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Andrew D. Miall

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ARTICLE

A Phanerozoic Time Chart for Canada

Andrew D. Miall
Department of Geology
University of Toronto
Toronto, ON, Canada, M5S 3B1
E-mail: miall@geology.utoronto.ca

INTRODUCTION

When Nick Eyles and I compiled our book *Canada Rocks* (Eyles and Miall 2007) no nationwide synthesis of the geology of Canada had been written since the Geological Survey of Canada's Economic Geology Report #1 (Douglas 1970). The Geological Society of America's Decade of North American Geology (DNAG), spanning the 1980s, generated a suite of regional volumes covering the entire continent, including Canada. The Canadian portion of the project was supervised by the Geological Survey of Canada and resulted in four regional volumes, plus a volume on part of the Canadian Shield and one on the Quaternary record. However, these were written for specialists and either did not include regional syntheses or incorporated highly technical summaries directed primarily at a professional audience.

In our planning for *Canada Rocks* we debated at length whether to adopt a 'time-slice' approach for the narrative or a 'regional' approach. The Canadian Shield is itself a distinctive 'region' of Canada, and was therefore treated as such (Chapter 4), but the description of its geology followed a sequential approach based on the age of the various terranes and orogenies. This worked well, in part because many of the Precambrian terranes are quite geographically limited in area or distribution, and therefore the description of each unit served as a mini-regional summary as well.

For the Phanerozoic the decision was more problematic. A time-slice approach works well for a description of the evolution of life and for the broader features of global geology, and we used this arrangement for the summary chapter (Chapter 3), which provides a concise history of the geology of Canada from the Archean to the present day.

For the Phanerozoic history of Canada, we decided that a 'regional' approach to the geology would work better. We predicted that most of our readers would be interested primarily in the region of Canada in which they lived, and that regional chapters for each region would therefore immediately satisfy their major interest. A regional approach allows for a continuous narrative through the various tectonic and other episodes for a given area, gradually building the geological framework for the landscape that exists at the present day. We used this approach for the Phanerozoic development of the four major regions of the country in four separate chapters (the Craton, Eastern Canada, Arctic Canada and Western Canada).

The one disadvantage of this approach is that, without considerable repetition, it is difficult to discuss regional histories in the context of the continental and global setting, and almost completely eliminates comparisons between the various regions. One of the most interesting aspects of Canadian geology is the plate tectonic history, in which events on one margin of the continent are matched by contemporaneous, but different, types of event on another margin. This kind of information tends to get lost in a regional approach.

The time-slice approach can, by contrast, keep a focus on continental and global events, but at the expense of a very fragmentary treatment of regional geology. A description of the geology and geological history of any given area might require dipping into four or five different chapters. For the non-specialist reader, we judged that this would be confusing.

The accompanying chart (Fig. 1) has been developed primarily so that the regional geologies of the different parts of Canada may be related to each other in terms of the time sequence of the major events.

EXPLANATION AND SOURCES

The time scale used in the chart (Fig. 1) is taken from *www.stratigraphy.org*, as it existed in 2009. Continual minor revisions of this scale are to be expected as an integral part of this online data source. The Sloss sequences, which were, of course, first defined by Sloss (1963), were assigned detailed stage ages by Sloss (1988; see also Burgess 2008). The ages of these stages have been adjusted (updated) according to the stratigraphy.org website.

The plate tectonic evolution of the North American continent has been reconstructed in considerable

