COLUMBIA HILLS – AN EXHUMED LAYERED IGNEOUS INTRUSION? Don Francis[1], [1]Earth and Planetary Sciences, McGill University, 3450 University St., Montreal, QC, H3A 2A7, Canada, donald.francis@mcgill.ca

The rover Spirit has used an Alpha Particle X-Ray Spectrometer to collect some 75 whole-rock chemical analyses on rock outcrops and boulders along its traverse across the Columbia Hills of Gusev Crater. The apparently “basaltic” compositions of many of these rocks, and the local presence of well developed layering, have lead to the widespread perception that the Columbia Hills represent a mafic pyroclastic sequence. Such a model has problems, however, explaining the compositional variation observed within the Columbia Hills analyses. There is a positive correlation between Fe and Mg in the Columbia Hills data that branches at high Fe contents into two distinct trends, one towards higher Mg values than the other. A comparison of “asis, brushed, and rated” analyses on an anhydrous basis indicates that these trends do not reflect weathering or alteration processes and are likely to be primary features of the rocks of the Columbia Hills. Strikingly, despite the small area surveyed by Spirit, the range in Fe contents obtained in the Columbia Hills rivals that observed in the basalts of the entire Solar System. The positive trends in Fe-Mg space exhibited by the rocks of the Columbia Hills contrast markedly with the negative correlations typical of mafic volcanic suites, whose compositions are controlled by crystal-liquid fractionation along a “gabbroic” cotectic. Furthermore, despite the relative coherence of the Columbia Hills array in Fe-Mg space, no plausible crystal fractionation model can explain the observed co-variation between Fe with Mg, if the analyzed rocks are assumed to represent volcanic compositions defining a liquid line of descent. This reflects a fundamental inconsistency between the compositions of the olivine (Fo ~ 50-60) present in the rocks, as estimated by Mössbauer analysis, and those predicted on the basis of Fe/Mg partitioning (Fo ~ 80^{+}), assuming the rocks represent volcanic compositions with reasonable oxidation states.

Positively correlated arrays in Fe - Mg space are, however, common features in whole-rock data collected across cyclically-layered igneous intrusions. The repeated alteration of feldspar-rich versus mafic–rich cumulates in such intrusions results in whole-rock compositions that scatter along mixing lines between feldspar near the origin and the mafic cumulate phases, whose slopes are determined by the latter’s $Mg^{\#}$’s. These positive arrays reflect the magmatic sorting of cumulus crystals as opposed to crystal-liquid equilibria. There is in fact a striking correspondence between the two Fe-Mg trends observed in the Columbia Hills data and the compositional arrays observed in the cumulate stratigraphy of a number of terrestrial layered intrusions; including the Proterozoic Lac Raudot and Kiglapait troctolite intrusions in the Grenville Province of Québec and Nain Province of Labrador respectively, and the Tertiary Skaergaard intrusion of eastern Greenland. The difference between the equivalent two Fe-Mg trends in these terrestrial layered intrusions corresponds to the appearance of magnetite as a cumulus phase at olivine compositions of ~ Fo 60. If the Columbia Hills rocks are assumed to represent cumulates whose compositions are determined by magmatic sorting of cumulus phases, then the estimated olivine composition (Fo 50-60) of this transition in the Columbia Hills matches the estimated composition of olivine actually present in the rocks.

In the model proposed here, the stratification seen at number of localities along Spirit’s traverse represents magmatic sedimentation in a layered igneous intrusion, rather than a layered pyroclastic deposit. According to this interpretation, the higher magnesium rocks analyzed on Hansen Ridge and in Eastern Valley are olivine-orthopyroxene and olivine gabbronorite cumulates without cumulus magnetite. The majority of the rocks of the Columbia Hills, however, appear to be olivine gabbronorites with cumulus magnetite, which are characterized by variable proportions of feldspar versus mafic silicates plus magnetite. Furthermore, a plot of P versus Mg indicates that the relatively low-magnesium, alkalis-rich rocks analyzed on West Spur and Cumberland Ridge of Husband Hill, which have previously been interpreted to be alkaline basalts, are better explained as gabbronorites to diorites with cumulus apatite, similar to those that characterize the upper layered series of both the Kiglapait and Skaergaard intrusions. The sequence of crystallization of the magma responsible for the Columbia Hills is therefore interpreted to be: olivine, followed by orthopyroxene, then plagioclase, magnetite, and finally apatite.

In conclusion, the compositional variation exhibited by the analyzed rocks and outcrops of the Columbia Hills are better explained if the rocks are considered to be intrusive magmatic cumulates rather than volcanic rocks. If this interpretation is correct, then the Columbia Hills likely represent a Noachian layered intrusion (or layered crust) that was exhumed by rebound following the meteorite impact that formed Gusev crater.