JADE: OCCURRENCE AND METASOMATIC ORIGIN

[1]HARLOW, G. E. and [2]SORENSEN, S. S. [1]American Museum of Natural History, New York, NY, U.S.A.; [2]Smithsonian Institution, Washington, DC, U.S.A.

The term jade, as used in geology and gemology, refers to two extremely tough, essentially monomineralic rocks used for carvings and gems. Amphibole jade is nephrite, a tremolite-actinolite [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$] rock with a felted, microcrystalline habit, and pyroxene jade is jadeite [$NaAlSi_2O_6$] rock (jadeitite) which varies from micro- to macrocrystalline textures. Both rock types have received relatively little attention due to their scarcity, minor economic importance, and cryptic petrography. The geological interpretation of both jade types has been hindered by poor exposure and the occurrence of major jadeitite deposits in politically unstable countries. However, recent investigations show not only that the jades share some common geological characteristics, but both result from and record important Earth processes.

Nephrite is the more common and less valuable of the two jade types. Important deposits occur at the Polar, Kutcho, and Ogden Mtn. properties in northern British Columbia, Canada (Gabrielse, 1990); along the Yurungkash and Karakash (White Jade and Black Jade) Rivers, Kunlun Mtns., Xinjiang, China (see Webster, 1975); SW of Lake Baikal in the East Sayan Mtns., Siberia, Russia (Prokhor, 1991); the Barguzin-Vitim Massif, Central Vitim Highland (East of Lake Baikal), Siberia, Russia (Sekerin et al., 1997); near Cowell, South Australia (Flint and Dubowski, 1990); the Westland (Arahura River– Cooper, 1995), the Livingstone, Nelson, Otago, and South Westland fields on South Island, New Zealand (Beck, 1984 & 1991); northeastern Taiwan (Wand,. 1987); Jordansmuhl, Poland (Visser, 1946); in the Granite Mtns., Lander Co., Wyoming (Madson, 1978); and along the Noatak & Kobuk Rivers south of the Brooks Range in Alaska (Loney and Himmelberg, 1985). Many minor occurrences are associated with small ultramafics in ophiolite belts around the world, such as in the Western and Central Alps, central Brazil, and the ophiolite belts from California to Alaska.

Nephrite ranges from pure, white tremolite ("mutton-fat jade") to dark green actinolite and occasionally black from Fe-actinolite or oxide / graphite pigment. Rarely nephrite can have an emerald-green color from Cr^{3+} in sodic-tremolite/actinolite. Staining to ochre colors from iron oxidation in weathering rinds of boulders is common. Minor coexisting minerals include diopside, calcic garnet, magnetite, chromite, graphite, apatite, rutile, pyrite, datolite, vesuvianite, prehnite, talc, serpentine polymorphs and titanite. Nephrite bodies result from contact and/or infiltration metasomatism of either dolomite by magmatic fluids or silicic rocks by serpentinite fluids. White nephrite is derived from siliceous metasomatism of dolomite by a "granitic" body or its pneumatolytic / hydrothermal apophyses (e.g., Yurung-kash [White Jade River], Kunlun Mtns.). However, dolomite metasomatism can yield green to black jade if a source of iron is present, such as from mafic bodies, iron-stone (e.g., Cowell and presumably Karakash, too). Other nephrites involve either metasomatism of silicic rocks in serpentinite (or serpentinite melange) by Ca-Mg-rich fluids or a boundary reaction/infiltration metasomatism of silicic rocks or fluids from them acting upon antigorite serpentinite and serpentinite fluids (see Karpov *et al*. 1988; Suturin, 1986), both being post-igneous processes (the serpentinite affinity places such nephrite deposits among the global distribution of ophiolite complexes, the scars of ocean basins closed by plate tectonics – Fig. 1). Ca saturation is most likely produced by clinopyroxene breakdown during maximum serpentinization, however, in part, it may also be the result of decreasing P and increasing T upon fluids rising through (and with) serpentinite melange—see below. Conditions can range from the high T limit of greenschist-amphibolite facies (< 550 °C) in the dolomite-derived type to moderate (~400 °C for Fengtian nephrite, Taiwan; *Yui et al*., 1988) to very low temperatures (~100 °C) in ophiolites; all occur at moderate to low pressure (<2kbar?). Supersaturation of interacting fluids or fluids and solids at low T appears to yield the fibrous-mat crystallizations characteristic of nephrite; alternatively some authors attribute the nephrite texture to recrystallization of metasomatic amphibole by subsequent shear deformation (e.g., Cooper, 1995) or replacement of antigorite (e.g., O'Hanley, 1996). Botryoidal nephrite from northern California appears to result from infiltration of serpentinite vein fluid into permeable graywacke blocks, reaction with the permeable matrix, and creation of little "cumulus cloud" structures (Harlow, unpublished data).

