Origin of the Torlesse terrane and coeval rocks, South Island, New Zealand: Discussion and reply

Discussion

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MacKinnon (1983) has presented yet another model for the formation of those enigmatic quartzofeldspathic, flysch-like rocks, which comprise most of the Southern Alps of New Zealand. His view that these rocks ("Torlesse Supergroup," as used by Suggate, 1978) were juxtaposed by transcurrent faulting against the coeval, volcaniclastic, Murihiku Supergroup represents a considerable advance over previous outrageous hypotheses, in which the Torlesse Supergroup was envisaged as part of a lost Pacifica continent (Nur and Ben-Avraham, 1977; Kamp, 1980) or part of an isolated oceanic island arc (Howell, 1980). In addition to the arguments advanced by MacKinnon (1983), the close similarity between Triassic megafossil plants of Murihiku and Torlesse Supergroups, eastern Australia, Antarctica, Chile, and Argentina (Retallack, 1977, 1981, 1983b) is evidence that all were part of the Gondwana supercontinent. MacKinnon's comparison of the Torlesse Supergroup with continental margin deposits south of the Chugach Mountains of Alaska is also supported by numerous sedimentological similarities between Middle Triassic fluvial conglomerates of the Torlesse Supergroup and gravels of the Alaskan coastal outwash plain (Retallack, 1979, 1983a). Although MacKinnon's model has much to recommend it, there are at least two main shortcomings.

First, there is no evidence for, and [illegible] reason to doubt the existence of, a Triassic marginal sea like the modern Bering Sea behind the volcanic arc that supplied the Murihiku Supergroup and associated volcaniclastic rocks (MacKinnon, 1983, Fig. 10). There may have been such a sea during Permian time. By the Triassic, however, the diversity of igneous and metamorphic pebbles and minerals in sediments of the Murihiku Supergroup, as well as granitic basement in places (Watters *in* Suggate, 1978), are indications that its source was much larger and more geologically varied than most oceanic island arcs. No fully marine Triassic fossils or rocks are known in eastern Australia south of Queensland or in western Antarctica, near where this part of New Zealand is presumed to have been attached during the Triassic. It is likely that the volcanic source of Triassic nonmarine rocks in the Transantarctic Mountains (Elliott, 1975; Barrett, 1981) and eastern Australia (Day and others, 1974; Retallack and others, 1977) was part of the same chain of volcanoes. In these regions, the volcanoes appear to have been on the continent, more like the present Cascade Range of the northwestern United States than the Aleutian Islands.

Second, there are also reasons to doubt MacKinnon's generalization that the Torlesse Supergroup was deposited and then shuffled laterally, always with younger rocks to the northeast. Such a view can be upheld only by ignoring or reinterpreting Permian limestones with fusulinids and corals in Northland. These are east of Cretaceous rocks customarily assigned to the Torlesse Supergroup (Hay *in* Suggate, 1978). The assignment of these rocks to "Maitai, Murihiku, Caples, and Brook Street terranes" as shown by MacKinnon (1983, Fig. 6) is an unconventional departure from past mapping which MacKinnon fails to explain. MacKinnon's view of age relations in the Torlesse Supergroup is partly based on the questionable assumption of a narrow stratigraphic range ("Lower Upper Triassic") for the fossil worm tube *Terebellina* (this is the correct name for *Torlessia* according to Begg and others, 1983). Only in one place has *Terebellina* been found associated with a shelly fauna (Begg and others, 1983). *Terebellina* and shelly fossils also occur together at another locality, but in separate parts of separate graded beds (Campbell and Pringle, 1982). The usual separate occurrence of *Terebellina* and shelly fossils, the siliceous composition of *Terebellina* tubes, and their association with trace fossils such as *Helminthoidea* and *Urohelminthoidea* are all indications that *Terebellina* lived in very deep water, probably below calcium carbonate compensation depth (Stevens *in* Suggate, 1978). In my opinion, *Terebellina* is an indicator of paleoenvironment, not geologic age. It could range throughout the Middle and Late Triassic. There is little reason to suspect that this enigmatic endemic fossil has biostratigraphic significance comparable to the cosmopolitan bivalves *Daonella, Halobia,* and *Monotis,* which are used to establish age elsewhere in the Torlesse Supergroup. As can be seen in MacKinnon's (1983) Figures 2 and 5, in the South Island of New Zealand, localities for these deep marine fossils are west, north, and northeast of shallow marine and terrestrial Middle Triassic deposits, which flank a large area of Permian and Carboniferous fossil localities. This distribution represents, at the very least, a deep invagination of the simple northeastward-younging arrangement proposed by MacKinnon. Considering sedimentological evidence for a mountainous source very close at hand to some of the Middle Triassic fossil plant localities (near Mount Potts and Otematata; Retallack, 1979, 1983a), the Permian and Carboniferous part of the Torlesse Supergroup appears to have been a landmass during Middle Triassic and perhaps also later times. Lateral shuffling of the Torlesse Supergroup according to MacKinnon's model may have entailed partial dislocation and rotation of this continental fragment. It may have been flanked on several sides by marine embayments, analogous to San Francisco Bay or the Gulf of California.

