Gondwanan faunal provinces in early Llanvirn and older rocks are restricted to the area southeast of Red Indian Line and Laurentian provinces to northwest of the line.

Although the Exploits Subzone and the Gander Zone were located on the same side of the Iapetus Ocean, they developed in separate tectonic settings until the late Arenig. Rocks of the Exploits Subzone formed on oceanic crust in an island arc and back-arc system, while those of the Gander Zone were probably deposited on continental crust as a continentally-derived sedimentary wedge.

In the late Arenig, rocks of the Exploits Subzone were thrust onto the Gander Zone during a tectonic event equated with the Penobscot Orogeny of Maine. This orogeny was roughly synchronous with the Taconian Orogeny, but is distinct because the two occurred on opposite sides of the still open Iapetus Ocean.

Following the Penobscot Orogeny, an upper Arenig to lower Llanvirn overlap sequence was deposited with varying degrees of conformity and unconformity on both the Gander Zone and the Exploits Subzone. Thermal activity later in the Llanvirn caused high grade metamorphism and granite intrusion in deep Gander Zone rocks, and granite intrusion and volcanism in rocks of the overlying Exploits Subzone. Most magmas of this age contrast with earlier ones in that they contain significant amounts of old, continental material.

A second overlap sequence succeeded the Llanvirn thermal activity. It has sporadic upper Llanvirn to lower Llandeilo limestone at its base, followed by Llandeilo to Ashgill black shale, Caradoc to Llandovery turbidites, and Ashgill to Ludlow shallow marine and subaerial deposits. Fossils in these rocks belong to Laurentian faunal provinces and indicate that from the late Llanvirn onwards there was free migration across the remnants of the Iapetus Ocean.

Renewed thermal activity in the Silurian Salinic Orogeny caused major granite intrusion and subaerial volcanism, and was accompanied by mainly sinistral shearing that displaced the Exploits Subzone southwestward relative to the Gander Zone, and the Gander Zone southwestward relative to the Avalon Zone. Post-tectonic granite intrusion sealed the boundary between the Gander and Avalon Zones in the Devonian and may have continued into the Carboniferous.

Paleomagnetic support for a mid-Ordovician wide Iapetus Ocean: a summary of the evidence

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In his 1966 paper, Tuzo Wilson recognized that paleomagnetism could be used to test his hypothesis of a Proto-Atlantic (Iapetus) Ocean. He correctly noted however: "...so far as I can ascertain, palaeomagnetic evidence which might bear upon this problem does not exist." We shall review the relevant paleomagnetic evidence now available from the hybrid blocks of Newfoundland, Britain and Ireland where comparisons can be made across collision sutures. The best evidence is from the mid-Ordovician and is particularly convincing in Britain and Ireland where a Iapetus width similar to that of the present Atlantic is inferred. Convincing evidence from Newfoundland is as yet lacking, partly due to pervasive Siluro-Devonian overprinting.

Continuity of crustal fabric patterns observed in deep seismic reflection profiles across the northern Appalachian/Caledonide orogen

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Deep seismic reflection transects of the Newfoundland Appalachians show similar crustal fabrics. To the northwest, in Laurentian crust, reflectors dip variably but predominantly to the southeast. Moving towards the former Gondwanan plate, a zone of strong northwesterly dipping reflections cuts most of the crust and soles at the Moho. The top of the zone truncates the southeasterly dipping reflections. It is suggested that the southeasterly dipping fabric existed prior to the northwesterly dipping fabric, which either (i) was superimposed on, and mainly obliterated, the southeasterly dipping fabric; or (ii) removed the crust which contained the earlier fabric from the areas where the northwesterly dipping fabric now occurs. By correlation with surface structures, it is inferred that the southeasterly fabric is principally of Taconic (Ordovician) age, while the northwesterly fabric is inferred to be of Salinic (Silurian) age, corresponding to the collision of Gondwana with Laurentia.

A very similar pattern is seen on most deep seismic profiles across the Caledonides, where the fabric 'confrontation' is interpreted to be associated with the Iapetus suture; and on profiles across the New England Appalachians, as far south as the Long Island platform. The pattern is not observed on deep seismic profiles across the southern Appalachians, in which a southeasterly dipping fabric with a strong and steep mid-crustal ramp is the common pattern.

The precise form of the 'confrontation' and its position relative to the surface tectonostratigraphic zones varies along the orogen. It is concluded that the structure is formed during the closure of Iapetus, and that its variable form and position relative to surface geology are related to differences in the timing and severity of collision along strike.

