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Carmichaelite, a new hydroxyl-bearing titanate from Garnet Ridge, Arizona

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ABSTRACT

Carmichaelite [$MO_{2-x}(OH)_x$, where M includes Ti, Cr, Fe, Mg, and Al] is a new hydrous titanate from Garnet Ridge, an ultramafic diatreme on the Colorado Plateau in Arizona. It is named in honor of Ian S.E. Carmichael, Professor of Geology at the University of California, Berkeley, in recognition of his many contributions to petrology, especially his studies of Fe-Ti oxides in volcanic rocks. The new mineral occurs as platy, cinnamon-brown inclusions in mantle-derived pyrope crystals, which also contain inclusions of rutile, srilankite, ilmenite, minerals of the crichtonite group, spinel, and olivine. Carmichaelite is commonly in contact with rutile and occasionally with srilankite. The average composition is TiO_2 = 62.16, Cr_2O_3 = 18.43, Al_2O_3 = 1.88, V_2O_3 = 0.87, Nb_2O_5 = 0.37, FeO = 7.61, MgO = 2.80, H_2O (calc) = 5.76, total 99.89 wt%, giving an empirical formula close to $Ti_{0.62}Cr_{0.19}Fe_{0.09}Mg_{0.06}Al_{0.03}V_{0.01}O_{1.5}(OH)_{0.5}$. A cation (non-H) to (O+OH) ratio of 1:2 was confirmed by microprobe analysis of oxygen, and the presence of the hydroxyl component was supported by IR data. Carmichaelite is monoclinic, space group $P2_1/c$, with a = 7.706(1), b = 4.5583(6), c = 20.187(3) Å, β = 92.334(2)°, V = 708.5(3) Å^3, and Z = 22. The calculated density is 4.13 g/cm^3. The strongest diffraction lines [$d(I, h\ k\ l)$] from a calculated powder pattern are 2.842 (100, $\bar{1}$15), 3.773 (94, 013), 2.664 (70, 213), 1.688 (54, $\bar{3}$22), 1.679 (44, 226), 1.661 (44, $\bar{1}$28), and 1.648 (34, 1.1.11). The crystal structure, which has been determined from single-crystal X-ray diffraction data, consists of stacked chains of cation octahedra within layers of hexagonal closest-packed anions. The arrangement of cation octahedra within a single chain has the same basic structural unit of five edge-sharing octahedra found in olivine, the humite group, and leucophoenicite.

Carmichaelite is inferred to have co-precipitated with its pyrope host and other titanates in the presence of a fluid or melt phase (i.e., mantle metasomatism) at temperatures of 650–750 °C and pressures of 20–25 kbar. It contains the highest OH content reported for titanates of mantle origin and offers a potential storage site for water and high field strength elements in the upper mantle. The new mineral is probably stabilized by high pressure and the high concentration of Cr. Certain features of the carmichaelite structure raise the possibility of a similar high-pressure phase in the Si-Al-O-H system.