CIRCUM-ATLANTIC TERRANE ANALYSIS: CONTRIBUTIONS FROM STRATIGRAPHY AND SEDIMENTARY PETROLOGY

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El definir los *terrenos* (asociaciones tectonoestratigráficas de unidades de rocas limitadas por fallas), es más fácil que determinar si son realmente *exóticos*. Los datos sobre estratigrafía y petrología sedimentaria pueden ayudar grandemente a juzgar si los terrenos actualmente adyacentes son o no exóticos, es decir, si la posición que ocupan actualmente unos respecto a otros y al bloque continental o zona móvil o ambos de quienes formaban parte, es diferente de posiciones pasadas. Por ejemplo, los fragmentos de lo que fueron en su día terrenos concretos se pueden identificar en base a su registro estratigráfico similar, ya que los terrenos individuales (incluidos los segmentos desligados) deberían mostrar homogeneidad y continuidad interna en su estratigrafía, estilo tectónico e historia (con considerables variaciones locales y regionales sin embargo debidas a factores como son las facies). Las características divergentes de la dispersión de sedimentos pueden ser utilizadas para deducir una relación exótica mutua entre terrenos actualmente próximos. Finalmente, la mineralogía básica de las fracciones detríticas de tamaño arena (expresada en términos de cocientes QtFL, QmFLt, QpLvLs y PmPK) puede ser usada para deducir el área fuente más adecuada para un terreno determinado (bloque continental, arco magmático, orógeno en desarrollo) y (2) la posición probable de los terrenos respecto al área fuente. En consecuencia, este tipo de datos petrológicos detallados deberían no sólo poder indicar si los terrenos adyacentes son exóticos sino también ser usados para deducir las épocas probables de atraque (amalgamación) de terrenos claramente exóticos.

Palabras clave: Terrenos, Petrología de areniscas, Indices composicionales, Facies, Orógeno Apalachiense-Caledoniano, Terreno Avalon, Terreno Meguma, Terrenos Tacónicos.

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Defining *terranes* (fault-bounded tectono-stratigraphic assemblages of rocks units) is easier than establishing that they are truly *exotic.* Data from stratigraphy and sedimentary petrology can greatly aid in judging whether or not now-adjacent terranes are exotic, i.e., that the position they now occupy with respect to one another and to the continental block and/or mobile belt of which they are a part differs from past positions. For example, fragments of what were once single terranes may be identifiable on the basis of similar stratigraphic record because single terranes (including misplaced segments) should exhibit an internal homogeneity and continuity of stratigraphy, tectonic style, and history (however, with considerable local and regional variation due to such factors as facies). Disjunctive patterns of sediment dispersal can be used to infer a mutually exotic relationship between now subjacent terranes. Finally, the framework mineralogy of sand-sized detritus (expressed in terms of QtFL, QmFLt, QpLvLs, and PmPK ratios) can be used to infer (1) the most likely source type for a given terrane (continental block vs. magmatic arc vs. developing orogen), and (2) the probable position of terranes relative to source. Consequently, such detailed petrologic data should indicate not only whether now adjacent terranes are exotic, but also can be used to help infer likely docking (amalgamation) times for proven exotic terranes.

Key words: Terranes, Sandstone petrology, Compositional indexing, Facies, Appalachian-Caledonide Orogen, Avalon terrane, Meguma terrane, Taconic terranes.

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Conventional plate tectonic explanations for the Appalachian-Caledonide Orogen regard each of the lithotectonic zones (for example, the Avalon, Gander, and Piedmont Zones) as essentially in place. That is, though they may be somewhat compressed in space, they are inferred to occupy spatial positions with respect to one another and within the overall orogen roughly identical with past positions (Williams 1974, 1978; Dewey 1969). On the other hand, the *terrane hypothesis* regards individual terranes (fault-bounded regions with tectonostratigraphic records and histories distinct from adjacent regions) as *suspect,* i.e., it accepts the possibility that individual terranes now occupy exotic, that is, different positions with respect to one another than those of the past. When it can be convincingly demon-strated that such *suspect terranes* have actually been transported from different sites and assembled together in collage-like fashion, their *exoticity* is established (Williams and Hatcher 1983; Zen 1983; Ziegler *et* al. 1977).

This paper suggests several schemes of investigation that stratigraphers and sedimentary petrologists might fruitfully pursue in order to *recognize* possibly suspect terranes in the cirum-Atlantic region, *define* their exent, and especially to *evaluate* their *exoticity.* Several lines of inquiry are outlined, and can be briefly summarized as follow:

1. Comparative study of orogenes outside the circum-Atlantic region may aid in gauging the likely size, shape, and arrangements of different terrane types.
2. The stratigraphic record preserved within scattered fragments of what were once the same terrane should show a common history of basin evolution. Consequently, terrane fragments of uncertain affinity might be identifiable on the basis of generally similar stratigraphic records.
3. As a corollary of point 2, recognition of viable terranes should be possible on the basis of stratigraphic-sedimentologic *integrity,* i.e., single terranes (including misplaced fragments) should exhibit an internal homogeneity and continuity of stratigraphy, tectonic style, and history. However, considerable local and regional variations should be expected. Obviously, a critical piece of stratigraphic-sedimentologic data for evaluating «degree of exoticity» is the presence or absence of along-strike, across-strike, and vertical variations of individual units. Caution is advisable, however, because modern continental borders and plate margins tolerate surpisingly rapid changes in stratigraphic character due to *facies* changes.
4. Discontinuous (i.e., disjunctive) patterns of sediment dispersal defined by primary directional structures, by scalar changes in mean and maximum grain size, and by overall lithofacies patterns can suggest the likelihood that now subjacent terranes were originally separated.
5. Detailed analyses of the mineralogy of the framework fraction of modern and ancient sandstones suggests that systematic differences in composition reflect contrasts in *provenance* and *plate tectonic setting.* Despite some formidable problems, this relationship can be profitably used. Compositional indexing of now subjacent terranes helps evaluate the likelihood of their being adjacent during earlier time intervals.