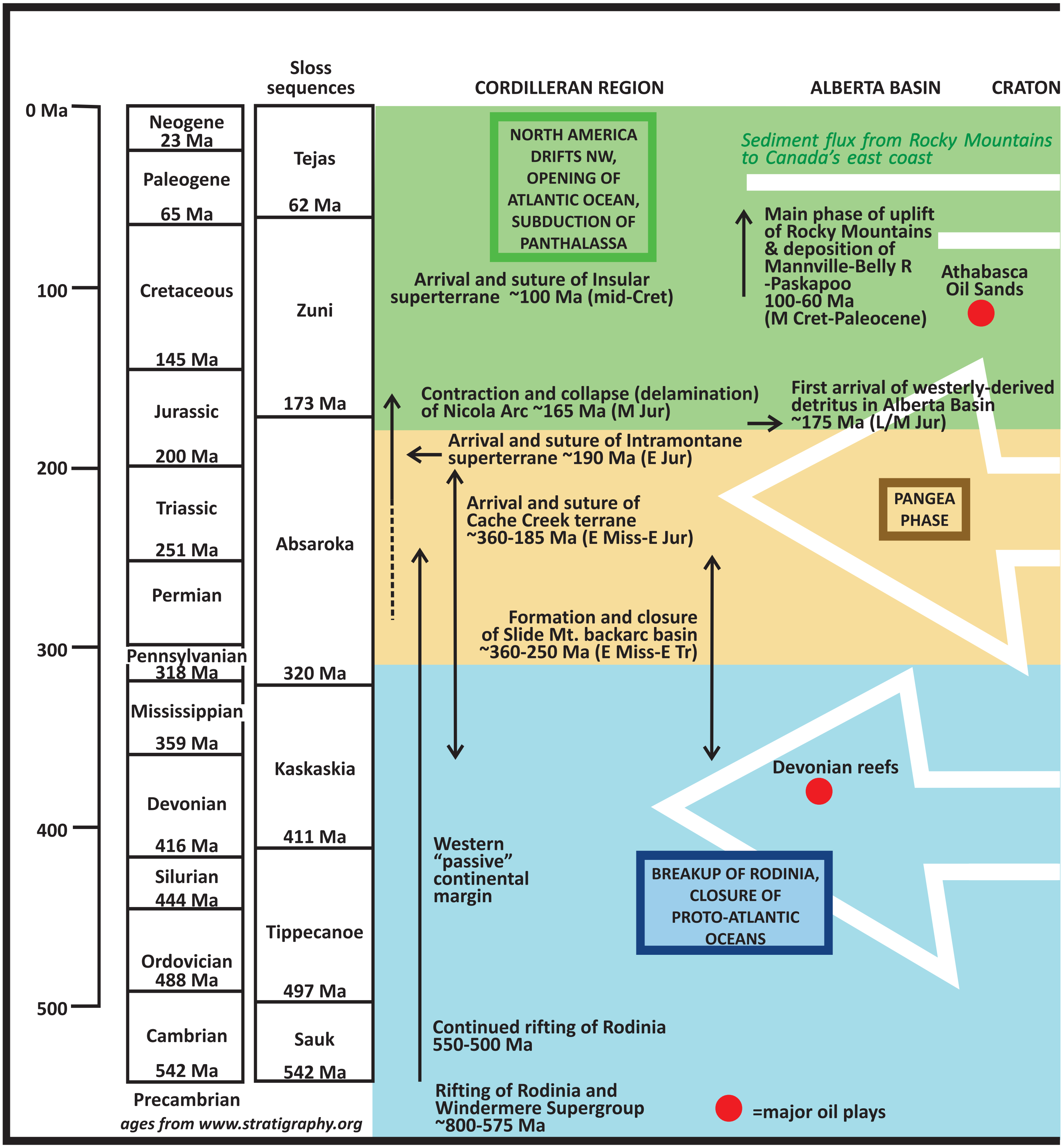

Figure 1. A Phanerozoic time chart for Canada.

detail by Ron Blakey, whose series of paleogeographic maps is posted on his website at www.nau.edu. Selected maps from this series are published in the synthesis chapter on North American sedimentary basins by Miall and Blakey (2008), and the central column of the time chart, showing the orientation and latitude of North America, is based on these reconstructions. Through much of the Phanerozoic, Canada lay in low latitudes and the equator transected the continent (see the column, 'Latitude and Orientation of North American Craton' on Figure 1). Approximate latitudes for the western and eastern margins of the continent, as they change through time, have been read off

