Comment on "A Model for Bonanza Gold Deposits"
By S.B. Romberger
Geoscience Canada, v. 19, p. 63-72.

J. Tuzo Wilson, Professor Emeritus
Department of Physics, University of Toronto
Toronto, Ontario M5S 1A7

SUMMARY

Romberger's (1992) paper suggests that deposition of 500 tonnes of gold in six unusually rich Nevada deposits was due to normal ore-bearing solutions flowing at a more rapid rate and for a longer period of time than usual through well-developed channels perpetuated by continual brecciation.

It is now understood that plate tectonics requires that 15 million years ago the Yellowstone mantle plume should have formed and begun to migrate eastward relative to the North American plate at a rate of approximately 35 km per million years. This paper proposes that the passage of the plume past the deposits coincided with the time of ore deposition, indicating that the plume was a factor in forming the ore bodies. It mentions some other reasons why plumes should be taken into account in economic geology.

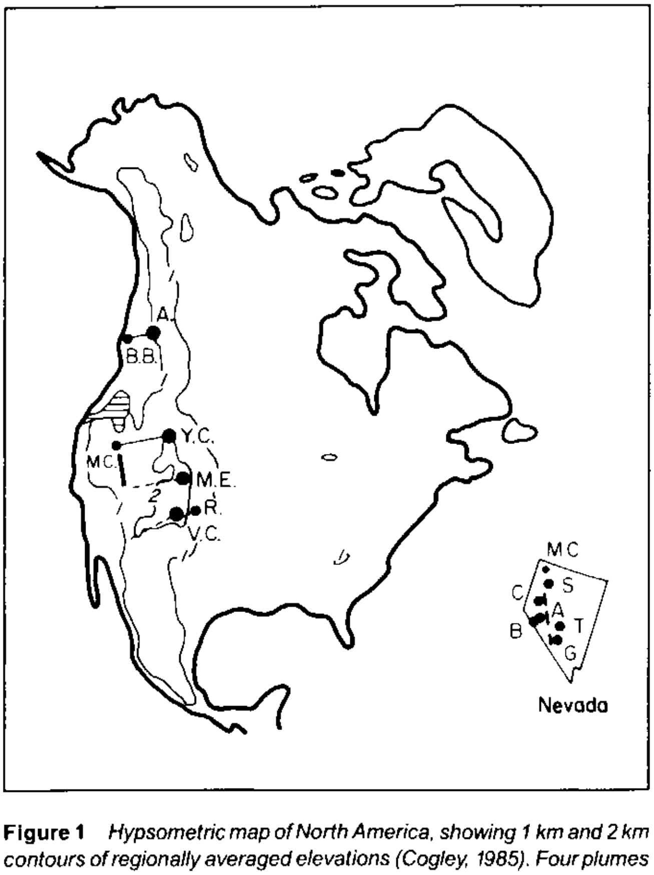

Figure 1 *Hypsometric map of North America, showing 1 km and 2 km contours of regionally averaged elevations (Cogley, 1985). Four plumes have been added: Anahim (A), Yellowstone caldera (Y.C.), Basalt peak near Mount Elbert (M.E.), and Valles caldera (V.C.) or Raton (R). So have their tracks, two of which begin at Bella Bella, (B.B.) and McDermitt caldera (M.C.). The Columbia River basalts are shaded and a line marks the location of the Nevada bonanza deposits which are shown in greater detail on the insert where the initial letters mark the McDermitt caldera and deposits at Sleeper, Comstock, Aurora, Bodie, Tonopah and Goldfield.*

INTRODUCTION:
COINCIDENCES BETWEEN FOUR EVENTS

This comment first draws attention to the close proximity in time and place of four events which created features all shown on Figure 1. All the events occurred between 17-14 Ma, all meet at McDermitt caldera, Nevada, and all required great energy.

The oldest event was that, between 17 and 16 Ma, many feeder dykes spread northwesterly from near the McDermitt caldera and fed the Columbia River flood basalts of Oregon and Washington (Hooper, 1982; Hooper, 1984).

The second event was the emplacement to the south of the caldera of six bonanza deposits. Romberger (1992) related them to the caldera, stating that the upper sequence of host rocks at Sleeper (the northernmost deposit) "consists of peralkaline rhyolite ash flow tuffs . . . erupted from the McDermitt caldera system, 55 km to the north, between 15 and 16 Ma". The average age of the host rocks at all six deposits is 14.5 Ma and the average age of deposition was 14 Ma. A similar close relationship exists in location, because if a median line be drawn through the deposits, it will be parallel to many fractures, and its extension will pass through or close to the caldera (see insert on Fig. 1).