These, and other North American analogs offered here, have as many problems in detail as the Alaskan analog proposed by MacKinnon (1983). Both the modern northwestern American and early Mesozoic southeastern Gondwanan coasts included both fold ranges and chains of volcanoes for much of their early history. Both appear to have been modified substantially by transcurrent movement of fragments of continental crust. Nevertheless, the early Mesozoic coast of Gondwana is not exactly matched by any modern coast, and its detailed paleogeography remains to be established.

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REFERENCES CITED

Armstrong, R. L., 1978, Pre-Cenozoic Phanerozoic time scale—Computer file of critical dates and consequences of new and in-progress decay-constant revisions, *in* Cohee, G. V., Glaessner, M. F., and Hedberg, H. D., eds., Contributions to the geologic time scale: American Association of Petroleum Geologists Studies in Geology, No. 6, p. 73–91.

Baird, A. K., 1962, Superposed deformation in the central Sierra Nevada foothills east of the Mother Lode: University of California Publications in Geological Sciences, v. 42, p. 1–70.

Bateman, P. C. and Clark, L. D., 1974, Stratigraphic and structural setting of the Sierra Nevada batholith, California: Pacific Geology, v. 8, p. 79–89.

Bateman, P. C., and Wahrhaftig, C. W., 1966, Geology of the Sierra Nevada: California Division of Mines and Geology Bulletin 190, p. 105–172.

Bateman, P. C., Clark, L. D., Huber, N. K., Moore, J. G., and Rinehart, C. D., 1963, The Sierra Nevada batholith—A synthesis of recent work across the central part: U.S. Geological Survey Professional Paper 414D, p. D1–D46.

Best, M. G., 1963, Petrology and structural analysis of metamorphic rocks in the southwestern Sierra Nevada foothills: University of California Publications in Geological Sciences, v. 42, p. 111–157.

Bogen, N. L., 1979, Four sets of structures in the Upper Jurassic Mariposa Formation, Tuolumne County, California [abs.]: Geological Society of America Abstracts with Programs, v. 11, p. 70.

Bogen, N. L., Girty, G. H., Hanson, R. E., Merguerian, C., and Schweickert, R. A., 1980, Contrasting styles of deformation during the Nevadan orogeny, Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 12, p. 98.

Bond, G. C., and Schweickert, R. A., 1981, Significance of pre-Devonian melange in the Shoo Fly Complex, northern Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 13, p. 46.

Brook, C. A., 1977, Stratigraphy and structure of the Saddlebag Lake roof pendant, Sierra Nevada, California: Geological Society of America Bulletin, v. 88, p. 321–331.

Cady, W. M., 1969, Regional tectonic synthesis of northwestern New England and adjacent Quebec: Geological Society of America Memoir 120, 181 p.

Cebull, S. E., and Russell, L. R., 1979, Role of Melones fault zone in the structural chronology of the North Yuba River area, western Sierra Nevada, California: Geological Society of America Bulletin, Part I, v. 90, p. 225–227; Part II, v. 90, p. 528–544.

Chen, J., and Moore, J. C., 1979, Late Jurassic Independence dike swarm in eastern California: Geology, v. 3, p. 129–133.