Jeanne d'Arc Basin core studies unlock basin development secrets

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The Global Petroleum Resource Evaluation Group (GPREG) has initiated studies of all core from the Jeanne d'Arc Basin in order to address questions of basin tectonic development, sedimentologic character, diagenetic modification, and hydrocarbon reservoir characterization. Sediments range from conglomerates sourced in Precambrian basement sediments, to sandstones of varied depositional environments, to oyster biostromes flanked by debris talus. Braided fluvial pebble conglomerates, shoreface bars, storm washover lobes, bioturbated and burrowed lagoonal and bay sands and muds, tidal channel lags, supratidal pond muds are but a few of the facies encountered. Diagenetic carbonate lenses and beds appear to be strongly facies controlled with spillover into adjacent facies. Such carbonate lenses act as reservoir partitions, as do the numerous facies changes. Soil zones are numerous. Shallowing and coarsening upward intervals reflect both regressive and transgressive sequences. Integration of core and well logs illustrates the interaction of shallowing sequences in overall transgressive settings. Present studies have begun in the Avalon and Ben Nevis formations. Hibernia sands are being studied in a newly initiated project. South Tempest sandstones are being studied as part of the investigation of the relationship of the Rankin carbonates to the stratigraphically lateral Downing Formation shales. Such detailed core analyses illustrate clearly the conflict encountered by proponents of seismic sequence stratigraphy concepts when applied to tectonically active basins.

Concepts of Paleozoic paleogeography in eastern and central North America

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Computerized basin modelling is modern technology which all too often suffers because the basic geologic information is incorrect or out-of-date, and the geologic interpretations and assumptions are wrong. The interrelationship between the Michigan and Appalachian Basins suffers from this malady. Development of successive carbonate margins throughout the Paleozoic occurred in conjunction with eastern continental margin tectonism. The result was progressive restriction of one or both of the basins. During the Cambro-Ordovician the Michigan Basin was bounded on the west by a carbonate margin which extended southeastward toward the continental margin. Basinal sediments in both basins were normal marine with only slight restriction in the Michigan Basin. Siliciclastic sedimentation finished this depositional cycle and was followed by subaerial exposure and erosion. During the late Middle Ordovician a carbonate margin across western Ohio isolated the Michigan Basin with the resultant deposition of sapropelic shales in its centre. At the same time normal marine basinal sediments were deposited in the Appalachian Basin. Carbonate margins established in western Pennsylvania and western Ohio during the Silurian. A major sea-level drop resulted in total isolation of the Michigan Basin which subsequently converted to evaporite sedimentation. The Ohio Basin was subject to partially restricted marine sedimentation and the Appalachian Basin to more normal marine environments with siliciclastic input from east and northeast. Devonian sedimentation was characterized by normal marine sedimentation followed by evaporite sedimentation. The continued development of carbonate margins along apparent tectonic hinge lines and Precambrian basement rifted zones indicates that deep basement structure is a critical factor in the understanding of the development of these basins. This basin setting provides a model for application to other structural penetrations into the continental platform, such as the Reelfoot rift, and perhaps even the St. Lawrence River embayment.

Rodinia to Gondwanaland to Pangea to Amasia: alternating kinematics of supercontinental fusion

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According to one model based on preliminary tectonic matchmaking between cratons, the Neoproterozoic supercontinent Rodinia was transformed into Paleozoic Gondwanaland by means of bilateral extraversion (turning inside-out). Following the piecemeal calving of a keystone block (Laurentia, Baltica, Siberia), the split halves of the remaining supercontinent (East Gondwanaland and the disaggregated cratons of West Gondwanaland) were folded back-to-back. Relatively young crust from the margins of Rodinia became landlocked within the interior of Gondwanaland; relatively old crust from the interior of Rodinia became vulnerable to tectonically-driven erosion at the outside of Gondwanaland. This effect contributed to the large concurrent shift in measured proxy seawater $^{87}Sr/^{86}Sr$ ratios from .706 in geon 7 to .709 in geon 5 (geon 5 = 599-500 Ma).

A comparable supercontinental extraversion appears to be under way at present. As the Atlantic basin opens inexorably at the expense of the Pacific basin, the Americas are swung clockwise with respect to Eurasia, pivoting about their diffuse mutual plate boundary beneath the Verkhoyansk Ranges of northeast Siberia. The western margin of the Americas seems destined to collide with the eastern margin of an already coalesced Africa+Eurasia+Australasia, instituting the future supercontinent Amasia. The isotopically young crust of the circum-Pacific region will have been landlocked within Amasia and the relatively old crust of the circum-Atlantic margins, formerly located within the interior of Pangea, will have been turned outward. Since the breakup of Pangea, this is reflected in the rise of proxy seawater $^{87}SR/^{86}Sr$ ratios from .707 to .709. Accordingly, Gondwanaland was and Amasia will be products of supercontinental extraversion.