The third event is that the main eruption of the caldera occurred 14.5 Ma, at the time of the deposition of the bonanza ores.

The fourth event was that the eruption of McDermitt caldera initiated the Yellowstone track and was the first of a sequence of rhyolitic calderas, partly concealed by basalts, which cross Idaho to Yellowstone (Anders and Sleep, 1992; Armstrong *et al.*, 1975; Blackwell, 1989; Smith *et al.*, 1989; Westaway, 1989).

A POSSIBLE EXPLANATION OF THESE EVENTS

These events are too important to be ignored. The Columbia River basalts are among a dozen of the world's greatest flood basalts (White and McKenzie, 1989). The eruption which formed the caldera at Yellowstone 2.0 Ma ago ejected an estimated 2500 km^3 of rhyolitic ash, approximately 1000 times the volume of ash erupted by Mount St. Helen's in 1980 (Smith *et al.*, 1989). Some of that ash is preserved on the Cypress Hills, Saskatchewan (Vrecken and Westgate, 1992). The Yellowstone caldera, although quiescent is, nevertheless, one of three principal sources of heat flow in the 48 coterminous states (Blackwell, 1989; Sass and Morgan, 1988). The McDermitt caldera appears comparable to it. The Geological Survey of Canada mapped Anahim, one of the four plumes illustrated in Figure 1 (Souther, 1986).

One can thus suggest that, as the McDermitt plume rose from the depths to initiate the Yellowstone track, it first made its presence known by melting rocks of the upper mantle to form basalts which poured out as the Columbia River basalts. The plume first erupted at McDermitt caldera north of a favourable zone in Nevada, which it flooded with superheated aqueous solutions. Relative to the migrating North America plate the plume appeared to move eastward, creating the Yellowstone track (Suppe *et al.*, 1975). The numerous earthquakes associated with any migrating plume kept fractures open (Anders and Sleep, 1992) which enabled solutions to flow freely. After the plume had passed, the earthquakes largely ceased, and the deposition of silica blocked many channels, which reduced the grade and rate of formation of ore.

Anyone who objects to relating such different events should recall that Sleep (1990) recorded equally diverse rock types along the plume track through Montreal and New England. It formed rocks related to kimberlites north of Montreal (Reed and Sinclair, 1991), nephelinites in the Monteregian Hills, alkali granites in New England, and basalts in the Atlantic ocean basin, but, unlike many plume tracks, it did not generate any mushroom-shaped plume head (White and McKenzie, 1989; Richards *et al.*, 1991).

It is surprising that a seismic investigation could not follow the plume beneath Yellowstone to a depth greater than 300 km (Iyer *et al.*, 1981). That raises a serious question about the existence of a plume of basalt extending to greater depths. Surely so large a body should have been detectable.

One speculative explanation is that at greater depths than 300 km the jets are rising as superheated weak aqueous solutions through columns which they create by fracturing the mantle. Below 300 km, such a system would be difficult to detect. Above 300 km, the heat could melt and transport the local rocks, producing kimberlites and related rocks and perhaps transporting small diamonds. The succession of rocks along a horizontal track should be related to those at progressively greater depths. The melting of the upper mantle and ocean floor would produce basalts. The melting of continental crust could yield nephelinites, granites and rhyolites. Caps of basalt could accumulate beneath the lithosphere wherever it had not been broken.

SOME EXTENSION OF THOSE IDEAS

About 60 plumes are now known. They are scattered as islands about every ocean or indicated by tracks on every continent (Crough and Jurdy, 1980; Morgan, 1983; Duncan and Richards, 1991; Eguchi *et al.*, 1979; Smith and Drewry, 1984; Gliko *et al.*, 1985). Although they vary widely, enough general studies have been made to show that plumes are moving about below the shallow depths of a few tens of km, which is all that geologists have been in the habit of considering, and that they have influenced the overlying rocks (Wilson, 1990a,b).