Clark, L. D., 1964, Stratigraphy and structure of part of the western Sierra Nevada metamorphic belt, California: U.S. Geological Survey Professional Paper 410, 70 p.

——— 1976, Stratigraphy of the north half of the western Sierra Nevada metamorphic belt, California: U.S. Geological Survey Professional Paper 923, 26 p.

Creely, R. S., 1965, Geology of the Oroville quadrangle, California: California Division of Mines and Geology Bulletin 184, 86 p.

Curtis, G. H., Evernden, J. F., and Lipson, J. I., 1958, Age determinations of some granitic rocks in California by the potassium-argon method: California Division of Mines Special Report 54, 16 p.

Durrell, C., and d'Allura, J., 1977, Upper Paleozoic section in eastern Plumas and Sierra Counties, northern Sierra Nevada, California: Geological Society of America Bulletin, v. 88, p. 844–852.

Eric, J. H., Stromquist, A. A., and Swinney, C. M., 1955, Geology and mineral deposits of the Angels Camp and Sonora quadrangles, Calaveras and Tuolumne Counties, California: California Division of Mines and Geology Special Report 41, 55 p.

Evans, J. R., and Bowen, O. E., 1977, Geology of the southern Mother Lode, Tuolumne and Mariposa Counties, California: California Division of Mines and Geology Map Sheet 36, scale 1:24,000.

Evernden, J. F., and Kistler, R. W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Fiske, R. S., and Tobisch, O. T., 1978, Paleogeographic significance of volcanic rocks of the Ritter Range pendant, central Sierra Nevada, California, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western Unived States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 209–222.

Girty, G. H., Schweickert, R. A., and Hanson, R. E., 1980, Structural fabrics of the Shoo Fly Complex near Bowman Lake, northern Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 12, p. 107.

Harland, W. B., Cox, A. V., Llewellyn, P. G., Pickton, C.A.G., Smith, A. G., and Walters, R., 1982, A geologic time scale: Cambridge, England, Cambridge University Press, Earth Science Series, 131 p.

Harwood, D. S., 1981a, Late Paleozoic pyroclastic rocks in eastern Placer County, Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 13, p. 59.

——— 1981b, Geologic map of the Granite Chief Wilderness Study Area and adjacent parts of the Sierra Nevada, California: U.S. Geological Survey Miscellaneous Field Studies Map MF 1273-A, scale 1:62,500.

——— 1983, Stratigraphy of upper Paleozoic volcanic rocks and regional unconformities in the northern Sierra terrane, California: Geological Society of America Bulletin, v. 94, p. 413–422.

Hietanen, A., 1973, Geology of the Pulga and Bucks Lake quadrangles, Butte and Plumas Counties, California: U.S. Geological Survey Professional Paper 731, 66 p.

Hinds, N.E.A., 1934, The Jurassic age of the last granitoid intrusives in the Klamath Mountains and Sierra Nevada, California: American Journal of Science, v. 227, p. 182–192.

Huber, N. K., and Rinehart, C. D., 1965, Geologic map of the Devils Postpile quadrangle, Sierra Nevada, California: U.S. Geological Survey Geologic Quadrangle Map GQ-437, scale 1:62,500.

Imlay, R. W., 1961, Late Jurassic ammonites from the western Sierra Nevada, California: U.S. Geological Survey Professional Paper 374D, p. D1–D30.

Irwin, W. P., Jones, D. L., and Kaplan, T. A., 1978, Radiolarians from pre-Nevadan rocks of the Klamath Mountains, California and Oregon, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 303–310.

Keith, W. J., and Seitz, J. F., 1981, Geologic map of the Hoover Wilderness and adjacent study area, Mono and Tuolumne Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1101A, scale 1:62,500.

Kistler, R. W., 1966a, Structure and metamorphism in the Mono Craters quadrangle, Sierra Nevada, California: U.S. Geological Survey Bulletin 1221E, 53 p.

——— 1966b, Geologic map of the Mono Craters quadrangle, Mono and Tuolumne Counties, California: U.S. Geological Survey Geologic Quadrangle Map GQ-462, scale 1:62,500.