Jadeitite is rarer than nephrite and, when translucent, is the "precious" jade used in jewelry. The largest and most important deposit is the Hpakan-Tawmaw tract, Kachin State, northern Myanmar (Burma) and in conglomerates and alluvials derived from that source (Chhibber, 1934; Bender, 1983; Hughes *et al.*, 2000). The important source of New World jade is in the middle Motagua Valley, Guatemala (Hargett, 1990, Harlow, 1994). Another important source with minor utilization, though some archaeological significance for Korean magatamas, is the alluvial deposits in the Ohmi-gawa, Kotaki-gawa, and Hime-kawa (rivers) near Itoigawa, Niigata Prefecture, Japan (Chihara, 1971; Komatsu, 1987). Relatively undeveloped deposits exist along Ketchpel River, Pay-Yer massif, Polar Urals (Morkovkina, 1960), and the Borus Mtns, West Sayan (Dobretsov, 1963) in Russia and Itmurundy, near Lake Balkhash, Kazakhstan (Dobretsov and Ponomareva, 1965). A small but well-described occurrence is along Clear Creek in the New Idria serpentinite, San Benito Co., California

(Coleman, 1961). Except for the Polar Urals occurrence, which is probably Devonian in age, and the Itoigawa source, which is probably Permian, jadeitite deposits are associated with post-Cretaceous geology.

Jadeitite is a very uncommon rock type restricted to primary occurrences in bodies of subduction-related serpentinite along major fault zones. Pure jadeite jade is white, “Imperial” emerald green is due to Cr^{3+}, leak-green from Fe^{2+}, blue-green from mixed Fe^{2+} and Fe^{3+} and mauve from Mn^{2+}. Blue jadeite/omphacite from the Itoigawa area is due to Ti (with TiO_2 ≤6 wt%, Matsubara, personal communication, and color probably resulting from intervalence charge transfer with Fe, as in sapphire) and a blue jadeitite from Guatemala has not as yet been studied. Pyroxene compositions in jadeite jades range from Jd_{100} to omphacite usually with Ac_{5-10}. Jadeitite occurs as veins (Myanmar, California) or tectonic blocks (Guatemala, Polar Urals) generally with surrounding albitite, actinolite schist and a blackwall rind bounding serpentinite. Minerals coexisting with primary jadeite include sodic amphibole (eckermannite to pargasite-glaucophane in Myanmar and Japan) or mica (phengite and/or paragonite in Guatemala) ± albite, titanite, rutile, zircon, apatite, chromite, pyrite, and graphite—quartz is absent except in a single non-gem sample reported by Smith and Gendron (1997). Crystals of jadeite in jadeitites are cryptically to rhythmically zoned, indicating crystallization from an aqueous fluid. Thus, most jadeitites probably began as vein crystallizations, although a partial metasomatic replacement origin is difficult to rule out. The host serpentinite is either highly faulted or a melange and is always associated with a major fault which is usually a lateral fault on the wedge side of a fossilized convergent margin. Consequently fluid flow in faulted serpentinite and emplacement of serpentinite along faults active during subduction or collision (continent-continent or fragment-continent) are critical features to jadeitite occurrences.

Jadeite is a high pressure mineral, but with $P_{H2O}=P_{total}$ and no quartz, P is only > 5-6 kbar (bounding reaction is Jd+W=Anl) rather than > 8-11 kbar (bounding reaction Jd+Qtz=Ab) for the low T environments (200 to 400 °C based on assemblages). Nevertheless, this represents substantial depth (>16 - 20 km) for a fluid that deposits jadeite in serpentinite (serpentinizing peridotite) by rising through an accretionary wedge or back along subduction-related faults. Fluid inclusions and O/H isotopic systematics infer the predominance of a seawater-like fluid entrained during subduction rather than the product of dehydration of deep metamorphic minerals, at least for Guatemala (Johnson and Harlow, 1999). Trace element studies of jadeite from jadeitites manifest considerable heterogeneity, suggesting diverse fluid trajectories for different jadeitites in the same deposit, although overall trends suggest some deposits may be derived primarily from sediments (perhaps in Guatemala) while others may record a significant felsic-igneous component (perhaps Myanmar) (Sorensen and Harlow, 1998, 1999, and in prep.). The high-pressure origin of jadeitites associates them in the belts of eclogites and blueschists around the world – Fig. 2.