TERRANES: COMPARISONS OF SCALE AND CONTINUITY-A SEARCH FOR GUIDING CONSTRAINTS

With the terrane hypothesis, individual orogens are regarded as *collages* or *mosaics* of small to large bits and pieces of crustal material assembled together as the result of continental drift and sea-floor spreading. Moving sea-floor transports crustal slivers across po-

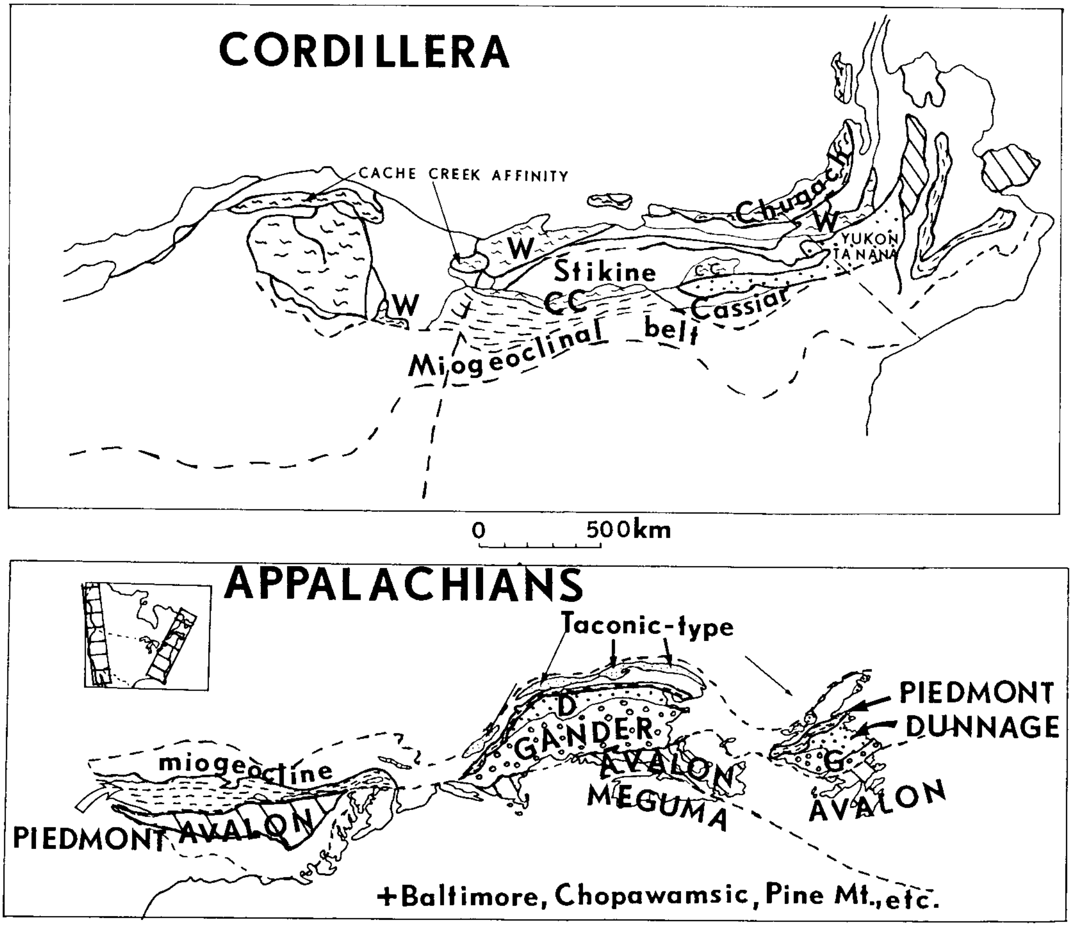


Fig. 1.—Major terranes of the Cordilleran and Appalachian Orogens compared in size, continuity, and general type «outboard» from the North American miogeoclinal margin. In the Appalachians, dashes represent subjacent eugeoclinal (continental rise-slope) deposits (Piedmont Belt); fine dots are displaced toe-of-rise deposits (Taconic allochthons); coarse dots are deep ocean basin sequences (D = Dunnage Belt); open circles are the Gander Belt (a continental rise-shelf embankment developed adjacent to Avalon?); slanted lines are «offshore slivers» of the Avalon «microcontinent»; and solid triangles are the Meguma Terrane.

tentially large distances and can ultimately plaster them (haphazardly?) together along the margins of existing continental blocks. Any mountain system so assembled is consequently analogous to a disjointed, nonrational collection of jigsaw puzzle-like pieces, put together as a somewhat irrational whole. It is incumbent upon geologists to develop effective means of identifying the component pieces, sorting them out, and reconstructiong the timetable by which such pieces were assembled together *(amalgamation history)*. This is the essence of terrane analysis. The most straightforward definition of a terrane is that of Howell and Jones (1984, p. 6), «tectonostratigraphic terranes are fault-bounded entities of regional extent, each characterized by a geology history that is different from the histories of contiguous terranes» (see also Keppie, 1985, p. 1218).

Convincing evidence suggests that much of western North America has grown through the accretion of far-travelled, discrete tectonostratigraphic terranes, but the case for applying the terrane concept to the circum-Atlantic belt in general, and to the Appalachian-Caledonide Orogen specifically is less compelling. Nevertheless, Fig. 1 shows for purposes of comparison, identical scale terrane maps for the Cordilleran belt (Coney, Jones and Monger 1980; Saleeby 1983) and the Appalachian belt (the preliminary terrane map of Williams and Hatcher 1982). Simple coding is used to index «like» geological provinces, for example, the «in-place» miogeoclinal margins, subjacent continental rise assemblages, and (where discernible) «offshore» microcontinental blocks. Several features are common to both terrane maps.

1. Note the wide variation in terrane extent in both orogens. Some terranes extend for 100's and 1,000's of kilometers (the Piedmont and Avalon terranes in the Appalachians; the Cache Creek and Wrangellia terranes in the Cordillera). Other terranes are of very limited extent (for example, the Chopawamsic, Baltimore, and various Taconic terranes of the Appalachians). California geologists now describe terranes with surface areas less than 25 Km^2 (Blake, Howell and Jayko 1984). Assuming comparably sized terranes exist within the Appalachians, can they be identified?

2. Is any meaningful pattern of terrane juxtaposition or placement discernible? For example, in the Appalachians, a systematic relationship seems to exist between the position of the miogeoclinal margin, the various overthrust Taconic sheets (commonly interpreted as distal «toe of rise» deposits), and transported, but essentially intact eugeoclinal rise deposits (Piedmont terrane). Should stratigraphers involved in terrane analysis be guided by expectation, i.e., can the spatial positioning of various kinds of bits and pieces be anticipated by mimicking relationships seen elsewhere?

3. On the other hand, it may be more logical to conclude that the terrane mechanism inherently imparts uniqueness, randomness, and individuality to each mobile belt. As a consequence, lessons learned and patterns discerned in one orogen may have little practical applicability to other orogens.

CAN TERRANE «PIECES» BE IDENTIFIED BASED ON A COMMON BASIC HISTORY-TRACKING TERRANES USING STRATIGRAPHIC-SEDIMENTOLOGIC «INTEGRITY»

Orogenic belt deformation should, more often than not, fragment individual terranes into bits and pieces that may eventually be widely dispersed about a single belt (or for that matter, be in part incorporated into other belts). nevertheless, it might be possible for stratigraphers and sedimentary petrologist to recognize and identify scattered terrane fragments by careful analysis of the detailed history of basin filling.