Kistler, R. W., and Swanson, S. E., 1981, Petrology and geochronology of metamorphosed volcanic rocks and a middle Cretaceous volcanic neck in the east-central Sierra Nevada, California: Journal of Geophysical Research, v. 86, p. 10489–10501.

Knopf, A., 1929, The Mother Lode system of California: U.S. Geological Survey Professional Paper 157, 88 p.

McMath, V. E., 1966, Geology of the Taylorsville area, northern Sierra Nevada, California: California Division of Mines and Geology Bulletin 190, p. 173–183.

Merguerian, C., 1981, Tectonic significance of the Calaveras–Shoo Fly thrust (CSFT), Tuolumne County, California [abs.]: Geological Society of America Abstracts with Programs, v. 13, p. 96.

——— 1982, The extension of the Calaveras–Shoo Fly thrust (CSFT) to the southern end of the Sierra Nevada metamorphic belt (SNMB), California [abs.]: Geological Society of America Abstracts with Programs, v. 14, p. 215.

Merguerian, C., and Schweickert, R. A., 1980, Superposed mylonitic deformation of the Shoo Fly Complex in Tuolumne County, California [abs.]: Geological Society of America Abstracts with Programs, v. 12, p. 120.

Moores, E. M., and Day, H. W., 1983, An overthrust model for Mesozoic Sierran tectonics [abs.]: Geological Society of America Abstracts with Programs, v. 15, p. 293.

Morgan, B. A., 1976, Geology of Chinese Camp and Moccasin quadrangles, Tuolumne County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-840, scale 1:24,000.

Nokleberg, W. J., 1981, Stratigraphy and structure of the Strawberry Mine roof pendant, central Sierra Nevada, California: U.S. Geological Survey Professional Paper 1154, 18 p.

Nokleberg, W. J., and Kistler, R. W., 1980, Paleozoic and Mesozoic deformations in the central Sierra Nevada, California: U.S. Geological Survey Professional Paper 1145, 24 p.

Ramsay, J. G., 1980, Shear zone geometry: A review: Journal of Structural Geology, v. 2, p. 83–99.

Ramsay, J. G., and Graham, R. H., 1970, Strain variation in shear belts: Canadian Journal of Earth Sciences, v. 7, p. 786–813.

Rinehart, C. C., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California, with a section on a gravity study of Long Valley by L. C. Pakiser: U.S. Geological Survey Professional Paper 385, 106 p.

Rinehart, D. D., Ross, D. C., and Huber, N. K., 1959, Paleozoic and Mesozoic fossils in a thick stratigraphic section in the eastern Sierra Nevada, California: Geological Society of America Bulletin, v. 70, p. 941–945.

Russell, S., and Nokleberg, W. J., 1977, Superimposition and timing of deformations in the Mount Morrison pendant and in the central Sierra Nevada, California: Geological Society of America Bulletin, v. 88, p. 335–345.

Saleeby, J., 1981, Ocean floor accretion and volcanoplutonic arc evolution of the Mesozoic Sierra Nevada, *in* Ernst, W. G., ed., The geotectonic development of California: Rubey Volume I: Englewood Cliffs, New Jersey, Prentice-Hall, p. 132–181.

Saleeby, J. B., 1982, Polygenetic ophiolite belt of the California Sierra Nevada: Geochronological and tectonostratigraphic development: Journal of Geophysical Research, v. 87, p. 1803–1824.

Saleeby, J. B., Goodin, S. E., Sharp, W. D., and Busby, C. J., 1978, Early Mesozoic paleotectonic-paleogeographic reconstruction of the southern Sierra Nevada region, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 311–336.

Schweickert, R. A., 1976, Shallow-level plutonic complexes in the eastern Sierra Nevada, California, and their tectonic implications: Geological Society of America Special Paper 176, 58 p.

——— 1978, Triassic and Jurassic paleogeography of the Sierra Nevada and adjacent regions, California and western Nevada, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 361–384.

——— 1979, Structural sequence of the Calaveras Complex between the Stanislaus and Tuolumne Rivers [abs.]: Geological Society of America Abstracts with Programs, v. 11, p. 127.