Rodinia and Pangea, on the other hand, seem to have been products of convergent kinematics, rather than extraversion. Rodinia coalesced through Grenvillian orogenesis in geons 11 to 10. In the Rodinia model mentioned at the outset, the now-dispersed segments of the Grenvillian orogenic belt are reunited in the form of a U-shaped loop, 10,000 km long. Its form suggests that the composite craton inside the loop (Laurentia+East Antarctica+Gawler) acted as a mega-indentor during the assembly of Rodinia. Existing orogen-scale kinematic data are consistent with identation: the Albany Fraser (Australia) and Eastern Ghats (India) belts on the left side of the loop (as viewed from its apex) experienced dextral transpression, while the Sveconorwegian (Baltica) and Grenville (Laurentia) belts on the right side of the loop underwent sinistral transpression. Detritus eroded from the Grenvillian mountains was carried by rivers to the Arctic, at the open end of the orogenic loop.

The fusion of Pangea culminated with the collision between Gondwanaland and Laurussia (Laurentia+Baltica), followed closely by the accretion of Kazakhstan and Siberia. Kinematically, the fusion of Pangea resembled that of Rodinia more than that of the extraverted supercontinents, although indentation (by Gondwanaland into Laurussia) was less extreme. Predictably, the accretion of Pangea was accompanied by a negligible shift in seawater proxy $^{87}SR/^{86}Sr$ ratios (but data for the interval encompassing the fusion of Rodinia and older supercontinents believed to have formed in geons 18 and 27 are lacking). Thus, we observe an alternation between convergent and extravergent kinematic instances of supercontinental fusion.

Exhumation of eclogite, western Baie Verte Peninsula: microprobe meets lithoprobe

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Eclogite within rocks now referred to as the East Pond Metamorphic Suite was first recognized by Church (1969). It is generally regarded as the result of high-pressure/low-temperature metamorphism associated with closure of Iapetus and consequent crustal-scale overthrusting. However, little attention has been paid to the questions of why the eclogites were preserved and when and how they were exhumed. Eclogite petrology indicates metamorphism at pressures of >12 kbar and temperatures of ~500 to 600°C. Garnet zoning and symplectite assemblages suggest decompression accompanied thermal relaxation over the P-T range 7 to 9 kbar and 700 to 750°C. Simple 1DT models of petrological P-T-t paths based on these data suggest that the eclogites must have been exhumed rapidly, before thermal relaxation effects could completely obliterate the eclogite assemblage. Mechanisms for rapid exhumation include syn-tectonic erosion associated with convergence and gravity-driven extension post-dating the main stage of convergence. Although most regional tectonic interpretations focus on thrusting, indirect geological evidence, including the common preservation in central Newfoundland of low-grade metamorphic rocks juxtaposed over short distances with high-grade rocks, suggests that extension should also be considered. The Lithoprobe East L-13 seismic reflection profile (Baie Verte Peninsula) and others crossing central Newfoundland offer the possibility of distinguishing crustal-scale normal and/or reverse structures, and thus distinguishing between alternative mechanisms for eclogite exhumation.

Evolution of a plume-generated segment of the rifted margin of Laurentia: early stage of a Wilson Cycle in operation

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The southern part of the Canadian Appalachians and the adjacent parts of the craton show a range of distinctive features pertaining to the operation of an early stage of the Iapetan Wilson Cycle. More specifically, the features form a set of signatures reflecting the mechanisms and processes involved in the rift and rift-drift transition stages of a segment of the continental margin of Laurentia. They probably constitute the most coherent set of such signatures known for any one segment of the ancient continental margin. Evidence points to an initial lithospheric rupture in the form of a three-pronged rift, probably induced by a rising mantle plume. Initiation of rifting appears to have been accompanied by the emplacement of tholeiitic diabase dykes, along rifts radiating from the RRR triple junction, ca. 590 Ma ago. The best preserved of these dykes are represented by the E-W trending dykes of the Grenville Swarm, more than 700 km long and injected into the strongly oriented stress field of the nascent failed arm (Ottawa Graben). A protracted (~35 Ma) period of rifting ensued during which alkalic-carbonatitic complexes were emplaced along the failed arm ca. 575 Ma ago. Approximately 20 Ma after the alkalic-carbonatitic magmatism, a volcanic outburst occurred at the triple junction, probably signalling the onset of a phase of rapid rifting, prior to the initiation of sea floor spreading. Whereas the early rift-related dykes are tholeiites, the late volcanics are mildly alkaline to transitional basalts with minor comenditic lavas and pyroclastics. The former may have formed by decompression melting of the upper parts of cooler mantle of a mushroom-shaped plume head, away from the plume axis, while the latter may have been derived from hotter mantle at the plume axis, beneath attenuated continental crust.

The volcanic outburst was followed by a short period of rift facies clastic sedimentation during which a large delta, of a river that drained the failed arm, formed over the volcanic shield. The beginning of the drifting stage is indicated by the establishment of open marine sedimentation on the continental margin, also in the Early Cambrian, possibly ca. 550 Ma ago.

