FINAL TECHNICAL REPORT

TITLE: Fine-scale traverses in cumulate rocks, Stillwater Complex: A lunar analogue study (NAG 9-212)

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Date: July 29, 1988

The objective of this research program was to document fine-scale compositional variations in cumulate rocks from the Stillwater Complex in Montana and to interpret these data in the context of planetary magma fractionation processes such as those operative during the formation of the Earth's moon. This research program involved collecting samples in the Stillwater Complex and analysing them by electron microprobe, x-ray fluorescence (XRF), and instrumental neutron activation analysis (INAA).

The field program in the Stillwater Complex for collecting samples was undertaken in June and July, 1987 by D. Elthon and three of his graduate students (K.Ross, B. Jones, and L. Yan). Although we had originally proposed to collect only three detailed traverses through cumulate ultramafic and gabbroic sequences, good weather and flawless operation of the drills enabled us to collect nine of these instead. The locations of these traverses and their characteristics are shown in Fig. 1 and Tables 1 and 2.

Our laboratory research effort involves three analytical programs. The electron microprobe is used to determine the compositions of cumulus and intercumulus phases in these rocks, the XRF is used to determine the bulk-rock major element and trace element (Y, Sr, Rb, Zr, Ni, and Cr) abundances, and the INAA lab is used to determine the trace element (Sc, Co, Cr, Ni, Ta, Hf, U, Th, and the REE) abundances of mineral separates and bulk rocks.

Our laboratory efforts to date have focused on three of the detailed traverses: Gish Mine, Chrome Mountain-1 and Chrome Mountain-2.

The Gish Mine traverse consists of 100 samples of harzburgite or bronzitite from the peridotite member. We have completed our microprobe study of the samples; these results and our preliminary interpretations were reported at the 1988 Lunar and Planetary Science Conference (LPSC) at JSC (Ross and Elthon, 1988). We have recently (May-July, 1988) completed INAA analyses of 40 samples (18 orthopyroxene separates, 4 olivine separates, and 18 bulk rocks) from this traverse. We have also completed a limited amount of XRF work on these samples; we don't believe that further XRF data on these samples will offer constraints and do not plan to pursue further XRF analyses. Ross and Elthon are presently interpreting these INAA, XRF, and electron microprobe data. We plan to have a completed manuscript, expanding on our preliminary report at the LPSC, submitted to the Journal of Geophysical Research by October-November, 1988.

We are presently working on documenting the chemical variations in the CM-2 and CM-3 traverses, two fine-scale traverses through bronzitite-harzburgite on Chrome Mountain. The collection of electron microprobe data on samples from CM-3 is completed and we are expecting to complete the electron microprobe data on CM-2 by the end of October, 1988. INAA data on these samples will be collected in autumn of 1988. We plan to present these results at the 1989 LPSC at JSC and have a manuscript ready for submission to the Journal of Geophysical Research in the spring of 1989.