Jadeitite formation requires devolatilization, primarily dewatering of sediments, within a subducting slab at depths down to the blueschist-to-eclogite transition. Such fluids will be enriched in components that are nearly saturated with jadeite (e.g., Manning, 1998). These fluids may become channelized through overlying serpentinized peridotite (of unknown provenance) which can diapirically rise along a fore-arc transform/lateral fault, which may be related to final oblique convergence of continental (Myanmar) or island arc (Guatemala) terrane. Crystallization of jadeite provides a focus for brittle fracture, fluid flow, and further deposition of jadeite during serpentinite diapirism and faulting. Fluid travels down P but up T which is key to the sequence jadeitite followed by albitite found at all jadeitite occurrences. Fractionation by jadeite crystallization and decrease in P progressively enriches the diopside content in the rising fluid, so pyroxene crystallization trends to omphacite at crystal rims. Increased silica activity at shallower depths leads to the co-crystallization of albite + omphacite or diopside. Interaction of the fluid with tectonic blocks entrained in the host serpentinite can lead to jadeitization, or in the case of basaltic blocks, the formation of Fe-rich omphacitites or omphacite-rich amphibolites. At the top of the system tremolite may saturate—with possible formation of nephrite. The diapiric rise of serpentine, perhaps enhanced by the collision process, exposes fossil jadeitite, however the rapid uplift may also result in a short duration of exposure, explaining the paucity and young age of most jadeitite deposits.

The formation of most nephrite and jadeitite deposits records events at convergent margins that involve fluid interactions in and around serpentinizing peridotite at depths from perhaps > 50 km to the near surface. Preservation of the jade is a relatively rare event that may require special tectonic conditions and a limited range of peridotite hosts for jadeitite and perhaps nephrite. Jades are thus unique probes of convergent margins and fluids derived from subduction zone devolatilization—profoundly interesting geologically as well as materially and archaeologically.

References:

Beck, R., 1984. *New Zealand Jade*. A.H. & A.W. Reed, Ltd., Wellington. 173p.

Beck, R., 1991. Jade in the South Pacific. In: Keverne, R. (Ed.) *Jade*. Van Nostrand Reinhold: 221-258, New York.

Bender, F., 1983. *Geology of Burma*. Gebrüder Borntraeger, 293, Berlin.

Chhibber, H. L., 1934. *The Mineral Resources of Burma.* MacMillan and Co., 320, London.

Chihara, K., 1971. Mineralogy and paragenesis of jadeites from the Omi-Kotaki area, Central Japan. Mineralogical Society of Japan, Special Paper 1: 147-156.

Coleman, R. G., 1961. Jadeite deposits of the Clear Creek area, New Idria district, San Benito County, California. Journal of Petrology 2: 209-247.

Cooper, A. F., 1995. Nephrite and metagabbro in the Haast Schist at Muddy Creek, Northwest Otago, New Zealand. New Zealand Journal of Geology and Geophysics 38: 325-332.

Dobretsov, N. L., 1963. Mineralogy, petrography and genesis of ultrabasic rocks, jadeitites, and albitites from the Borus Mountain Range (the West Sayan). Academia Scientifica USSR (Siberian Branch), Proceedings of the Institute of Geology and Geophysics 15: 242-316.

Dobretsov, N. L. and Ponomareva, L. G., 1965. Comparative characteristics of jadeite and associated rocks from Polar Ural and Near-Balkhash Region. Academia Scientifica USSR (Siberian Branch), Trudy, Institute of Geology and Geophysics 31: 178-243.

Flint, D. J. and Dubowski, E. A., 1990. Cowell nephrite jade deposits. In: Hughes, F.E. (Ed.), *Geology of the mineral deposits of Australia and Papua New Guinea; Volume 2*. Australasian Institute of Mining and Metallurgy, 14: 1059-1062, Melbourne.

Gabrielse, H., 1990. *Cry Lake jade belt, north-central British Columbia.* Open-File Report 2262. Geological Survey of Canada, Calgary.

Hargett, D., 1990. Jadeite of Guatemala: A contemporary view. Gems and Gemology, 26: 134-141.

Harlow, G. E., 1994. Jadeitites, albitites and related rocks from the Motagua Fault Zone, Guatemala. Journal of Metamorphic Geology, 12: 49-68.