Carboniferous tectonics, basin development and deformation in the Cabot Strait area

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A geophysical data set from the Cabot Strait, including conventional reflection seismic, gravity and magnetic data, was interpreted. This data was combined with published onshore geological data to characterize and reconstruct the tectonic history of the area. The Cabot Strait is situated at the northeast corner of the Maritimes Basin, which developed in mid-late Devonian times as a pull-apart basin ("rhombochasm") associated with offset along a regional strike-slip system. From Cape Breton Island northeastward, this system is represented by the Cabot Fault, which acts as a focus for tectonic activity. Two other fault systems parallel the central Cabot Fault: the Cape Ray fault to the east, and the "Coastal" fault to the west; these three faults subdivide the Strait into two deep linear basins, with separate tectonic and depositional histories. Several major unconformities and the sequences that they bound are imaged on seismic data; these mainly terrestrial packages are related to periods of local fault movement and regional tectonics, rather than to conventional sea level curves. Sediments within these basins display a variety of deformational styles, including steep thrusts, salt-related decollement, salt diapirism, and inversion.

On the nature, timing and relationships of Late Precambrian tectonic events on the southeastern (Gondwanan) margin of the Newfoundland Appalachians

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The Precambrian tectonic history of the Avalonian elements of the Newfoundland Appalachians chronicles the development of part of a larger peri-Gondwanan orogenic belt that formed in the interval between the Grenville and Appalachian orogenic cycles. These rocks form the basement of the southeastern (Gondwanan) margin of the Appalachian orogen and reveal a geologic history that is more protracted and complex than previously envisaged. Avalonian rocks east of the Dover and Hermitage Bay faults, record at least four prominent, pre-Iapetan orogenic events: ca. 760 Ma, ca. 680 Ma, ca. 630 to 600 Ma and ca. 575 to 550 Ma. Unconformities and intrusive relationships between precisely dated rocks demonstrate that amalgamation of major, distinctive tectonic entities occurred at least twice prior to the deposition of a Cambrian platformal cover, which is widely but not accurately viewed as the fingerprint of the Avalonian orogenic cycle. Coeval Precambrian tectonic events are recorded in similar Precambrian rocks preserved inboard of the type Avalon Zone, in southwestern Newfoundland, where the composite Avalonian block, with a Silurian cover, overthrusts mid-Ordovician Dunnage Zone. The observed leading edge of the composite Avalonian block was the focus of a widespread and complex Silurian tectonothermal event which reactivated fundamental Precambrian structures.

The oldest recognized events are likely linked to coeval generation of Pan African ophiolites early in the evolution of that orogenic belt. The next youngest event, largely compressional in nature, is recorded in arc-related volcanic and associated plutonic and metamorphic complexes in the southwestern Avalon Zone (s.s.) and in coeval Avalonian (s.l.) rocks in the Hermitage Flexure region. These rocks locally form the basement to 630 to 600 Ma sequences that deposited during the third, and perhaps most diagnostic Avalonian tectonic event. Arcs and marine basins that formed in the Avalon Zone (s.s.) during this interval were inhomogeneously deformed prior to onset of volcanism and plutonism related to a final 580 to 550 Ma event, synchronous with the rift-drift transition on the Laurentian margin of Iapetus. These diverse elements of the composite Gondwanan margin of the Newfoundland Appalachians were variably dispersed or otherwise separated prior to the Cambrian, allowing significant Cambrian to earliest Ordovician tectonothermal events to be recorded on the inboard margin of this block while platformal sediments were being deposited elsewhere.

Orphan Knoll: a window on the opening of the North Atlantic

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Orphan Knoll has stood as an isolated continental remnant since the initial breakup. It initially moved away from North America with the Irish and Porcupine Bank blocks. Spreading then failed west of Orphan Knoll and the spreading centre jumped to the east of the Knoll, separating Orphan Knoll and the Porcupine Bank conjugate margins. Thus, Orphan Knoll's eastward-facing steep slope represents an unsedimented continental margin and provides a record of the rocks beneath not only Orphan Knoll and Porcupine Bank but also parts of Orphan Basin and Porcupine Basin.

The top of Orphan Knoll at 2000 m is blanketed by a thin 180 m cover of Tertiary pelagic sediments. The whole top of the Knoll is marked by a field of bedrock mounds that generally border a thin (70 m), narrow graben of Cretaceous limestone capped by chalk. Dredge sampling of the bedrock mounds in 1971 and 1978 obtained probable scree and a mix of ages. While Ordovician and Silurian-aged material could be recently ice-transported from Canadian or Greenland sources, the Devonian-aged material cannot be, and reflects nearby bedrock found higher up on the mounds. This record of Palaeozoic platform limestones on Orphan Knoll has palaeogeographic and palaeobiologic implications for the early Atlantic: it also speaks to possible source rocks beneath the conjugate margin basins.