For example, the Avalon terrane in its «type area», the Avalon Peninsula of eastern Newfoundland, exhibits a systematic pattern of Late Precambrian and Early Palaeozoic evolution, as can be inferred from the stratigraphic record (King 1980). (1) An initial period of Late Precambrian crustal thinning led to the development of basin and range topography, the growth of a series of ensialic grabens, and the accumulation of several kilometers of dominantly subaerial volcaniclastic rocks. (2) A later stage of deeper water marine turbidite and shale deposition followed, punctuated by Late Precambrian glaciation. (3) Subsequent deformation and uplift generated latest Precambrian and Early Palaeozoic shallow marine, deltaic, fluvial, and alluvial plain sediment. (4) Finally, following erosional bevelling, the Avalon Peninsula behaved as a relatively stable area and was transgressed by the sea, with basal transgressive quartz sandstone overlain by thin, extensive, mudrock shelf deposits.

If similar stratigraphic sequences (and hence, an identical scenario of basin evolution) can be discerned elsewhere around the circum-Atlantic region within other discrete, fault-bounded blocks, such scattered regions might be collectively identified as «Avalon-type» terranes and simply be displaced fragments of a single original terrane. This seems to be precisely the case for several regions across the circum-Atlantic region (Cape Breton, southern New Brunswick, eastern Massachussetts, southern Britain) (Skehan and Rast

1983; O'Brien, Wardle and King 1983; Schwab *et al.* 1988).

It is obviously incumbent on stratigraphers and sedimentologists involved in terrane analysis to look at stratified assemblages in terms of gross «packages», recognizing if possible; coherent patterns of basin fill history which might be used to characterize and identify other displaced fragments of what were once arguably a single terrane.

FACIES CHANGES VERSUS «TERRANE HOPPING»

Although «misplaced»: or «dispersed» fragments of the same terrane should exhibit a stratigraphic-sedimentologic integrity that is *«intact»* (i.e., an internal homogeneity and continuity of stratigraphy, tectonic style, and history), it is important to recognize that considerable local and regional variations can occur within a single, coherent crustal block. Subsequent faulting within that single block might produce a false impression, convincingly suggesting that rapid difference in sediment thickness and character actually due to normal facies changes reflect instead the existence of several terranes.

As a case in point, consider the Late Precambrian-Early Palaeozoic continental margin of the Central and Southern Appalachians (Fig. 2-A). Late Precambrian stratified assemblages of the Blue Ridge and adjacent areas document an episode of Appalachian rifting. Several Late Precambrian sequences represent deposition in a series of disconnected Triassic-like interior rift basins. Other units suggest the existence of a major, rifted continental margin with topographically high scarps facing a developing ocean basin along the true continental edge. Still other units document the existence of aulocogens extending into the continental interior (Schwab, 1986a, 1986b). Random sampling of the Late Precambrian stratigraphy from various points within this framework would suggest several radically different histories and basin settings. Some areas would show only older crystalline basement, with no apparent history of Late Precambrian rifting. Adjacent areas would suggest a history of rifting with the development of interior basins. Still other localities would reveal and extensive history of continental margin rifting and ocean basin opening across a broad region. Obviously, random placement of even minor faults between these various segments would generate the impression that a series of markedly distinct terranes were being traversed, rather than a single, albeit complex, developing rift margin.

A similar point can be made by referring to Fig. 2-B which schematically summarizes the subsequent Early Palaeozoic history of passive margin development (Schwab, 1986a, 1986b). Shallow, basal Cambrian clastic sediments together with overlying Cambrian-Ordovician carbonate bank deposits mark a continental shelf or terrace area, bordered towards the east by finer-grained, deeper water turbidites and muddrocks of a continental rise. This rather simple picture is somewhat more complicated in the area presently near Baltimore and Chesepeake Bay, where an oceanic embayment extended into the continental margin, leaving a tongue-shaped sliver of continental crust now exposed in the area of the Baltimores gneiss dones. This peninsular sliver was also the site of a developing volcanic arc that extended southwestward into the open ocean basin, perhaps as a trench-subduction zone related chain.

A modern analogue to this very complicated Early Palaeozoic setting (Fig. 2-B) is sketched in Fig. 2-C, which shows modern embayments like the Sea of Okhotsk and Yellow Sea along the Western Pacific separated from the major Pacific Ocean basin by peninsular slivers of continental crust (Kamchatka and Korea respectively). Even the arcuate volcanic arc-trench system has modern analogues in the Kuril and Rykyu Islands.

The significant point is that modern settings like the Western Pacific clearly demostrate that abrupt changes in sediment thickness and character occur whenever depositional setting changes rapidly in space. It is unnecessary to cross from one lithospheric plate to another in order for facies to change rapidly. Once again, unfortuitous development of small-displacement faults critically situated between adjacent depositional belts would suggest to future stratigraphers the existence of different terranes in the Western Pacific, when in actual fact, a series of simply faulted blocks derived from a single, though stratigraphically varied continental margin exist.