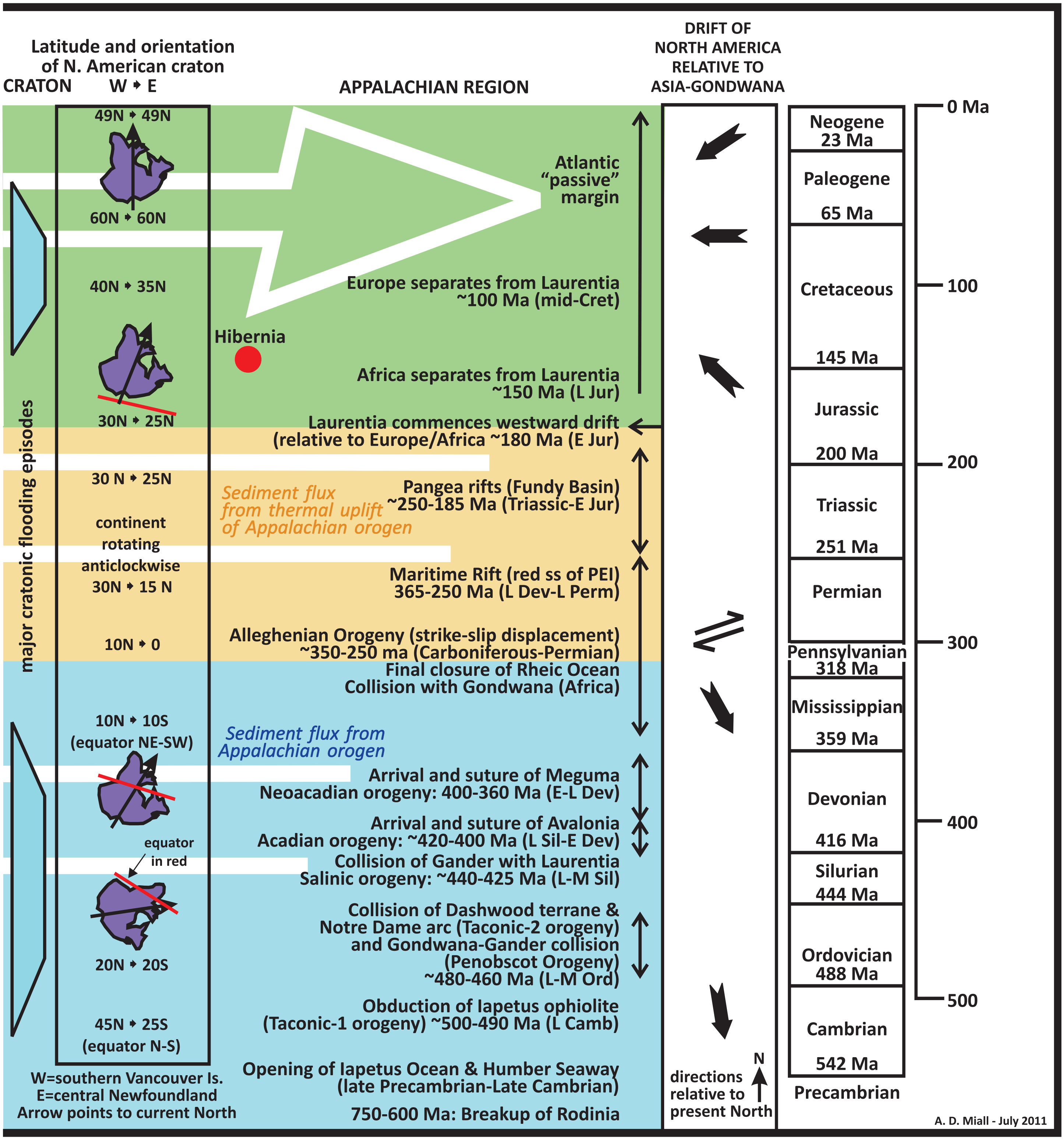

Figure 1. A Phanerozoic time chart for Canada.