——— 1981, Tectonic evolution of the Sierra Nevada Range, *in* Ernst, W. G., ed., The geotectonic development of California: A symposium in honor of W. W. Rubey: Englewood Cliffs, New Jersey, Prentice-Hall, p. 87–131.

Schweickert, R. A., and Bogen, N. L., 1983, Tectonic transect of Sierran Paleozoic through Jurassic accreted belts: Society of Economic Paleontologists and Mineralogists, Pacific Section, 22 p.

Schweickert, R. A., and Cowan, D. S., 1975, Early Mesozoic tectonic evolution of the western Sierra Nevada, California: Geological Society of America Bulletin, v. 86, p. 1329–1336.

Schweickert, R. A., and Hanson, R. E., 1982, Geologic transect of the northern Sierra Nevada along the north fork of the Yuba River: Peninsula Geological Society Second Annual Field Trip, 18 p.

Schweickert, R. A., Armstrong, R. L., and Harakal, J. E., 1980, Lawsonite blueschist in the northern Sierra Nevada, California: Geology, v. 8, p. 27–31.

Sharp, W. D., 1980, Ophiolite accretion in the northern Sierra [abs.]: American Geophysical Union Transactions, v. 61, p. 1122.

Sharp, W. D., and Saleeby, J., 1979, The Calaveras Formation and syntectonic mid-Jurassic plutons between the Stanislaus and Tuolumne Rivers, California [abs.]: Geological Society of America Abstracts with Programs, v. 11, p. 127.

Speed, R. C., and Moores, E. M., 1981, Geologic cross-section of the Sierra Nevada and the Great Basin along 40°N lat., northeastern California and northern Nevada: Geological Society of America Map and Chart Series, no. MC-28L.

Steiger, R. H., and Jager, E., 1978, Subcommission on geochronology: Convention in the use of decay constants in geochronology and cosmochronology, *in* Cohee, G. V., Glaessner, M. F., and Hedberg, H., eds., Contributions to the geologic time scale: American Association of Petroleum Geologists. Studies in Geology No. 6, p. 67–71.

Stern, T. W., Bateman, P. C., Morgan, B. A., Newell, M. F., and Peck, D. L., 1981, Isotopic U-Pb ages of zircon from the granitoids of the central Sierra Nevada, California: U.S. Geological Survey Professional Paper 1185, 17 p.

Strand, R. G., and Koenig, J. B., 1965, Sacramento sheet, Geologic map of California: California Division of Mines and Geology, scale 1:250,000.

Taliaferro, N. L., 1942, Geologic history and correlation of the Jurassic of southwestern Oregon and California: Geological Society of America Bulletin, v. 53, p. 71–112.

Tobisch, O. T., and Fiske, R. S., 1976, Significance of conjugate folds and crenulations in the central Sierra Nevada, California: Geological Society of America Bulletin, v. 87, p. 1411–1420.

——— 1982, Repeated parallel deformation in part of the eastern Sierra Nevada, California and its implications in the dating of structural events: Journal of Structural Geology, v. 4, p. 177–195.

Tobisch, O. T., Fiske, R. S., Sacks, S., and Taniguchi, D., 1977, Strain in metamorphosed volcaniclastic rocks and its bearing on the evolution of orogenic belts: Geological Society of America Bulletin, v. 88, p. 23–40.

Tuminas, C. A., 1980, Structural relations in the eastern part of the Smartville ophiolite block, northern Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 12, p. 156.

Van Hinte, J., 1976, A Jurassic time scale: American Association of Petroleum Geologists Bulletin, v. 60, p. 489–497.

Varga, R. J., 1980, Structural and tectonic evolution of the early Paleozoic Shoo Fly Formation, northern Sierra Nevada range, California [Ph.D. thesis]: Davis, California, University of California, 248 p.

Varga, R. J., and Moores, E. M., 1981, Age, origin, and regional significance of an unconformity that predates island-arc volcanism in the northern Sierra Nevada: Geology, v. 9, p. 512–518.

Xenophontos, C., and Bond, G. C., 1978, Petrology, sedimentation, and paleogeography of the Smartville ophiolite, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 291–302.

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REFERENCES CITED

Barrett, P. J., 1981, History of the Ross Sea region during deposition of the Beacon Supergroup 400–180 million years ago: Royal Society of New Zealand Journal, v. 11, p. 447–458.