The mounds have been suggested as erosional remnants of pinnacle reefs; they may also be remnant karst topography or salt diapirs reactivated by the 2000 m hydrostatic pressures on tight formations. A submersible sampling program is presently being planned to search for exposed bedrock of the unsedimented margin and the mounds.

Transpression and transtension in the Jeanne d'Arc Basin, Grand Banks

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Mapping of the southern Jeanne d'Arc basin was undertaken to determine the structural architecture of the oldest Mesozoic sediments within the basin. The structure at the mid-Jurassic near the Whale Member, the Lower Jurassic top of the Iroquois Formation, and the top of an Upper Triassic/ Lower Jurassic basalt were interpreted using mainly 2-D seismic reflection data. Variation in architecture at and between mapped horizons was used to evaluate the tectonic stresses experienced in the pre-Mesozoic basement and transmission of these stresses into the overlying sediments. Correlations at additional younger horizons and previously published maps were used to assist in timing of tectonic events and determination of related stress orientations.

Synchronous sedimentation and normal growth are demonstrated along NE-SW-trending en echelon faults of the Late Triassic to earliest Jurassic rift period. The en echelon extension faults are interpreted to be generally separated by tilted-basement relay ramps or accommodation zones rather than by cross-strike transfer faults.

The NW-SE-trending cross-basin faults, which bound and dissect numerous hydrocarbon-bearing structures, are demonstrated as being initiated at the mid-Aptian and grew through late Albian times rather than having been initiated in latest Jurassic/earliest Cretaceous times with decreasing growth during the mid-Aptian to late Albian.

The NW-SE-trending Spoonbill Fault is identified as the headwall fault limiting extension in the basement below the Jeanne d'Arc Basin during mid-Aptian to late Albian times. Synchronous strike-slip movements of basement blocks along reactivated NE-SW-trending faults are interpreted to result in a number of transpressional and transtentional structures along restraining and releasing fault bends. Low-dipping reverse faults, inversion structures, forced folds (i.e., Cormorant fold), wrench related folds (e.g., Terra Nova arch) and preferential salt diapirism (e.g., Egret ridge) are all recognized as responses to transfer fault movements during mid-Aptian to late Albian times.

Evidence for the role of the Pocologan, New Brunswick and Burlington, Massachusetts shear zones in the Neoproterozoic Wilson cycle

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The Proterozoic rocks of the Avalon belt, in part a former epicontinental volcanic arc, in coastal New Brunswick (NB) and in southeastern New England (NE), in both places contain an extensive shear zone at least 50 km long and 2 to 5 km broad: the Pocologan and the Burlington mylonite zones respectively. Both have been polyphasally deformed and intruded by arc-batholiths of the 625 Ma Cape Spencer Granite and the 630 Ma Dedham Plutonic Suite. The rock sequence cut by the Pocologan zone consists of gneissose basement associated with the Green Head Group carbonates, pelites and quartzites; of still younger volcanic and volcaniclastic rocks of the Coldbrook Group; and intrusive granodiorites, gabbro-diorites, granophyres, porphyries, and mafic dikes. The rock sequence cut by the Burlington zone consists of the Westboro Formation and Blackstone Group of quartzites, pelites and some carbonates, and of the Middlesex Fells Volcanic Complex and associated gabbro-diorites intruded by granitoids, porphyries and mafic dikes. The Burlington mylonite zone is intruded by the ca. 630 Ma Dedham Plutonic Suite. Therefore, in general, the sequence of events in New Brunswick and Massachusetts is similar.

That part of the Avalon terrane which hosts the mylonites is bounded on the northwest in New Brunswick by the Lubec-Long Reach fault and in the northeast by the Bloody Bluff fault. The eastern margin of the Nashoba belt, of suspect affinities, includes ca. 750 Ma gneisses. Within the Avalon belt of Massachusetts and southeast of the shear zone lies the Late Neoproterozoic to Cambrian Boston basin, now overthrust from the north by older rocks including those of the shear zone.

We propose a four stage model for the pre-arc evolution of the two great mylonitic shear zones: (1) The Avalon belt, in the breakup of the late Proterozoic supercontinent, was involved in the formation of grabens. This led to the sub-Green Head and sub-Westboro unconformities at ca. 700 Ma. (2) Extensional grabens led to the formation of a passive margin marked by the Middlesex Fells Volcanic Complex and the older Coldbrook Group, and intruded by alkalic gabbro-diorites and minor granitoids. (3) The extensional regime changed to transpressional, leading to the formation of the Pocologan and Burlington mylonite zones. (4) The transpressional regime was succeeded by compression associated with the formation of a subduction zone and a related epicontinental island arc with major granitic to dioritic intrusives and calc-alkaline volcanicity at ca. 600 Ma in Massachusetts, and even younger volcanic events in New Brunswick.