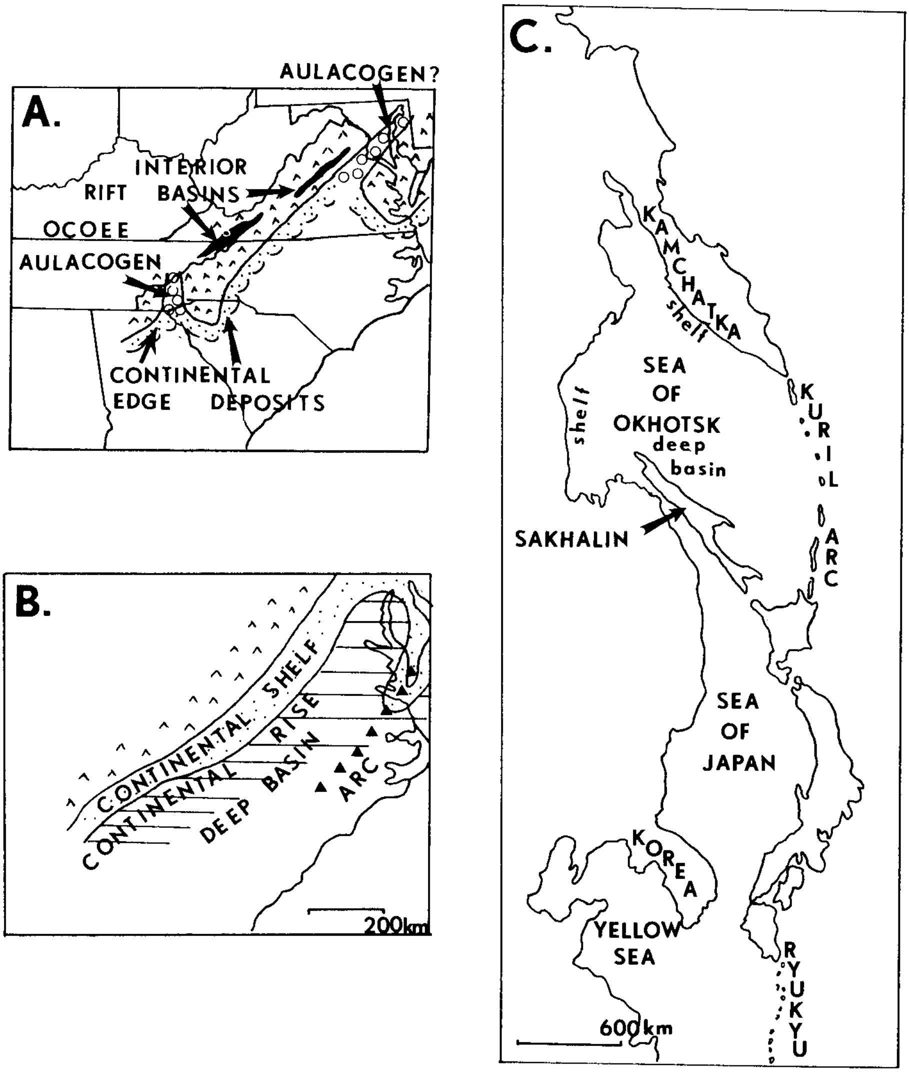


Fig. 2.—(A) Speculative palaeogeographic reconstruction showing late Precambrian stratified assemblages accumulating within Triassic-like interior rift basins (solid black); within aulacogen-like embayments into the topographically high continental margin (open circles); and along the zig-zagging continental edge, offset perhaps by transform faults (stippled pattern). (B) Speculative palaeogeographic reconstruction showing an Early Palaeozoic passive, Atlantic-type continental margin with sediments accumulating upon a shallow-water continental shelf, an adjacent, deeper-water continental rise, and within a deep embayment into the margin west of a developing volcanic arc. (C) Modern Western Pacific margin showing striking similarities to the Early Palaeozoic setting in the Central and Southern Appalachians with inland seas, offshore peninsular continental blocks (Korea and Kamchatka), and trench-related volcanic arcs (Kurils and Rykyus).

Obviously, discriminating changes due to facies from changes due to crossing terrane boundaries is not an easy task. To successfully separate the two will require a more precise knowledge of facies variations across modern continental margins than is presently at hand.

INFERING EXOTICITY FROM DISJUNCTIVE DISPERSAL PATTERNS

Now adjacent, fault-bounded terranes that are mutually suspect can be examined for possible exoticity using information on sediment dispersal. Two contrasting examples can be compared. Fig. 3-A shows palaeocurrent patterns for two presumably *linked* (nonexotic-nondisplaced) terranes. Fig. 3-B shows palaeocurrent patterns for two terranes that are demonstrably exotic with respect to each other.

Fig. 3-A summarizes the paleocurrent system for the Late Precambrian to Early Palaeozoic sedimentary sequences of the Central and Southern Appalachians already described above. This system can be documented using primary directional structures (cross-bedding and ripplemarks) and regional changes in lithofacies and thickness. Provenance studies further substantiate derivation of the bulk of these Late Precambrian and Early Palaeozoic sediments from continental block source areas located north and west of the present exposure belt. Two coeval Early Palaeozoic assemblages, miogeoclinal rocks along the northwestern flank of the Blue Ridge Province, and eugeoclinal rocks along its southeastern flank, clearly mark the evolution of an eastward-facing passive continental margin that Wehr and Glover (1985, p. 285) believe straddled, «a reactivated hinge zone separating continental crust of relatively normal thickness to the west from highly attentuated continental crust to the east». Despite the dissimilarity in facies across the axis of the Blue Ridge, it is apparent, based on the measurable, internally logical and uniform palaeocurrent pattern, that the two sequences together form a cohesive whole, and should not be considered as mutually exotic terranes.

Quite the opposite case characterizes the Meguma terrane which underlies most of Nova Scotia proper (Schenk 1970, 1971, 1978, 1981) (see Fig. 3-B, this paper). The Meguma terrane lies inmediately adjacent to (but in fault contact with) the Avalon terrane, a broad zone of Late Precambrian volcanic and sedimentary rocks overlain by almost flat-lying Early Palaeozoic shallow water mudrock. The Avalon terrane is considered by many to be a microcontinental block, perhaps a crustal sliver ripped away from the original North American continent. On the other hand, the Meguma terrane underlies all of Nova Scotia southeast of the Glooscap Fault, and probably

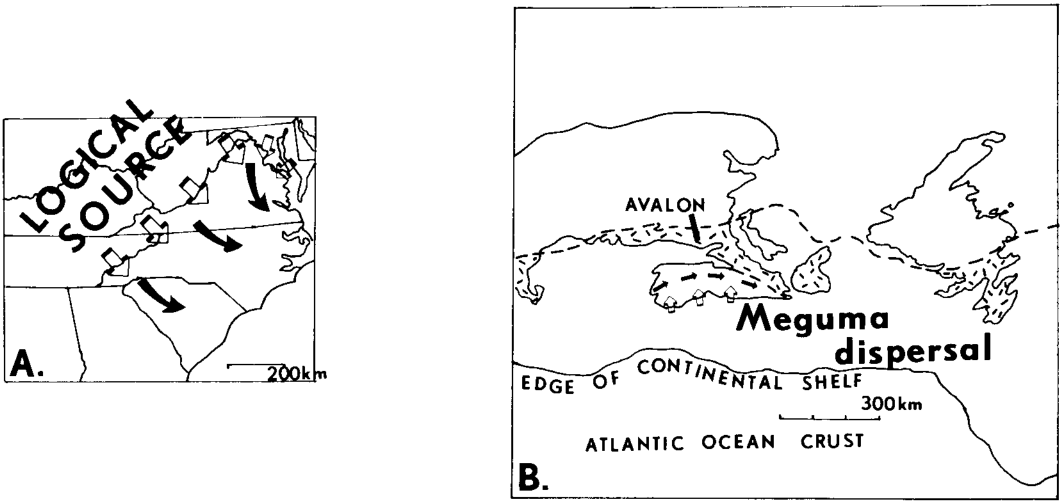


Fig. 3.–(A) Nonexotic-mondisjunctive dispersal pattern showing sediment transport from cratonic source areas northwest of miogeoclinal margin from northwest to southeast across shallow shelf (open arrows) with continued northwest to southeast transport down and acros the continental rise, Early Palaeozoic, Central and Southern Appalachians. (B) Disjuntive dispersal pattern for the Maguma Group, Nova Scotia, suggesting exotic nature of the terrane. Transport is from southeast to northwest generally, with a curious deflection to the east in eastern Nova Scotia, perhaps due to deflection by offshore topographic highs. The area inferred as a source is presently underlain by modern Atlantic ocean crust, but implied source was uplifted continental crust.

extends out beneath the Scotia Shelf, Bay of Fundy, and the continental shelf area south of Newfoundland.