Begg, J. G., Cave, M., and Campbell, J. D., 1983, *Terebellina mackayi* Bather in Oretian Murihiku rocks, Wairaki Hills, Southland: New Zealand Journal of Geology and Geophysics, v. 26, p. 121–122.

Campbell, J. D., and Pringle, I. J., 1982, An association of *Torlessia* and late Middle-early Upper Triassic fossils as at Pudding Hill Stream, central Canterbury: Royal Society of New Zealand Journal, v. 12, p. 5–10.

Day, R. W., Cranfield, L. C., and Schwarzböck, H., 1974, Stratigraphic and structural setting of Mesozoic basins in southeastern Queensland and northeastern New South Wales, *in* Denmead, A. K., Tweedale, G. W., and Wilson, A. F., eds., The Tasman geosyncline: Brisbane, Queensland Division of the Geological Society of Australia, p. 320–363.

Elliott, D. H., 1975, Gondwana Basins of Antarctica, *in* Campbell, K.S.W., ed., Gondwana geology: Canberra, Australian University Press, p. 493–536.

Kamp, P.J.J., 1980, Pacifica and New Zealand; proposed eastern elements in Gondwanaland's history: Nature, v. 288, p. 659–664.

Howell, D. G., 1980, Mesozoic accretion of exotic terranes along the New Zealand segment of Gondwanaland: Geology, v. 8, p. 487–491.

MacKinnon, T. C., 1983, Origin of the Torlesse terrane and coeval rocks, South Island, New Zealand: Geological Society of America Bulletin, v. 94, p. 967–985.

Nur, A., and Ben-Avraham, Z., 1977, Lost Pacifica continent: Nature, v. 270, p. 41–43.

Retallack, G. J., 1977, A biostratigraphy for terrestrial Triassic rocks of Gondwanaland [Ph.D. dissert.]: Armidale, Australia, University of New England, 371 p.

——— 1979, Middle Triassic coastal outwash deposits and plain deposits in Tank Gully, New Zealand: Royal Society of New Zealand Journal, v. 10, p. 31–63.

——— 1981, Middle Triassic megafossil plants from Long Gully, near Otematata, north Otago, New Zealand: Royal Society of New Zealand Journal, v. 11, p. 167–200.

——— 1983a, Middle Triassic estuarine deposits near Benmore Dam, southern Canterbury and northern Otago, New Zealand: Royal Society of New Zealand Journal, v. 13 (in press).

——— 1983b, Middle Triassic megafossil marine algae and land plants from near Benmore Dam, southern Canterbury: Royal Society of New Zealand Journal, v. 13 (in press).

Retallack, G. J., Gould, R. E., and Runnegar, B., 1977, Isotopic dating of a Middle Triassic megafossil flora from near Nymboida, north-northeastern New South Wales: Linnaean Society of New South Wales, Proceedings, v. 101, p. 77–113.

Suggate, R. P., ed., 1978, The geology of New Zealand, Volume 1: Wellington, New Zealand, Government Printer, 343 p.

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Reply

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The points brought forth by Retallack are critical to my interpretations (MacKinnon, 1983). I therefore welcome this opportunity to respond.

Retallack argues that there is no reason to believe that a marginal sea existed behind the Brook Street terrane volcanic arc; he further argues that this arc was probably part of a continental margin. In contrast, I contend that there is convincing evidence that the Brook Street terrane was an *island* arc, and, therefore, there must have been a marginal sea or some large body of water behind it. I give the following evidence to support this (see also MacKinnon, 1983, p. 980, paragraph 4):

1. Large areas of the Brook Street terrane are dominated by fragmented material deposited by turbidites and associated depositional mechanisms (Houghton, 1981; Williams, 1978). Marine fossils are present in some areas, and pillow lavas are common. The evidence clearly shows that most Brook Street terrane sedimentary and flow rocks were deposited in a marine environment.

2. There are no older continental-type rocks as roof pendants or country rock within the Brook Street terrane. These would be expected in a continental arc.