Blakey's maps, and are shown below each of the small maps of the continent. Southern Vancouver Island and central Newfoundland did not, of course, exist in their present form until terrane-accretion events took place (in the Cretaceous and the Devonian, respectively), but these end points serve as useful markers for mentally positioning the continent. The orientation of the small maps, and the latitude values, show how North America rotated anticlockwise and then, commencing in the Jurassic, drifted northward to its present high-latitude position, It is not generally appreciated that for most of Phanerozoic time Canada occupied tropical to warm-temperate regions, and these persisted, even in the Arctic Islands, until the Miocene.

Major events in four regions – the Cordillera, Alberta Basin, the Craton, and the Appalachians – are shown on the chart (Fig. 1). These regions, and the events used to typify them, essentially constitute a transect of the geology along the Trans-Canada Highway from Vancouver Island through southern British Columbia, the Prairies, southern Ontario and the Maritimes, finishing in Newfoundland. Again, the focus here is on the expected interests of the typical reader of *Canada Rocks* (and, for that matter, the average geologist), whose main experience of the country is likely to be the more densely populated strip of land north of the US border. The Arctic is not shown at all, and events in other northern regions, such as northern British Columbia and Yukon, are necessarily omitted. Needless to say, that which is shown is highly simplified, and many readers will be aware of local details that imply considerably greater complexity. The aim of the chart is to convey an overall impression. For this reason, the ages of events have been rounded off to easily remembered whole numbers, and the equivalent standard Phanerozoic ages indicated in each case.

Events shown for the Cordilleran region and the events associated with the Cordilleran orogen in Alberta are based on the southern Alberta–British Columbia transect described in the field guides by Price et al. (1985) and Price and Monger (2003). The latter, in particular, is much more than a field guide, providing a detailed tectonic history for the regions described. In the chart, the persistence of the western continental margin as a 'passive' margin from the late Precambrian to the Permian or Triassic is based on the geology of the foreland and Omineca belts. Paleogeographic reconstructions for the US portion of the margin and for northern British Columbia and Yukon reveal the interpreted presence of offshore terranes and arcs (see Miall and Blakey 2008), but these did not significantly affect southern British Columbia until their arrival at the continental margin after about 300 Ma. The evolving geology of the Cache Creek subduction complex and the Nicola arc are the key events that help to define the terrane-accretion history of this area, and are particularly well exposed along and near the Trans-Canada Highway.

The geology of the Prairies portion of the craton and of the Alberta Basin is described in detail by Ricketts (1989) and Mossop and Shetsen (1994). Two major episodes of high sea level, during the Late Cambrian–Mississippian and again during the Cretaceous, are indicated by the blue trapezoids. These two sealevel cycles are based on the Phanerozoic stratigraphy underlying the Prairies (Burgess 2008), which typically consists of a Cretaceous to mid-Cenozoic section resting unconformably on a Cambrian or Ordovician to Devonian section and this, in turn, rests with profound unconformity on the rocks of the Canadian Shield. Two of the major oil plays of this region are shown according to the ages of the reservoirs, by red spots on the chart.

For the Appalachian region, for *Canada Rocks*, we were guided mainly by the regional synthesis published by the Atlantic Geoscience Society (2001). Eyles and I also found most informative the IGC field guide by Neale (1972), because this booklet contains the first fully-formed plate-tectonic reconstruction of the island, in which the opening and closure of the Iapetus Ocean and the obduction of the Bay of Islands Ophiolite are well described (see also Geological Survey of Canada 1992). This latter event is now termed the Taconic-2 orogeny (van Staal et al. 2009). A modern, non-technical treatment of the geology of Gros Morne National Park, where these and other rocks are beautifully exposed, was provided by Burzynski and Marceau (1990). For the purpose of the chart presented here, the pre-Carboniferous geological events have been updated based on the recent synthesis by van Staal et al. (2009).