Schenk extensively studied the mineralogy and primary directional structures of the Meguma Group, a Cambrian and Ordovician sandstone-shale sequence that underlies most of the Meguma terrane. The source area for the Meguma Group clearly lay southeast of the present belt of exposure, as indicated by directional structures (orientation of channels, flute axes, convolute stratification, flame structures, and imbricated inclusions) as well as scalar sedimentary properties (for example, trend surface maps of coarsest grain size, percentage of rock fragments, biotite, etc.).

The dispersal pattern for the Meguma Group is clearly *disjunctive,* it cannot be logically explained in the context of the present position of the Meguma terrane relative to the Avalon terrane and the present Atlantic Ocean. No logical continental block source area *now* exists off the southern margin of Nova Scotia, yet the material obviously came from that direction, rather than Avalon to the north. Schenk offers several likely sources for the Meguma (peninsular Europe, northwestern South America, northwestern Africa), but cannot convincingly select the most likely candidate (see further discussion below). Nevertheless, based on paleocurrent pattern alone, the Meguma and Avalon and Avalon terranes must be interpreted as mutually exotic.

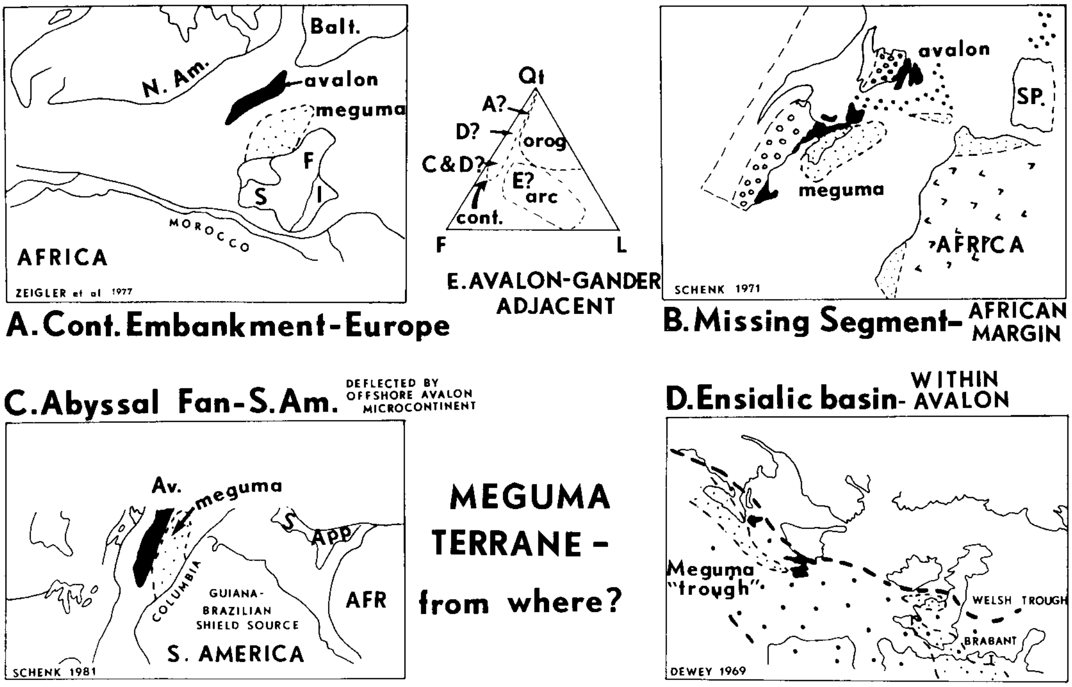
INDEXING TERRANE PROVENANCE AND PLATE TECTONIC SETTING USING SANDSTONE FRAMEWORK MINERALOGY

Considerable data on the mineralogy of modern sands demonstrates that the overall mineralogy of sand-sized detritus is fundamentally controlled by provenance and plate tectonic setting, with climate playing a subordinate and measureable role. The basic data for inferring provenance and plate tectonic setting have been summarized by Dickinson and Suczek, 1979, Dickinson and Valloni, 1980, and Dickinson, 1984. Several studies have successfully pinpointed the likely plate tectonic setting and provenance of ancient sandstone units using such indexing (Dickinson 1984; Schwab 1975, 1981). Even with low to medium grade metamorphic overprinting,

TABLE I.—Key compositional characteristics of sands derived from various major provenance types (Dickinson 1984)

Provenance Type	Tectonic Setting	Derivative Sand Miniralogy
Stable craton	Continental interior os passive platform	Quartzose sands (very high Qt content) with high Qm/Qp and K/P ratios
Basement uplift	Rift shoulder or transform rupture	Quartzofeldspathic (Qm-F rich) sands low in Lt with Qm/F and K/P ratios similar to bedrock
Magmatic arc	Island arc or continental arc	Feldspatholithic (F-L rich) volcaniclastic sands with high P/K and Lv/Ls ratios grading to quartzofeldspathic (Qm/F rich) batholith-derived sands
Recycled orogen	Subduction complex or fold-thrust belt	Quartzolithic (Qt/Lt rich) sands low in F and Lv with variable Qm/Qp and Qp/Ls ratios

Qt = total quartzose grains (monocrystalline and polycrystalline quartz); Qm = monocrystalline quartz; Qp = polycrystalline quartz; K = K-feldspar; P = plagioclase feldspar; F = total feldspar; Lv = volcanic rock fragments; Ls = sedimentary rock fragments; Lt = total lithic fragments (stable and unstable).