3. Sandstone composition of Maitai, Murihiku, and Caples rocks, thought to have been derived from the Brook Street terrane by most workers, strongly indicates an island-arc source. Percentage of QFL quartz (Q) is consistently $<20\%$, and the ratio of volcanic lithics to total lithics (Lv/L) is $\geqq 0.90$. In contrast, sandstones derived from continental volcanic arcs generally have a more varied source, are more quartzose, and have a much higher percentage of nonvolcanic rock fragments. For example, marine sands derived from the modern Cascade Range, which Retallack suggests as a possible analog, have %Q values ranging from 20% to 50% (Kulm and Fowler, 1974). Further comparisons between sandstones derived from island-arc versus continental-arc sources are given by numerous authors (for example, Dickinson and Suczek, 1979).

Retallack argues that the rock suite in the Murihiku terrane is too diverse to have been derived from an island-arc source. To support this, Retallack cites the presence of granitic rocks in the New Zealand terranes. However, granitic rocks are present in many modern island arcs and are present in the Brook Street terrane (Challis and Lauder, 1977).

The closest modern analog for the Brook Street terrane that I am aware of is the Aleutian arc. Rock types and their relative proportions, including the strong dominance of fragmental material, are very similar in both the Brook Street terrane (MacKinnon, 1980, 1983; Challis and Lauder, 1977; Houghton, 1981; Williams, 1978) and the Aleutian arc (Marlow and others, 1973; Gates and others, 1971).

Retallack objects to part of my northward-younging model because he contends that in Northland, Cretaceous rocks "customarily assigned to the Torlesse Supergroup" lie west of Permian Torlesse rocks. The Cretaceous rocks to which he refers were at one time lumped with Torlesse rocks to the east. However, most current workers now view these rocks as part of the volcanogenic suite because they contain predominantly volcanogenic rather than quartzofeldspathic sandstones (Sporli, 1978, his Waipapa terrane).

Retallack also questions my view that the Torlessia zone was deposited sometime between the Middle Triassic *Daonella* zone and the Upper Triassic *Monotis* zone. I emphasized that this view is not based on biostratigraphic grounds. Rather, I cited evidence of geographic distribution, fossil association, and sandstone compositional differences between the various zones to support my contention (MacKinnon, 1983, p. 969, paragraphs 10 and 11).

Retallack contends that Torlessia-Tithia (*Terebellina*) are paleoenvironmental indicators rather than age indicators, implying that they may represent an age-equivalent facies of another fossil zone. However, I pointed out that almost all of the Torlesse, including the Torlessia zone, was deposited in a deep-marine environment and that, in general, there are no consistent lithofacies differences between the various fossil zones.

The exceptions to this are the rare and isolated shallow-marine and terrestrial localities in the Torlesse. Most of these are of Middle Triassic age, and one might argue that the deep-marine Torlessia zone and the shallow marine-terrestrial Middle Triassic deposits are facies of the same age. I would argue against this, however, because the composition of Torlessia zone and Middle Triassic sandstones are distinctly different (MacKinnon, 1983). These differences cannot be explained by simple maturing of one from the other by paleoenvironmental control of sandstone composition. Instead, they must have come from sources with different compositions. The most likely conclusion, taking into account regional relationships, is that they were derived at different times from an evolving source terrane.

REFERENCES CITED

Challis, G. A., and Lauder, W. R., 1977, Geology of Longwood Range: New Zealand Geological Survey Miscellaneous Series Map 11, scale 1:50,000, Map (1 sheet) and notes (28 p.); New Zealand Department of Science and Industrial Research.

Dickinson, W. R., and Suczek, C. A., 1979, Plate tectonics and sandstone composition: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164–2182.

Houghton, B. F., 1981, Lithostratigraphy of the Takitimu group, central Takitimu Mountains, western Southland: New Zealand Journal of Geology and Geophysics, v. 24, p. 333–348.

Gates, O., Powers, H. A., and Wilcox, R. E., 1971, Geology of the Near Islands, Alaska, with a section on superficial geology by J. P. Schafer: U.S. Geological Survey Bulletin 1028-U, p. 709–822.

Kulm, L. D., and Fowler, G. A., 1974, Cenozoic sedimentary framework of the Gorda-Juan de Fuca plate and adjacent continental margin—A review, *in* Dott, R. H., and Shaver, R. H., eds., Modern and ancient geosynclinal sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 19, p. 212–229.