Have the remnants of the Proto Atlantic any use as fuel? Some implications for the early history of the Earth, early life and other things

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Mantle sections of the Bay of Islands Ophiolite complex are remarkably unserpentinized but are presently undergoing serpentinization as groundwater drains through the peridotites. Calcium in diopside does not fit into serpentine minerals and is expelled as dilute solutions of $Ca(OH)_2$ at springs and seeps with pHs between 8 and over 11. Calcite tuffa forms by reaction with atmospheric CO_2. Fossil springs are marked by weathered tuffa, some of which is now dolomite. It may be possible to study paleohydrology by dating the tuffa (^{14}C). Reducing conditions during serpentinization results in the local generation of H_2 from water. The gas presumably escapes from the earth which becomes a little more oxidized, an effect that may have been more important during the Archean when there were more ultramafic rocks at the surface.

A diverse microbial community lives in the springs and streams. Circumstantial evidence suggests that the microbes help to precipitate the tuffa sometimes as microstromatolites. Their tolerance to high alkalinity may mean that they are descended from microbes that lived in the ancient alkaline oceans.

Many geomorphic features, such as protalus lobes with a high angle of repose, prove to be stable because they are cemented with calcite.

Ironically, the survival of so much olivine for more than 450 Ma may be due to serpentinization itself, though stratigraphic and tectonic processes are also involved.

Structure and tectonic setting of the Port au Port Peninsula, western Newfoundland: implications for Humber Zone tectonics and Acadian versus Taconian overthrust events

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The Cambro–Ordovician carbonate platform of the Humber zone, western Newfoundland, has traditionally been interpreted as structurally autochthonous to parautochthonous. Our recent reinterpretation of 1970's–vintage offshore multichannel seismic data (Stockmal and Waldron, 1990, Geology, 18, pp. 765–768) coupled with mapping on the Port au Port Peninsula (Waldron and Stockmal, 1991, CJES, 28, December) suggests instead that the platform is substantially allochthonous, perhaps on the order of several tens of kilometres. The Appalachian structural front in western Newfoundland, in the vicinity of the Port au Port Peninsula and the Bay of Islands, is characterized by a triangle zone or tectonic wedge of "Acadian" (post–Pridolian) age. Transported rocks within the triangle zone include rocks of the Humber Arm Allochthon, remnants of the Middle Ordovician clastic foreland succession, the Cambro–Ordovician platform succession, and crystalline Grenvillian basement. Our interpretation of the structural geology of Port au Port Peninsula has been aided substantially by the construction of six serial cross sections, constrained in part by the limited marine seismic data set. Our preferred interpretation involves: (1) relatively early Taconian normal–sense reactivation of a major Iapetus rift-phase(?) basement–cutting east–dipping normal fault and associated antithetic faults; (2) emplacement of the Humber Arm Allochthon above the resultant half–graben which was infilled with Goose Tickle Group foreland clastics; (3) Acadian thrust–sense reactivation of the major normal fault with concomitant development of a structural triangle zone at the active deformation front; (4) eastward "out–of–sequence" stepping of the triangle zone upper detachment; and (5) relatively minor normal and strike–slip dismemberment along probable Carboniferous faults. The implied duplication of the passive margin succession and its underlying basement is apparently consistent with the recently acquired Lithoprobe East Vibroseis data set. By virtue of known stratigraphic and structural relationships between the carbonate platform and the southern edge of the Long Range massif, a substantially allochthonous platform succession implies a substantially allochthonous Long Range Inlier.

Volcanogenic sulphide metallogeny of the Iapetus Ocean in the Canadian Appalachians: complexities in time, space and tectonic setting

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Remnants of the Cambro-Silurian Iapetus Ocean in the Canadian Appalachians record a long-lived multistage history of volcanism and related volcanogenic mineralization. Geological and geochemical (whole rock, mafic volcanic) data suggest that volcanogenic sulphide deposits were formed in at least five distinct plate tectonic environments: (1) ensimatic primitive island arcs—Mafic volcanics are dominantly arc tholeiites. The environment is variously represented by suprasubduction-zone ophiolites or by thick volcanic-epiclastic sequences. Massive sulphides (e.g., Duck Pond, Tilt Cove, Rambler, Newfoundland.; Huntington, Eustis, Quebec) are locally associated with refractory mafic volcanics and, particularly in non-ophiolitic sequences, with high-silica rhyolites; (2) ensimatic mature island arcs—Mafic volcanics are calc-alkalic basalt and andesite. Massive sulphides (e.g., Buchans, Newfoundland) are typically associated with dacite-rhyolite domes, and locally may have formed in submarine collapse calderas; (3) ensimatic mature back-arc basins—Mafic volcanics are typically high-TiO_2 tholeiite or alkalic basalt. Massive sulphides (e.g., Great Burnt Lake, Newfoundland.; Annidale, New Brunswick) are cupriferous, broadly Besshi-type deposits; (4) continental-margin (ensialic back arc) rifts—Volcanics are dominantly rhyolite, underlain by mafic arc tholeiites and overlain by continental tholeiites and alkalic basalt. Massive sulphides (e.g., Bathurst, New Brunswick) are broadly associated with rhyolites, but commonly are sediment-hosted; (5) syntectonic transtensional basins—Mafic volcanics are typically high-TiO_2 tholeiite and alkali basalt. Massive sulphides (e.g., Memphremagog, Clinton River, Quebec) range from volcanic-hosted to broadly Besshi-type deposits.