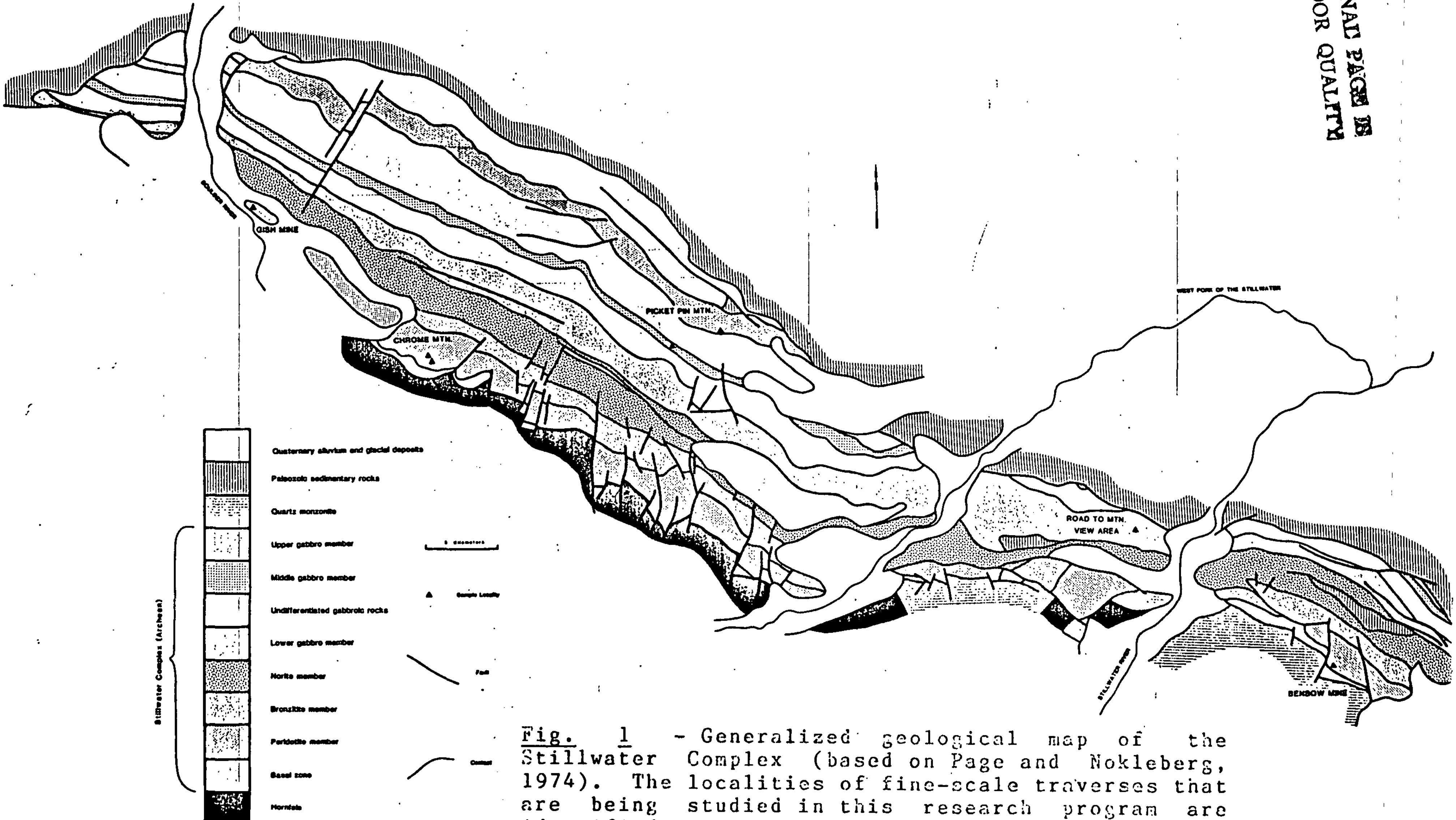
The remaining traverses that we collected will probably not be studied unless we can obtain additional funding from some source. These samples are curated at the University of Houston and will be available to other investigators for study.

MANUSCRIPTS:

[1] Ross, D.K., and D. Elthon (1988) Fine-scale cryptic layering in the peridotite member of the Stillwater Complex, Montana. Lunar and Planetary Science Conference XIX.

[2] Komor, S.C., and D. Elthon, Formation of anorthosite/gabbro rhythmic phase layering. To be submitted to Journal of Petrology by August 15, 1989.

[3] Ross, D.K., and D. Elthon, Cryptic petrochemical variations in a fine-scale traverse through cumulate ultramafic rocks of the Stillwater Complex. In preparation for Journal of Geophysical Research. Submission date of October-November, 1988.



<u>Fig. 1</u> - Generalized geological map of the Stillwater Complex (based on Page and Nokleberg, 1974). The localities of fine-scale traverses that are being studied in this research program are identified as triangles. More complete information on these traverses is in Tables 1 and 2.

TABLE 1: SUMMARY OF STILLWATER ULTRAMAFIC SERIES SAMPLES

LOCALE / TRAVERSE	NUMBER OF SAMPLES	STRATIGRAPHIC HEIGHT	ROCK TYPE
Golf Course Point, Benbow BSP-1	34	13.8 m	harzburgite chromitite
Chrome Mtn. CM-1	25	6.8 m	harzburgite
Chrome Mtn. CM-2	30	14.6 m	harzburgite
Chrome Mtn. CM-3	42	20.5 m	bronzitite harzburgite
Gish mine, GM-1	100	33.7 m	harzburgite bronzitite

Note: The previous five traverses were collected from the peridotite member of Segerstrom and Carlson, 1982. Traverses CM-1 and CM-2 sample, in part, the same stratigraphic level within the complex. The upper 10 samples of CM-1 sample the same interval as the lowermost 8 samples of CM-2; the two traverses are separated from one another along strike by 10 meters of unexposed section.