Hughes, R.W., Galibert, O., Bosshart, G., Ward, F., Oo, T., Smith, M. Sun, T.T., and Harlow, G.E., 2000. Burmese Jade: The Inscrutable Gem. Gems and Gemology 36, No. 1: 2-26.

Johnson, C. A. and Harlow, G. E., 1999. Guatemala jadeitites and albitites were formed by deuterium-rich serpentinizing fluids deep within a subduction-channel. Geology 27: 629-632.

Karpov, I. K., Chudnenko, K. V. and Suturin, A. N., 1988. Physicochemical modeling of processes of contact-infiltration metasomatism. Transactions (Doklady) of the U.S.S.R. Academy of Sciences: Earth Science Sections, 297: 189-192.

Komatsu, M., 1987. Hida "Gaien" Belt and Joetsu Belt. In: *Pre-Cretaceous Terranes of Japan*. (K. Ichikawa, S. Mizutani, I. Hara, S. Hada, and A. Yagi, eds.) IGCP project No. 224: 25-40. Nippon Insatsu Shuppan Co., Ltd., Osaka 413pp.

Loney, R. A. and Himmelberg, G. R., 1985. Ophiolitic ultramafic rocks of the Jade Mountains-Cosmos Hills area, southwestern Brooks Range. In: The United States Geological Survey in Alaska; accomplishments during 1984. U. S. Geological Survey Circular: 13-15. Reston, VA.

Madson, M. E., 1978. Nephrite occurrences in the Granite Mountains region of Wyoming. In: Boyd, R. G., Boberg, W. W. and Olson, G. M., (Eds.) Resources of the Wind River Basin. Guidebook - Wyoming Geological Association. 30: 393-397, Casper, WY.

Manning, C. E., 1998. Fluid composition at the blueschist-eclogite transition in the model system Na_2O-MgO-Al_2O_3-SiO_2-H_2O-HCl. Schweizerisches Mineralogisches und Petrographisches Mitteilungen 78/2: 225-242.

Morkovkina, V. F., 1960. Jadeitites in the hyperbasites of the Polar Urals. Izvestia Akademia Nauk SSSR Izvestia, Seria Geologicheskaya, no. 4: 78-82.

O'Hanley, D. S., 1996. Serpentinites, recorders of tectonic and petrological history: Oxford Monographs on Geology and Geophysics 34, 256, Oxford.

Prokhor, S. A., 1991. The genesis of nephrite and emplacement of the nephrite-bearing ultramafic complexes of East Sayan. International Geology Review 33: 290-300.

Sekerin, A.P.; Sekerina, N.V., Men-shagin, Yu.V. and Lashchenov, V.A., 1997. Printsipy prognozirovaniya neftenosnykh oblastey (Translated Title: Principles for prediction of nephrite deposits). Otechestvennaya Geologiya. 1997, 5: 42-46.

Smith, D. C. and Gendron, F., 1997. New locality and a new kind of jadeite jade from Guatemala; rutile-quartz-jadeitite. Terra Abstracts. 9, Suppl. 1: 35.

Sorensen, S. S. and Harlow, G. E., 1998. A cathodoluminescence (CL)-guided ion and electron microprobe tour of jadeitite chemistry and petrogenesis. Abstracts with Programs, 30, 1998 Annual Meeting, Geological Society of America: A-60.

Sorensen, S. S. and Harlow, G.E., 1999. The geochemical evolution of jadeitite-depositing fluids. Abstracts with Programs, 31, 1999 Annual Meeting, Geological Society of America: A-101.

Suturin, A.N. 1986. Physicochemical model of nephritization. Transactions (Doklady) of the U.S.S.R. Academy of Sciences: Earth Science Sections. 291: 199-201.

Visser, J. M., 1946. Nephrite and chrysoprase of Silezia. Mineralogist, 14; Oregon Agate and Mineral Society: 460-462, Portland.

Wand,.W.-S., 1987. Nephrite deposits of Taiwan. In: Pacific Rim congress 87; an international congress on the geology, structure, mineralization and economics of the Pacific Rim. Australasian Institute of Mining and Metallurgy: 639-640, Parkville, Victoria.

Webster, R., 1975. *Gems: Their Sources, Descriptions and Identification*. Third Edition, Archon Books, Shoestring Press, Inc., 931, Hamden, CT, U.S.A.

Yui, T-F., Yeh, H-W. and Lee, C. W., 1988. Stable isotope studies of nephrite deposits from Fengtian, Taiwan. Geochimica et Cosmochimica Acta 52: 593-602.