A. Cont. Embankment - Europe

B. Missing Segment - AFRICAN MARGIN

C. Abyssal Fan - S. Am. DEFLECTED BY OFFSHORE AVALON MICROCONTINENT

D. Ensialic basin - WITHIN AVALON

E. AVALON-GANDER ADJACENT

Fig. 4.—Schematic maps showing the Meguma Terrane occupying various past positions in the Circum-Atlantic region. (A) Part of a continental shelf-rise embankment developed off Europe-Amorica (hence with quartz-rich sandstone petrology in QtFL diagram); (B) Part of a continental shelf-rise embankment rifted away from the West African margin (hence with slightly more feldspathic sandstones petrology); (C) part of a continental shelf-rise embankment developed adjacent to Western Sout America (with an inferred higher feldspar content in sandstones); (D) As part of an ensialic basin developed within the Avalon microcontinental block (presumably wich a quartzo-feldspathic sandstone petrology); and (E) (not shown in map view) As part of a continental rise-submarine fan system developed adjacent to an island arc complex. In the small triangular diagram Qt = total quartz, F = total feldpsar, L = unstable rock fragments. The compositional fields of Dickinson (1984) corresponding to continental block provenance (cont.), volcanic arc provenance (arc), and recycled orogen provenance (orog) are shown wich dashed boundaries.

such mineralogical «finger-printing» is successful.

Collecting data for this approach requires sandstones point counts to be done in a precise manner (the Dickinson-Gazzi technique) which express the framework mineralogy as a series of critical ratios, namely:

1. *QtFL,* where Q = total quartz; F = total feldspar; L = unstable rock fragment;
2. *QmFLt,* where Qm = monocrystalline quartz; F = total feldspar; Lt = unstable rock fragments plus polycrystalline quartz;
3. *QpLvLs,* where Qp = polycristalline quartz; Lv = volcanic rock fragments; Ls = sedimentary rock fragments; and
4. *QmPK,* where Qm = monocrystalline quartz; P = plagioclase; K = K feldspar.

Using these critical, sand-sized mineral fragment rations, it is possible to fit raw (but converted) compositional data to the control base of modern sands and infer not only a likely plate tectonic setting, but for the purposes of terrane analysis, a likely provenance. Table I (Dickinson 1984) summarizes the likely source area composition fields which are also reproduced in miniature on Figures 4,5, and 6.

Obviously, an effective means for judging whether or not two, now adjacent terranes have been displaced with respect to one another and are now mutually exotic is to com-

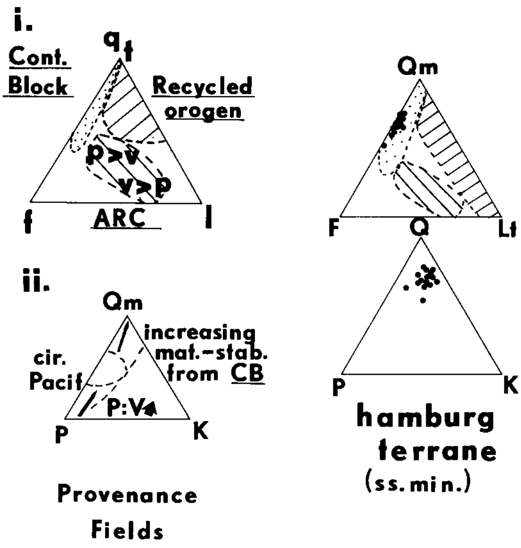


Fig. 5.—Compositional indexing of provenance for sandstones from the Hamburg Terrane. (i) The reference QtFL plot of Dickinson (1984) on the left with data from the Hamburg Terrane on the right clearly suggest only a continental block source for the Hamburg, raising an least the possibility that the James Run-Chopawamsic volcanic arc is exotic. (ii) The reference QmPK plot of Dickinson (1984) on the left and data from the Hamburg Terrane on the right confirm this inference.

pare the composition of coeval sandstone sequences from both terranes. The framework mineralogy of such sandstones, coupled with directional structures indicating dispersal, should clearly indicate both (1) the most likely source area type for each terrane (continental block vs. magmatic arc vs. developing or recycled orogen), and (2) the probable positions of individual terranes relative to source. Aditional inferences about docking (amalgamation) times of proven exotic terranes might also be made. The basic essentials of this approach, using sandstone framework mineralogy to track or trace terranes, is illustrated below with specific case studies.

Case Study 1: The Meguma terrane

The Meguma terrane has been briefly described above. It occupies most of Nova Scotia and sits inmediately adjacent to the Avalon terrane. As described above, the inferred palaeocurrent pattern (showing source areas to the south and east) clearly suggest that Avalon and Gander were not formerly adjacent to one another as they now are, and that some additional source area originally lay south of Nova Scotia and Meguma.

Schenk (1981) was unable to pinpoint the specific source for the Meguma Group, although be limited possible sources to continental blocks, either Western Europe (Fig. 4-A), northwestern South America (Fig. 4-B), northwestern Africa (Fig. 4-C), or a now-eroded uplifted segment of the Avalon microcontinent (Fig. 4-D). Detailed comparison of detritus now derived from these different sources might conceivably allow a definitive choice to be made. However, compositional indexing of provenance obviously has its limitations. Perhaps it is only possible to discriminate among only dramatically distinct source compositions, for example, magmatic arcs vs. continental blocks, rather than, as in Schenk's preferences, among generally similar continental block sources. Furthermore, it may not be obvious that now adjacent terranes were once widely separated if, in former times, different terranes that were proximal duplicated in general the detrital mineralogy of the presently contiguous blocks.

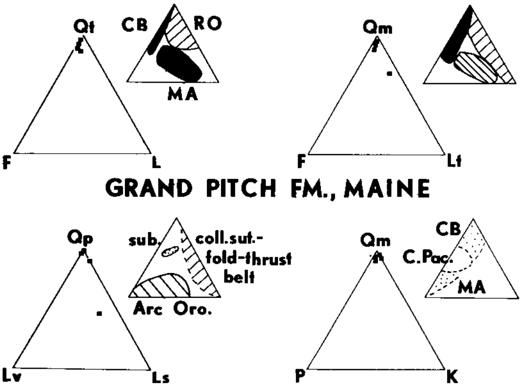


Fig. 6.—QtFL, QmFLt, QpLvLs and QmPK plots of sandstones from the Grand Pitch-Shin Brook Terrane («Island» number 3 in Fig. 8) (large triangular plots). The small, adjacent ternary plots are those of Dickinson (1984) indexing various provenance types where CB = continental block, RO = recycled orogen, and MA = magmatic arc. Sandstone petrology clearly suggests a continental block source, rather than a volcanic arc source for the Grand Pitch-Shin Brook assemblage.

Case Study 2: Trans-Newfoundland terranes

A more clearcut example of terrane tracking via sandstone mineralogy is offered in Newfoundland (Fig. 7). Newfoundland can be subdivided into a series of lithofacies belts that Williams and Hatcher (1983) have reconsidered as terranes (Gander belt, Avalon belt, Piedmont belt, Dunnage belt, etc.). Conventional plate tectonic or «Wilson-cyle» models for the Newfoundland as a two-sided, now closed (sutured) orogen that developed as the result of continental distension, ocean basin opening, and subsequent ocean basin closure.