It is now known that central Newfoundland – the original Dunnage zone of Williams (1978) – comprises the remnants of several small oceans and short-lived island arcs (e.g. van Staal et al. 1998, 2009), but the omission of these from the synthesis (and from the description of this area in Eyles and Miall 2007) does not detract from the sweeping vision of plate tectonic events that first came to light in the reconstructions of this area based on the then imaginative model of Wilson (1963), and the spectacular map compiled by Williams (1978).

The final column on the chart, on the right hand side, shows the relative motion of North America in relation to Gondwana. The arrows define three broad periods (the three 'phases' of Miall and Blakey 2008), which are also indicated by the background colouring of the chart. The first phase corresponds to the breakup of Rodinia and the subsequent assembly of Pangea, during which North America was closing in a southward direction relative to the Gondwana margin (the margin of what became northwest Africa). The Iapetus Ocean was first opened and then closed, and other minor oceans, including the Rheic Ocean, developed and then disappeared. The second phase corresponds to the period when North America collided with Gondwana to form Pangea, and was undergoing post-suture adjustments in the form of right-lateral strike-slip displacement. The third phase corresponds to the breakup of Pangea, and the northwestward and then westward drift of North America away from Europe/Africa, with the development of the modern Atlantic Ocean.

Also shown on the chart, in the form of three broad white arrows, is the changing flux of sediment transport across the continent (simplified from the summary in Miall 2008). Detrital zircon studies reported by Dickinson and Gehrels (2003) confirm a suggestion made first by Dickinson (1988) that much of the thick Paleozoic and early Mesozoic detrital succession present in the Colorado Plateau area (including the units exposed in the Grand Canyon) were derived by uplift and erosion of the eastern continental margin. Zircons of Grenville and Appalachian provenance are abundant, indicating the presence of long-vanished river systems transporting detritus westward across the continental interior. This dispersal pattern may have originated during the Neoproterozoic. Rainbird et al. (1997) suggested that sandstones of this age exposed on Victoria Island, in the western Arctic, were derived by erosion of the Grenville orogen 3000 km to the east, based on U-Pb and Sm-Nd geochronology of the detrital components.

A reversal of this continental transport pattern is indicated by the upper white arrow on the chart. An east-flowing drainage system was suggested by McMillan (1973), who was speculating about the possible sources of the thick Cretaceous–Cenozoic sedimentary accumulations on the Labrador shelf. The concept has received support from Duk-Rodkin and Hughes (1994), who mapped remnant landforms and terraces in parts of northern Canada. This drainage pattern was disrupted by glacial erosion and glacial meltwater drainage channels during the late Cenozoic.

Except for the last, glacially related drainage system, these continent-wide dispersal patterns required regional tilting of the continent. The westward tilt during the Paleozoic is a dynamic topographic effect related to heating of the crust near the centre of Pangea. The westward tilt during the Cretaceous and Cenozoic reflects uplift associated with the development of the Cordilleran orogen. This drainage system was then disrupted by the southward spread of continental ice in the Neogene.

INSTRUCTIONAL USE OF THE CHART

I have developed courses on the Phanerozoic geology of Canada based on *Canada Rocks* for two different audiences: a professional audience of petroleum geologists in Calgary (for the Canadian Society of Petroleum Geologists), and an undergraduate audience at the University of Toronto.

While delivering the course for petroleum geologists, in the spring of 2008, I realized that the regional approach meant that the cross-Canada correlations and comparisons were assigned secondary status and that the continental and global picture therefore received less emphasis. It was at this time that the idea evolved for the chart presented in this article.

At the University of Toronto, we experimented with this course as one of the required courses for the Geology Major program. In my judgment it might work well for an advanced undergraduate audience, but at the second-year undergraduate level at which it was given in 2010, my impression was that it was too complex and over the heads of many students. The regional approach to the geology was used, but the chart was referred to repeatedly as a means of tying the regions together and reminding the students, at selected moments, of the unifying plate tectonic and other events that helped to explain the evolution of the continent as a whole. Given the complexity of the overall story, my impression was that this was still too much for a student audience with only a single year of university training behind them. The chart is offered here as a tool to be used in any suitable context.

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