TABLE 2: SUMMARY OF
STILLWATER BANDED SERIES SAMPLES

TRAVERSE	LOCALE	NUMBER OF SAMPLES	STRATIGRAPHIC HEIGHT	ROCK TYPE
SG-1	Picket Pin Mtn.	17	4.65 m	norite anorthosite
SG-2	Picket Pin Mtn.	17	3.4 m	norite anorthosite
SG-3	Picket Pin Mtn.	56	13.0 m	leuconorite
SG-4	Road to Mtn. View area	48	8.4 m	gabbronorite
PM-1	Picket Pin Mtn.	13	28.0 m along strike	gabbronorite

Notes: The traverse PM-1 samples a single layer along strike within the middle gabbro member of Segerstrom and Carlson, 1982. SG-4 was collected from the unit labeled as Alg, lower gabbro on the map of Segerstrom and Carlson, 1982.

SG-1, SG-2 and SG-3 were collected from the unit labeled as upper gabbro (Aug) on the map by Segerstrom and Carlson, 1982. Traverse SG-2 was collected down-section from SG-1 with 2-3 meters of intervening covered section. Traverse SG-3 was collected down-section from SG-2 with about 10-15 m. of intervening covered section.

FINE-SCALE CRYPTIC LAYERING IN THE PERIDOTITE MEMBER OF THE STILLWATER COMPLEX, MONTANA. D. K. Ross[1] and D. Elthon[1,2] (1) Dept. of Geosciences, University of Houston, Houston Tx. 77004. (2) Lunar and Planetary Institute, 3303 NASA Rd. 1, Houston, Tx. 77058.

The Stillwater Complex is an Archean basic layered intrusion that outcrops along the northern margin of the Beartooth Mountains in south-central Montana. In this abstract, we report preliminary results of a microprobe study of mineral compositions in a detailed sampling traverse (100 samples collected over a stratigraphic interval of ≈ 33 meters) from outcrops near the Gish Mine, in the Boulder River Valley. This traverse samples a small portion of the peridotite member of the Ultramafic Series. Previous studies of cumulate mineral compositions in the Stillwater Complex have shown a narrow range of variation, with frequent resets to more primitive compositions (e.g. Raedeke and McCallum, 1984; Page et al., 1985). Many of the previous studies have utilized sampling intervals of tens of meters between samples. Coherent trends in mineral compositions with stratigraphic height often are not observed with this coarse sampling interval. We have collected several fine-scale traverses from a variety of levels in the complex in order determine whether the narrow range of compositions found in previous studies is a result of the coarse sampling interval.

The Gish Mine traverse consists of bronzitites, olivine bronzitites, harzburgites and dunites. The samples contain cumulus bronzite, olivine, disseminated chrome-spinel and sulfides (pyrrhotite, pentlandite and chalcopyrite), with minor intercumulus clinopyroxene.

The range of compositions for the cumulus minerals in this traverse follows: Mg-number of orthopyroxene: 82.2-85.5, Cr_2O_3=0.33-0.56 wt.%, Al_2O_3=1.1-1.7 wt.%; Fo in olivine=79.9-84.1, NiO in olivine=0.19-0.37 wt. %; Chrome-number of spinel=55.1-61.4, Mg-number of spinel=26.4-37.7. Mg-number in bronzite, forsterite in olivine and TiO_2 in spinel are plotted versus stratigraphic height in the traverse in Fig. 1. The section has been divided into a series of cryptic units, A, B, C, and D. The boundaries between these units have been selected based on major reversals in Mg-number in orthopyroxene. Bronzite is a major phase in all samples, whereas olivine is rare or absent in the lower part of the section where gaps are shown in the olivine data. Units A and C show trends of increasing Mg-number in OPX with stratigraphic height. This behavior is believed to be related to mixing between evolved and more primitive liquids. It is uncertain whether the more primitive end member in this mixing represents a new input of fresh magma into the chamber or whether it is due to a resident magma, already present in the chamber, once quasi-isolated but now mixing with the local magma due to convective overturn in the chamber or due to breakdown of a double-diffusive interface. Unit B shows decreasing Mg-number with height, indicating that this zone represents normal fractionation of an isolated magma batch. Unit D shows little variation with height. The scale of these magmatic resets, with brief stratigraphic zones in units A, B, and C could indicate the presence and quasi-isolation of small magma batches in the chamber. Unit D appears to represent a much larger magma batch, with removal of > 10 meters of cumulates producing very little change in mineral compositions.