E.D. Mayo (1958) pointed out that in the southwestern United States some, but not all, large fractures and faults have provided sites for ore deposits. Two factors may be important in forming ore bodies. First, a fracture should have been open for a long time and second, it should at some time have been in close proximity to a plume. The Jemez lineament has been particularly important because it lies over a major contact in the basement (Thomas *et al.*, 1988) and attracted the Valles and Raton hotspots to form their track along it (Fig. 1). Because it was open, aqueous solutions may have moved freely along it, so that they did not follow a regular pattern of aging (Aldrich and Laughlin, 1984).

In Canada ore bodies lie along steeply dipping faults at Noranda, Kirkland Lake, Thompson Nickle belt, and at Pine Point and Yellowknife, but many other similar faults are barren. Do plumes mobilize ore-bearing solutions? Have no plumes ever reached the barren faults?

NEED TO SUPPORT CANADIAN INVESTIGATIONS

Many Canadians have studied plumes, including Cogley (1985) who has shown the precise match between the location of plumes and the regions of highest elevations (Fig. 1). That demonstrates that since plate tectonics demands that most plumes must migrate, so must those mountains which they uplifted.

The idea of moving mountains is unconventional, but evidence for it is clear, and many problems in tectonics cannot be solved until it is accepted. Halls and Fahrig (1987) have shown that swarms of hundreds of dikes stretch for hundreds of km across continents, demanding extensive deep fluid sources to feed them. Gough (1984, 1986 and 1989) has mapped the location of some of these on several continents. Farrar and Dixon (1984), Souther (1986), Thomas *et al.* (1988) and Mareschal (1987, 1989) are other Canadians who have contributed to this neglected, but promising basic research in geology.

REFERENCES

Aldrich, M.J., Jr. and Laughlin, A.W., 1984, A model for the tectonic development of the southeastern Colorado Plateau boundary: Journal of Geophysical Research, v. 89, p. 10, 207-10, 218.

Anders,M.H. and Sleep, N.H., 1992, Magmatism and Extension: the thermal and mechanical effects of the Yellowstone hotspot: Journal of Geophysical Research, v. 97, p. 15, 379-15, 393.

Armstrong, R.L., Leeman, W.P. and Malde, H.E., 1975, K-Ar dating, quaternary and Neogene volcanic rocks of the Snake River plain, Idaho: American Journal of Science, v. 275, p. 225-251.

Blackwell, D.D., 1989, Regional implications of heat flow of the Snake River Plain, northeastern United States: Tectonophysics, v. 164, p. 323-343.

Cogley, J.G., 1985, Hypsometry of the continents: Zeitschrift fur Geomorphologie, Supplementband 53, 48 p.

Crough, S.T. and Jurdy, D.M., 1980, Subducted lithosphere, hotspots, and the geoid: Earth and Planetary Science Letters, v. 48, p. 15-22.

Davies, G.F., 1992, Plates and plumes: dynamos of the Earth's mantle: Nature, v. 257, p. 493-494.

Duncan, R.A. and Richards, M.A., 1991, Hotspots, mantle plumes, flood basalts, and true polar wander: Reviews of Geophysics, v. 29, p. 31-50.

Eguchi, T., Uyeda, S. and Maki, T., 1979, Seismotectonics and tectonic history of the Andaman Sea: Tectonophysics, v. 57, p. 35-50.

Farrar, E. and Dixon, J.M., 1984, Overriding of the Indian-Antarctic ridge: origin of Emerald Basin and migration of late Cenozoic volcanism in southern New Zealand and Campbell Plateau: Tectonophysics, v. 104, p. 243-256.

Gliko, A.O., Grachev, A.F. and Magnitski, V.A., 1985, Thermal model for lithospheric thinning and associated uplift in the Neotectonic phase of intraplate orogenic activity and continental drifts: Journal of Geodynamics, v. 3, p. 137-193.

Gough, D.I., 1984, Mantle upflow under North America and plate tectonics: Nature, v. 311, p. 428-432.

Gough, D.I., 1986, Mantle upflow tectonics in the Canadian Cordillera: Journal of Geophysical Research, v. 91, p. 1909-1919.

Gough, D.I., 1989, Magnetometer array studies, earth structure and tectonic processes: Reviews of Geophysics, v. 27, p. 141-157.

Halls, H.C. and Fahrig, W.F., eds., 1987, Mafic dyke swarms: Geological Association of Canada, Special Paper 34.

Hooper, P.R., 1982, The Columbia River basalts: Science, v. 215, p. 1463-1468.

Hooper, P.R., 1984, Physical and chemical constraints on the evolution of the Columbia River basalt: Geology, v. 12, p. 495-499.