Figure 1: World-wide nephrite occurrences.

Fig. 2: World-wide jadeitite occurrences.

This citation is:

Harlow, G.E. and Sorensen, S.S. (2001) Jade: Occurrence and metasomatic origin — extended abstract from International Geological Congress 2000. The Australian Gemmologist 21, 7-10.

Principal author and contact:

George E. Harlow, Ph. D.

Dept. Earth and Planetary Sciences,

American Museum of Natural History

Central Park West at 79th St., NY, NY 10024-5192 U.S.A.

Phone (212)769-5378 FAX (212)769-5339

Email: gharlow@amnh.org

Second author:

Sorena S. Sorensen, Ph. D.

Department of Mineral Sciences, NHB-119

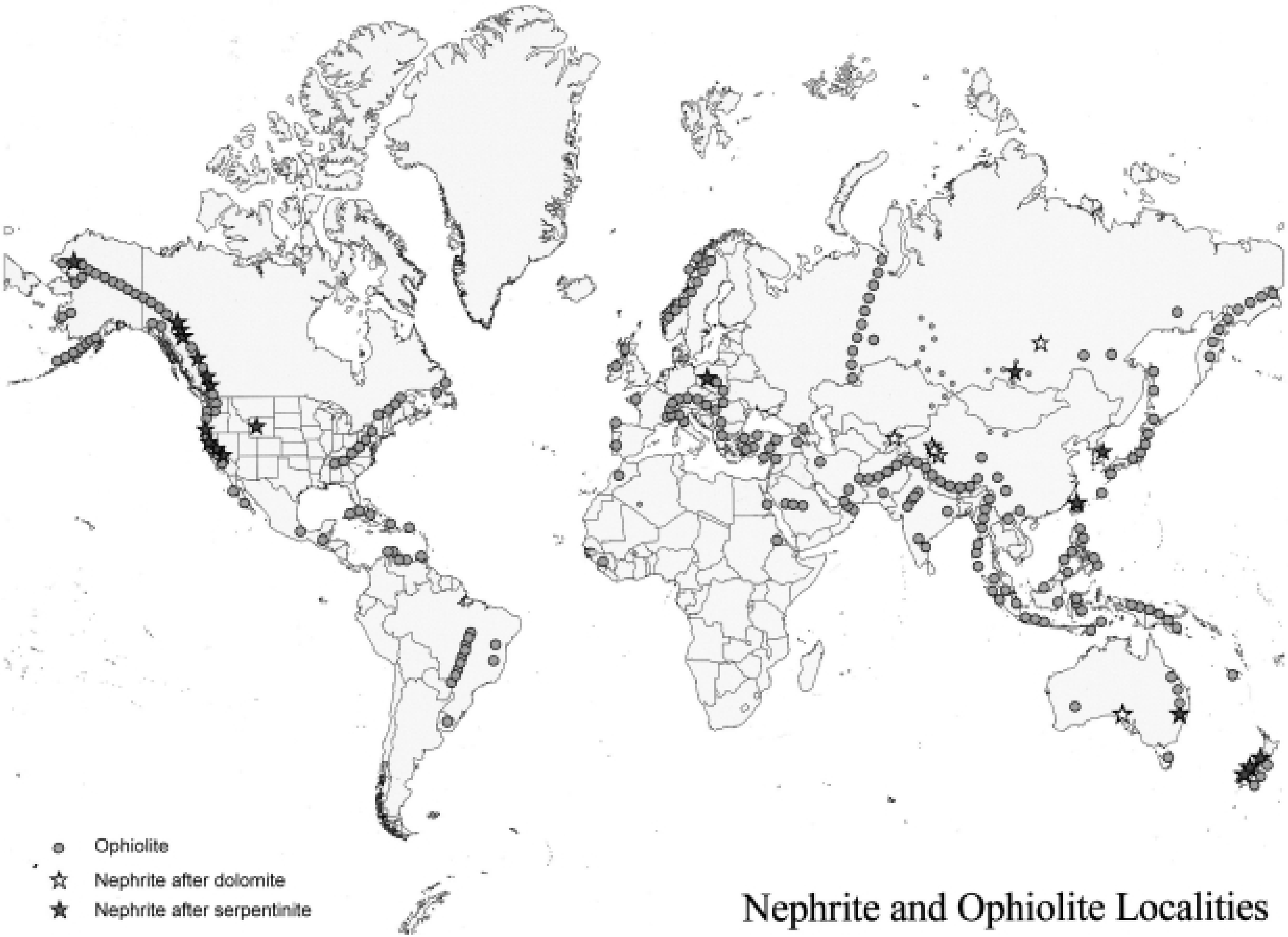
National Museum of Natural History

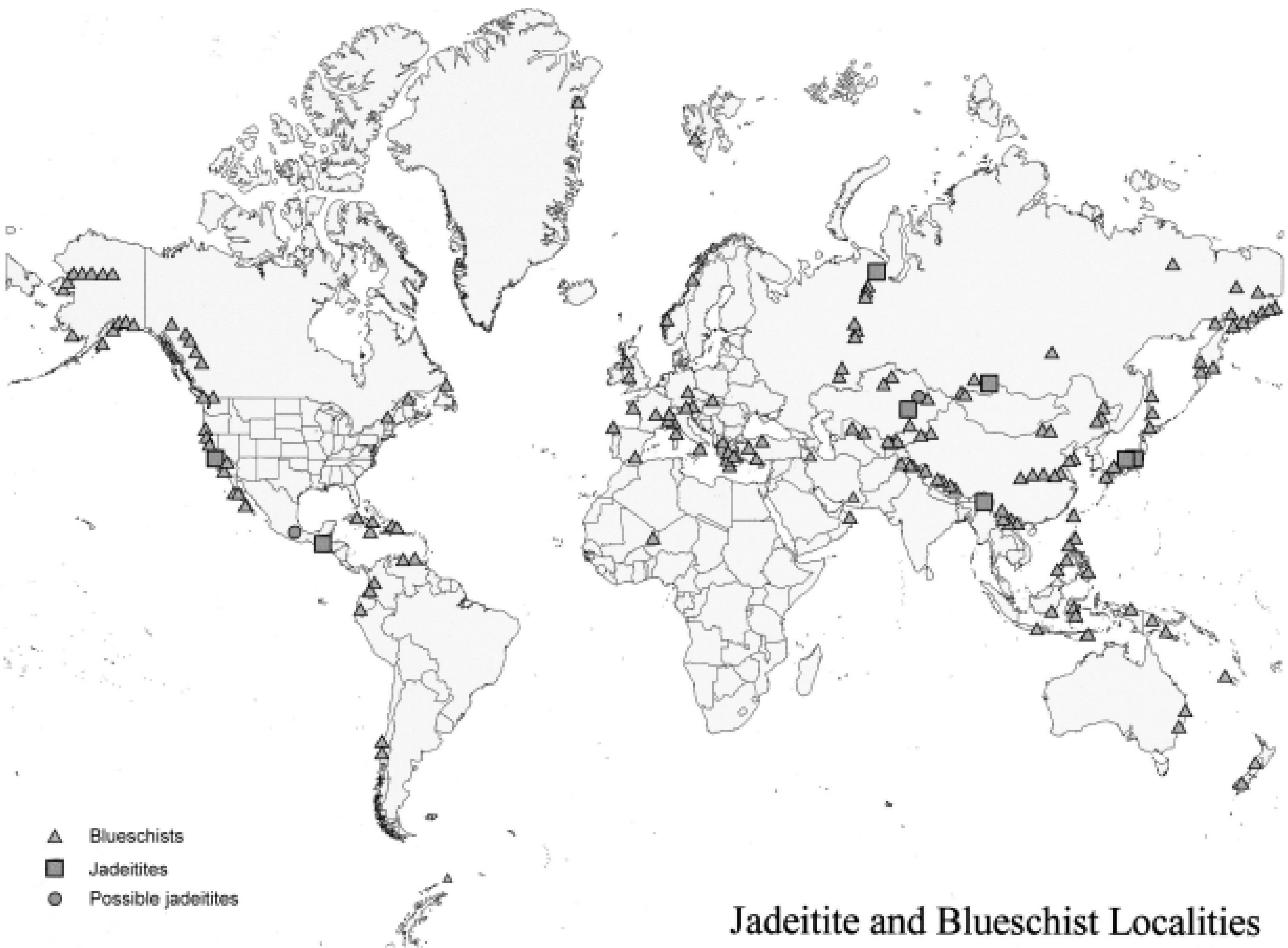
Smithsonian Institution

Washington, DC 20560-0119 U.S.A.

Phone (202) 357-4010 FAX (202) 357-2476

Email: sorena@volcano.si.edu


Ophiolite
Nephrite after dolomite
Nephrite after serpentinite
Nephrite and Ophiolite Localities


Blueschists
Jadeitites
Possible jadeitites
Jadeitite and Blueschist Localities