Other chemical factors in these samples, such as Mg-number and Cr-number in spinel, and Cr and Al in pyroxene do not display well defined trends versus stratigraphic height and are not shown in Fig. 1. It is believed that these factors have been modified by sub-solidus reequilibration. Olivine-spinel geothermometers (Engi, 1983; Fabries, 1979; and Fujii, 1977) indicate temperatures of equilibration in the range 500-800 ° C. The geothermometer of Sachtleben and Seck (1981), based on aluminum solubility in orthopyroxene, also yields sub-solidus temperatures, most of which fall in the range 800-1150 ° C.

References: Engi, M. (1983), Am. J. Sci., 283A, 29-71. Fabries, J. (1979), Contrib. Mineral. and Petrol., 69, 329-336. Fujii, T. (1977), Yrbk. Carnegie Inst. Wash., 76, 563-569. Page, N. et al. (1985), in Montana Bureau of Mines and Geology Spec. Pub. 92, pp. 147-209. Raedeke, L. D. and I. S. McCallum (1984), J. Petrol., 25, 395-420. Sachtleben. T. and H. A. Seck (1981), Contrib. Mineral. Petrol., 78, 157-165.

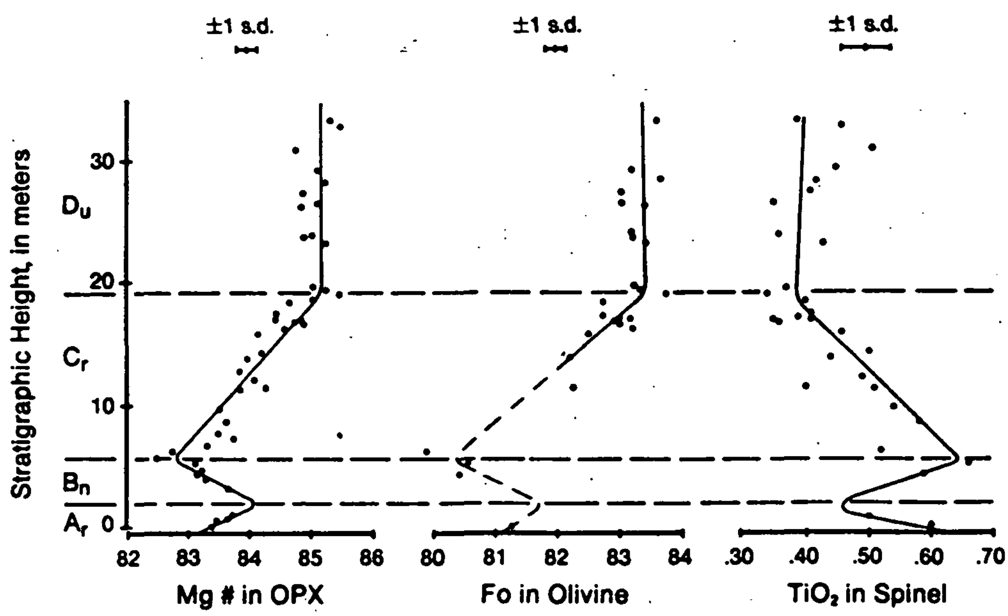


Figure 1. Fine-scale cryptic trends in mineral compositions for the Gish Mine traverse. Units showing reverse trends are labelled 'r', 'n' is for normal trend and 'u' is for uniform, as in unit D, which shows near constant orthopyroxene and olivine compositions with height.