Iyer, H.M., Evans, J.R., Zandt, G., Stewart, R.M., Coakley, J.M. and Roloff, J.N., 1981, A deep low-velocity body under the Yellowstone caldera, Wyoming: delineation using teleseismic P-wave residuals and tectonic interpretation: Geological Society of America Bulletin, v. 92, p. 792-798.

Mareschal, C.-J., 1987, Plate tectonics: scientific revolution or scientific program: Eos, Transactions of the American Geophysical Union, v. 68, p. 529-544.

Mareschal, J.-C., Hamdani, Y. and Jessup, D.M., 1989, Downward continuation of heat flow data: Tectonophysics, v. 164, p. 129-137.

Mayo, E.B., 1958, Lineament tectonics and some ore districts of the southwest: Mining Transactions of the American Institute of Mining Engineering, v. 210, p. 1169-1175.

Morgan, W.J., 1983, Hotspot tracks and early rifting of the Atlantic: Tectonophysics, v. 94, p. 123-138.

Reed, L.E. and Sinclair, I.G.L., 1991, The search for kimberlite in the James Bay lowlands of Ontario: Canadian Institute of Mining Bulletin, v. 84, p. 132-139.

Richards, M.A., Jones, A.L., Duncan, R.A. and DePaolo, D.J., 1991, A mantle plume initiation model for the Wrangelia flood basalt and other oceanic plateaus: Science, v. 254, p. 263-267.

Romberger, S.B., 1992, A model for bonanza gold deposits: Geoscience Canada, v. 19, p. 63-72.

Sass, J.H. and Morgan, P., 1988, Conductive heat flux in VC-1 and the thermal region of Valles Caldera, Jemez Mountains, New Mexico: Journal of Geophysical Research, v. 93, p. 6027-6039.

Sleep, N.H., 1990, Monteregian hotspot track: a long-lived mantle plume: Journal of Geophysical Research, v. 95, p. 21, 983-21, 990.

Smith, A.G. and Drewry, D.J., 1984, Delayed phase change due to hot asthenosphere causes Transantarctic uplift? Nature, v. 309, p. 536-568.

Smith, R.B., Reilinger, R.E., Meertens, C.M., Hollis, J.R., Holdahl, S.R., Dzurisin, D., Gross, W.K. and Klingale, E.E., 1989, What's moving at Yellowstone? Eos, Transactions of the American Geophysical Union, v. 70, p. 113, 119, 123-125.

Souther, J.G., 1986, The western Anahim belt: Canadian Journal of Earth Sciences, v. 23, p. 895-908.

Suppe, J., Powell, C. and Berry, R., 1975, Regional topography, seismicity of Quarternary volcanism and the present-day tectonics of the western United States: American Journal of Science, v. 245A, p. 397-436.

Thomas, M.D., Grieve, R.A.F. and Sharpton, V.L., 1988, Gravity domains and the assembly of the North American continent by collision tectonics: Nature, v. 331, p. 333-334.

Vrecken, W.J. and Westgate, J.A., 1992, Miocene tephra beds in the Cypress Hills of Saskatchewan, Canada: Canadian Journal of Earth Sciences, v. 29, p. 48.

Westaway, R., 1989, Northeast Basin and Range province active tectonics: an alternative view: Geology, v. 17, p. 779-783.

White, R. and McKenzie, D., 1989, Magnatism at rift zones: the generation of volcanic margins and flood basalts: Journal of Geophysical Research, v. 94, p. 7685-7729.

Wilson, J.T., 1990a, On the building and classification of mountains: Journal of Geophysical Research, v. 95, p. 6611-6628.

Wilson, J.T., 1990b, Continental drift and a theory of convection: Terra Nova, v. 2, p. 519-538.

Editor's Note:

As many of our readers will know, Dr. Wilson died suddenly in Toronto in early April at the age of 84. His contributions to the earth sciences, both as a researcher and as one who made science available and intelligible to the public, continued until his death. The preceding short paper was prompted by S.B. Romberger's paper on bonanza gold deposits, and presents some of Dr. Wilson's ideas on relations between mantle plumes and tectonics, which he believed will revolutionize the earth sciences. The same ideas formed the core of an invited address to a joint CIM-PDA luncheon at the 1993 annual meeting of the Prospectors and Developers Association of Canada. Not just geology, but all science in Canada has lost an imaginative and forceful mind with his passing.