Geochronological, geological and radiogenic isotopic data indicate that environments 1 to 3 recurred several times at two or more Cambrian to Middle Ordovician subduction complexes in different parts of Iapetus. Environment 4 occurred at a Middle Ordovician continental margin outboard of Laurentia, and environment 5 formed in re-entrants in the Laurentian margin, synchronous with Taconian collision of oceanic terranes on the adjacent promontories.

Silurian Notre Dame Bay nappe in the Newfoundland Appalachians

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The 65 km wide Notre Dame Bay (NDB) nappe forms the structurally highest element of the Dunnage Zone (DZ) of the Newfoundland Appalachians. The NDB nappe consists of ophiolitic and volcano-sedimentary units of Cambrian to Ordovician age, which display lithological and geochemical features typical of rocks found in modern, supra-subduction zone settings. The major, NE-SW trending Green Bay Fault (GBF) forms the western limit to the Notre Dame nappe, whereas the southern and eastern boundary of the nappe are formed by the Lobster Cove-Chanceport Fault (LCCF). The northern boundary lies off-shore and is not exposed, but can be delineated on the basis of its geophysical signature. The correlation of the western and southern boundaries of the NDB nappe with the gravity high suggests that the elliptical gravity pattern bounded by the 30 mGal contour corresponds with the offshore extent of NDB nappe.

Structural and stratigraphic relations observed along the LCCF suggest that it represents the sole thrust of the NDB nappe. Detailed kinematic studies along this fault (Szybinski, 1988; Calon and Szybinski, 1988) indicate eastward emplacement of the NDB followed by post-emplacement "collapse" of the nappe towards the west and late stage steepening of its southern boundary. The Baie Verte Line, currently lying about 20 to 30 km west of the GBF and corresponding with the western margin of the Dunnage Zone, provides a maximum western site for the root zone. The apparent younging of rocks of the nappe towards the LCCF implies that the NDB nappe may form a regional-scale recumbant fold.

The NDB nappe is underlain by the Silurian Springdale Group (SG) and by the Buchans-Roberts Arm Volcanic Belt (BRAVB). Both, the SG and the BRAVB are deformed into fold and thrust belts, but the BRAVB displays a pronounced pre-Silurian deformation history. Both are also overlain by red beds, which are the youngest stratigraphic unit overridden by the NDB nappe. It is suggested that red beds are in fact dynamically related to the NDB nappe, and were deposited in the foreland basin forming in front of the advancing nappe. Age constraints imply a post-425 Ma age for the red beds and pre-408 Ma for nappe emplacement.

The presence of the NDB nappe has significant implications for the definition and distribution of the Notre Dame Subzone. The nappe emplacement records a distinctive geologic event in evolution of the Dunnage Zone and requires reappraisal of current tectonostratigraphic divisions, which should not only reflect lateral, but also vertical zonation to address the presence of a nappe pile with subhorizontal rather than vertical boundaries. We propose to define the Notre Dame Bay nappe as an additional Dunnage subzone and to abandon the name "Notre Dame Subzone". Alternatively, different nappes, such as the NDB nappe and BRAVB can be treated as nappe complexes within the Dunnage allochthon, similarly to the nomenclature used presently in the Scandinavian Caledonides.

Dunnage-Gander relations in the Appalachian-Caledonian orogen: evidence for an early Ordovician arc-continent collision