The deformation of the belt was interpreted to have resulted from the collision of a southeastern continental block (Avalon) with a northwestern continental block (marked on its eastern boundary by the miogeoclinal belt of Western Newfoundland). Inmediately adjacent to these bordering continental blocks were wedge-shaped continental rise-slope sediment prisms (respectively the Gander belt developed along the northwestern margin of Avalon, and the Piedmont belt developed along the southeastern margin of North America). Though these models concede that considerable crustal shortening has occurred compressing the various lithofacies belts together, the individual belts nevertheless would not be exotic terranes in a traditional sense, because they still occupy positions relative to one another consistent with their earlier positions.

However, if the terrrane hypothesis is applied to the Newfoundland Appalachians, the contiguous nature of Avalon and Gander, for example, *must* be regarded with suspicion; like-

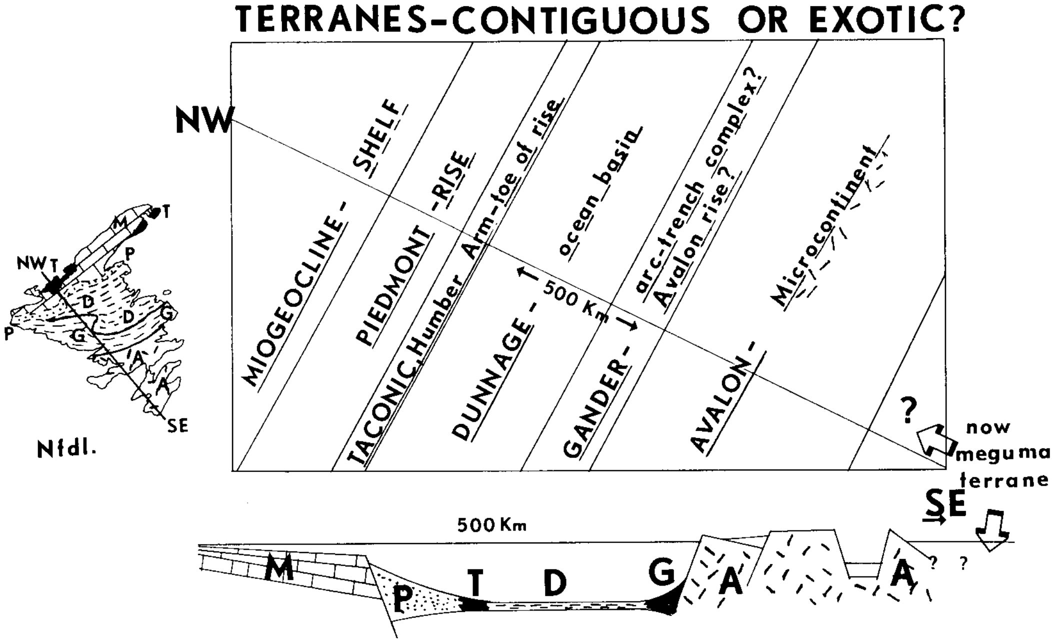


Fig. 7.–Simplified map and cross-section of the various tectonostratigraphic belts or terranes of Newfoundland: M = miogeocline; P = eugeocline; T = allochthonous toe-of-rise deposits now resting on the miogeocline; D = Dunnage Belt (ocean basin assemblage); G = Gander Belt (continental shelf-rise embankment along northwestern margin of Avalon?); and S = Avalon Terrane. The «suspect terrane model» requires that such now adjacent, fault-bounded, distinct tectonostratigraphic terranes occupy potencially different positions with respect to one another than in the past. Conventional plate tectonic models, while conceding considerable crustal shortening, nevertheless regard these individual terranes as nonexotic because they would still occupy positions relative to one another consistent with past positions. Sandstone provenance studies of, for example, the Gander Belt, should convincingly determine whether os nor Gander sediments were deposited subjament to an Avalon-like source area.

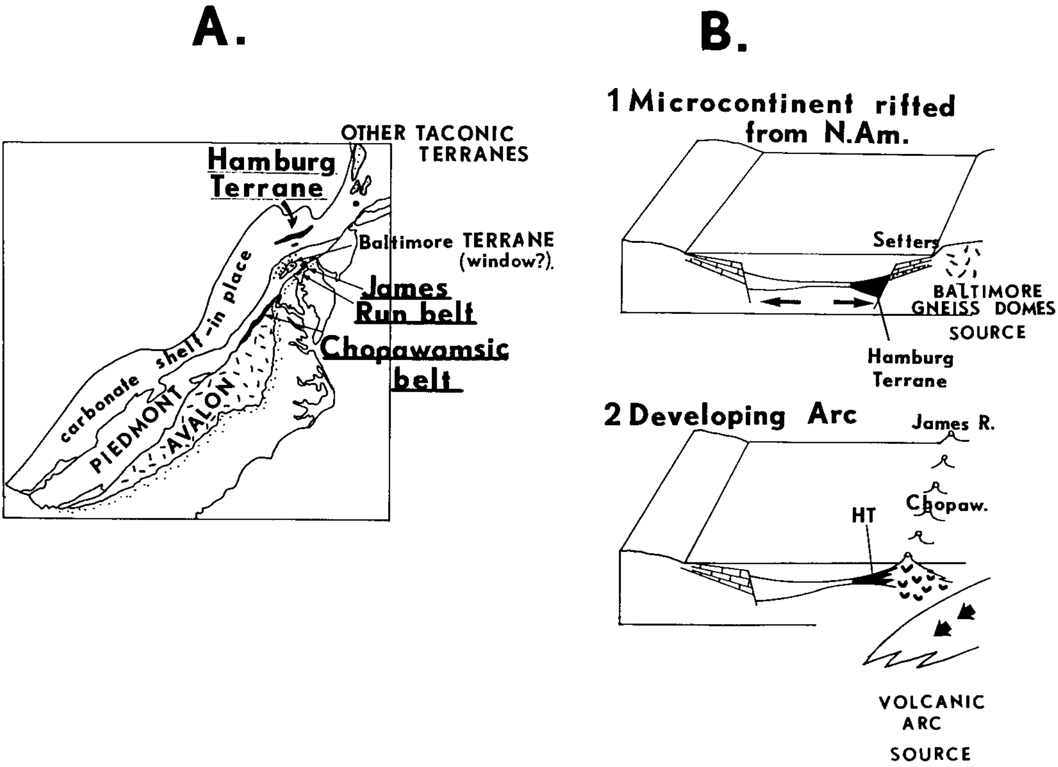


Fig. 8.—(A) Simplified geological map showing areal distribution of the Hamburg Terrane (solid black), carbonate shelf deposits, Piedmont belt (exposing the Glenarm Supergroup), Baltimore Gneiss domes, and volcanic arc deposits of the James Run-Chopawamsic Belt (B) Contrasting scenarios for the setting of the Hamburg sediments: (1) as a continental rise prism derived from a microcontinental crustal block (presumably the Baltimore Gneiss domes) and (2) as a continental rise prism derived from the James Run-Chopawamsic volcanic arc. Hypothesis 1 permits the volcanic arc to be exotic.

wise the present adjacentness of the Piedmont and miogeoclinal belts. Analyses of the sandstone framework mineralogy (linked with dispersal studies) should help to convincingly select one of these two alternative interpretations. For example, if the general pattern of east to west dispersal suggested for the Gander Group can be substantiated, and if sandstone mineralogy implies a continental block (Avalon-like) source area, Avalon and Gander are unlikely candidates to be mutually exotic terranes.