MacKinnon, T. C., 1980, Sedimentologic, petrographic, and tectonic aspects of Torlesse and related rocks, South Island, New Zealand [Ph.D. thesis]: Dunedin, New Zealand, University of Otago, 294 p.

——— 1983, Origin of the Torlesse terrane and coeval rocks, South Island, New Zealand: Geological Society of America Bulletin, v. 94, p. 967–985.

Marlow, M. S., Scholl, D. W., Buffington, W. C., and Alpha, T. R., 1973, Tectonic history of the central Aleutian arc: Geological Society of America Bulletin, v. 84, p. 1555–1574.

Sporli, K. B., 1978, Mesozoic tectonics, North Island, New Zealand: Geological Society of America Bulletin, v. 89, p. 415–425.

Williams, J. G., 1978, Eglinton Volcanics—Stratigraphy, petrography, and metamorphism: New Zealand Journal of Geology and Geophysics, v. 21, p. 713–732.

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Eocene biostratigraphy of South Carolina and its relationship to Gulf Coastal Plain zonations and global changes of coastal onlap: Discussion and reply

Discussion

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I am distressed in regard to a number of points raised in the article by Powell and Baum (1982), largely because of extensive investigations in much of the region which is discussed. Rather than discussing the text in detail, I shall follow the proverb that a picture is worth a thousand words, and examine specifically Figure 1. I find the data presented in Figure 1 largely long out of date, compared to more recent investigations, and the interpretation in Figure 1 seriously deficient in structure, tectonic framework, lithostratigraphy, and biostratigraphy.

With respect to structure, two faults are presented—the "Santee" and the "Dorchester" with upthrown and downthrown blocks indicated. I question the validity of these structures, because I find no evidence on any subsurface correlations or surface outcroppings to indicate their presence. I gather from lack of displacement on the figure that they are either vertical (beds and fault plane) or have not been active since at least the middle Eocene, but I also note that all contacts are approximate. I suggest that putting in faults following theory but not observed fact is a rather dangerous game with respect to detailed knowledge of the Atlantic Coastal Plain.

With respect to tectonic framework, Figure 1 follows the old (1936) Coastal Plain interpretation of Wythe Cooke's Cooper and Hawthorne Formations in a "bull's-eye" interpretation of lithostratigraphic "biostratigraphic" units swinging from northwest toward southwest and generally centered in Charleston County. In actual fact, however, other work (Colquhoun and Johnson, 1968, Fig. 5) indicates a subcrop line for the Paleocene-Cretaceous contact and most of the other regional erosional unconformities present through the Oligocene, extending toward the northwest, from the Atlantic Ocean toward the Fall Line.

With regard to lithostratigraphy, I question the existence of an upper Eocene "Cross Formation" consisting of biosparrudite and biomicrudite extending west from the limestone quarries near Harleyville in the center of the area shown in Figure 1. In actual fact, both Pooser's early (1965) data as shown plus 20 or 30 holes drilled since then indicate that the unit TCR as generally mapped is in fact a marl and occasionally a siltstone (noncalcareous). Previous investigators (Ward and others, 1979) have called this unit the "Cooper Formation," feeling *that* to be a more appropriate designation than "Cooper Marl" which I employed in detailed studies throughout the Eutawville-Harleyville area (Colquhoun and Duncan, 1966). Ward and others divided the Cooper Formation into two members: the Harleyville and Parker's Ferry, and they assigned a late Eocene age. These members of the Cooper Formation are overlain by the Oligocene Ashley member to the south. I also question the lithology of the Caw Caw Member as a molluscan mold mudstone diatomite in western Orangeburg and Calhoun Counties. *That* lithology comprises less than 1% of the outcrop near Caw Caw Branch, which is largely a fine- to medium-grained, well- to moderately well-sorted sand and is underlain by several tens of feet of similar sediment in adjacent auger holes (No. 38-23 Pooser, 1965, Orangeburg No. 92, and others).

With regard to biostratigraphy, it is quite obvious that Pooser (1965) distinguished only middle Eocene from Oligocene ostracods. Indeed, he

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