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Conceptually, rocks of the Dunnage Zone are vestiges of Iapetus; those of the Gander Zone are the eastern passive margin of Iapetus. In Newfoundland, New Brunswick, and southeast Ireland, Dunnage (Exploits Subzone)-Gander boundaries are marked by remnants of Lower Ordovician ophiolite complexes, which structurally overlie melanges that contain Gander Zone rocks. A sedimentary linkage indicates Dunnage-Gander juxtapositioning by Llandeilo. Rare preserved stratigraphic relationships suggest that Middle Ordovician volcanic and sedimentary rocks form an overstep sequence between the Lower Ordovician oceanic Dunnage Zone and the passive margin Gander Zone. Early Ordovician amalgamation (Penobscottian Orogeny) is explained by northwest subduction of the Gander Zone beneath a Cambrian-Early Ordovician arc-back arc system. Faunal provinciality, provenance, paleomagnetic, and isotope tracer data, as well as a spatial association with exposed rocks of the Avalon Zone, suggest that this arc-continent collision took place along an Avalon margin. Collision was followed by a reversal in subduction polarity. New southeast-directed subduction caused back-arc spreading (Exploits Basin) behind the reactivated Penobscot arc. The Penobscot arc then collided with the Taconic arc at the Laurentian margin in the Middle-Late Ordovician. Arc-arc collision caused another subduction polarity reversal, this time leading to the closure of the Middle Ordovician Exploits marginal basin by repeated northwest subduction of the Gander Zone and overlying Middle Ordovician overstep sequence. This event was followed by a Late Ordovician-Early Silurian collision between composite Laurentia and composite Avalonia. The vestiges of Iapetus (Dunnage) represent the remnants of a complex Pacific-type rather than a kinder and gentler Atlantic-type ocean.

Post-Taconian history of the Newfoundland Humber Zone

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The Humber Zone of western Newfoundland is characterized by the presence of Grenville basement overlain by Cambro-Ordovician shelf sediments that represent the pre-Taconian passive margin of North America; this succession is frequently described as an 'autochthon', on the basis of its relationship to the overlying Taconian Humber Arm Allochthon. Several lines of evidence suggest that the 'autochthon' was in fact significantly transported during post-Taconian deformation related to the accretion of exotic terranes to the east.

Offshore seismic profiles to the west of Newfoundland indicate the presence of a thrust front in which the upper Silurian Clam Bank Formation is deformed. To the south, the thrust front can be traced to Port au Port Peninsula where balanced section construction suggests duplication of the carbonate platform succession, and reactivation of Taconian normal faults as Acadian thrusts.

Inland, Lithoprobe East Vibroseis line 12 shows subhorizontal and gently dipping reflectors beneath the 'inlier' of Grenville basement at Indian Head. This suggests that the considerable shortening represented at the surface in this area by folding and faulting is accommodated by a major detachment at depth. To the north, between the Bay of Islands and Deer Lake, platform carbonates are similarly intensely shortened and show several generations of fabric development. Subhorizontal, parallel reflectors displayed on Lithoprobe lines 2 and 3 can be traced continuously beneath Deer Lake. These are interpreted as autochthonous shelf sediments beneath allochthonous units that outcrop at the surface.

Farther north, the southern edge of Grenville basement of the Long Range massif is a NW-trending monocline which we interpret to reflect a hangingwall ramp on a major detachment surface. Outcrop of Grenville rocks is bounded to the west by a thrust fault (the Long Range thrust) which dies out southward and which probably accommodates only a minor amount of displacement. Just west, the Parson's Pond Thrust is interpreted to be a major detachment, transporting platform and basement rocks above the Cow Head portion of the Humber Arm Allochthon. We infer that the trace of this detachment passes offshore close to Green Point, and links with the seismically imaged thrust front offshore.

Ideas on the evolution of the Appalachian Orogen before the Wilson Cycle

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No thorough grasp of a subject can be gained unless the history of its development is clearly appreciated. Before the wide acceptance of continental drift and the Wilson Cycle for orogenic development, the protolith of the Appalachian Orogen was a geosyncline. The nature of geosynclines, their developmental patterns, and their positions with respect to continents and oceans were controversial and enigmatic topics. Few agreed on fundamental concerns such as reasons for initiation, causes of subsidence, siting, basement relationships, and controls of ensuing mountain building.

The Appalachian Orogen is the world's type geosyncline. Before the advent of plate tectonics, the main ideas on mountain building in North America emanated from the Appalachian example.

The history of ideas is traced from the time of Hall (1850's) and Dana (1870's) to Schuchert (1920's), Kay (1950's), and finally Wilson (1960's).

Two scientific revolutions in the earth sciences

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T.S. Kuhn has shown that science advances by stages or paradigms of normal science occasionally altering with greater, nonrational scientific revolution. This century examples of revolutions have been associated with distant galaxies, quantum mechanics and DNA molecules. Each was found by recognizing a long-standing error or deficiency. In geology Kuhn mentions only that Hutton and Lyell founded a paradigm. Many since have sought a revolution.

This paper suggests that geology and geophysics are separate paradigms, each ripe for revolutions. The error in geology has been neglect of mantle plumes which rework the surface. J.D. Dana first noted and then repudiated them. In geophysics the error has been neglect of the control of faulting in the lithosphere by the Coulomb/Navier/Stokes law of brittle failure which E.M. Anderson indicated, and which also applies to mountain building.

Two separate revolutions to correct these errors seem likely to lead to a common fresh paradigm uniting structural geology, geophysics and classical physics.