Case Study 3: Displaced Taconic-type terrane, eastern Pennsylvania

A third case study further exemplifies the logic of evaluating terrane exoticity using sandstone mineralogy. The Hamburg terrane of eastern Pennsylvania (Fig. 8-A) is a Taconic-like allochthonous sheet of Early Palaeozoic deep water sediment laterally thrust over equivalently-aged shallow water carbonate shelf deposits of the Valley and Ridge Province (Lash, 1985). The terrane was thrust from the southeast. Immediately southeast of the allochthonous Hamburg klippe and the underlying, autochthonous carbonate sequence is part of the Piedmont belt, where (allochthonous?) deep water deposits of the Glenarm Series or Supergroup are exposed. Shallower water shelf deposits at the base of this sequence rim basement rocks of the Baltimore gneiss domes (which may be windows exposed through the overthrust Piedmont sequences). Still farther east lies the Chopawansic-James Run belt, perhaps a coeval, Early Palaeozoic volcanic arc remnant. Various scenarios have been suggested to explain these spatial relationships. Fig. 8-B illustrates two possibilities: 8-B (1) shows the Hamburg sequence (which is clearly derived from source areas that lay southeast of it) as a continental rise prism derived from a peninsula or offshore sliver of continental crust, specifically the rocks now exposed within the Baltimore gneiss domes; 8-B (2) conversely, shows the Hamburg terrane accumulating immediately adjacent to the James Run-Chopawamsic volcanic arc. The first hypothesis would require the developing James Run-Chopawamsic arc to be shielded from the Hamburg basin and not show up as a likely source based on provenance indexing using sandstone mineralogy. Such «shielding» could result either from the Baltimore gneiss dome operating as a topographic barrier, or as a consequence of distance (i.e., the James Run-Chopawamsic belt would be a truly exotic terrane, swept into its present position some time after it had formed). The second hypothesis (Fig. 8-B (2)) requires the James Run-Chopawamsic belt to form in place, inmediately adjacent to the Hamburg terrane, in which case it should not be copnsidered exotic. Sandstone mineralogy of samples from the Hamburg slice (Fig. 5, with all data from Lash 1986) clearly suggests that *only* a continental block source was present, at least raising the possibility that the James Run-Chopawamsic belt is truly exotic, or at least was somehow shielded from the Hamburg basin (Lash 1985, 1986; Lash and Drake 1984).

Case Study 4: Maine «islands in the sea»

According to Neuman (1984), convergence and closure of the Iapetus sea has brought what were once widely dispersed islands or terranes scattered about Iapetus into close proximity to one another. Fig. 9-A shows those once scattered islands in their present position with respect to one another. Fig. 9-B shows those same island complexes in their original positions, widely dispersed (and consequently now mutually exotic) and situated

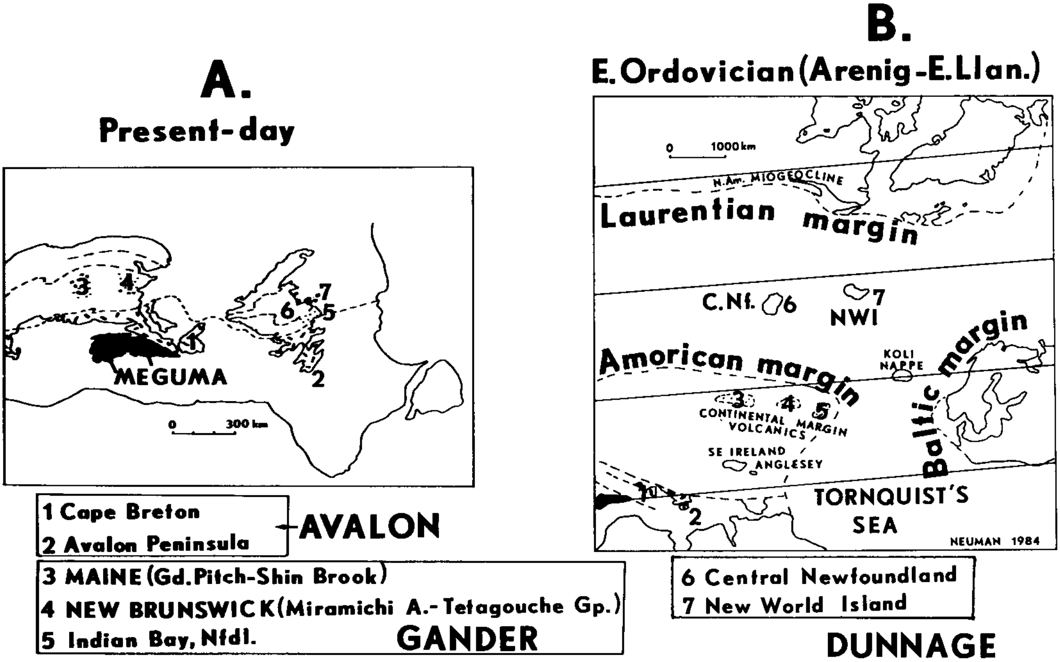


Fig. 9.–(A) Various «island» terranes of Newman (1984) shown in their present-day positions. (B) Original location for various island terranes along the margins of Iapetus.

along at least three margins of Iapetus. Sandstone mineralogy provenance indices should help confirm the original placement of such terranes. Por example, the late Precambrian to Early Palaeozoic Grand-Pitch-Shin Brook complex of north-central Maine (terrane number 4 in Fig. 9) is shown by Neuman as having accumulated along a volcanic arc developed along the northwestern margin of Africa-Amorica. Yet compositional analyses of several sandstone samples of the Grand Pitch-Shin Brook (Fig. 6) suggests instead derivation from a stable, continental block source area, conceivably even the now nearby North American miogeoclinal margin. Obviously additional data on composition as well as dispersal should allow this «terrane» to be more specifically tracked.

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