APPENDIX 1
Technical Analyses

MATERIAL RESEARCH OF SELECTED GANDHARAN RELIEFS DEPOSITED AT THE NÁPRSTEK MUSEUM, PRAGUE

Richard Přikryl and Marek Chvátal

INTRODUCTION

Determination of source locality of stones used in antiquity is important for dating and provenancing artefacts or for identifying copies. Many approaches are used including macroscopic appearance and microscopic characteristics of stones (Lazzarini et al. 1980, Renzulli et al. 1999), quantitative fabric analysis (Schmid et al. 1999), geochemistry of major, minor and trace elements of the whole rock by XRF (Rapp 1985), laser ablation microprobe with inductively coupled plasma-mass spectrometry (Mallory-Greenough et al. 1999a), electron microprobe (e.g. Mallory-Greenough et al. 1999b, 2000), electron paramagnetic resonance spectroscopy (Baïetto et al. 1999), gamma ray spectrometry (Williams-Thorpe et al. 2000), isotopic analysis (Craig and Craig 1972; Herz 1985) or cathodoluminiscence (Barbin et al. 1992). The selection of appropriate method(s) depends largely on the source rock genesis and composition, and on the amount of material available for analysis.

This study presents results of material research of stone materials sampled from selected Gandharan reliefs deposited at the Náprstek museum of Asian, African and American Cultures (Prague, Czech Republic). Material was sampled by the museum restorers. Due to the limited amount of material, it was possible to conduct only X-ray diffraction measurements. Three samples were supplied in sufficient amount to allow ordinary petrographic examination of thin sections.

MICROSCOPY

The stone fragments (about 2-3 mm in diameter and 5 mm long) were cast in epoxy resin, sawed and standard covered thin sections were prepared (Czech Geological Survey, Prague). These thin sections were observed in optical microscope in polarised light mode. All studied samples belong to low-grade metamorphic rocks with pronounced planar fabric (metamorphic foliation) (Figures 1 and 2) due to the presence of platy minerals like muscovite. Quartz and muscovite along with paragonite have been found as major rock-forming minerals observable in optical microscope. The abundant opaque phase (20-30 vol. %) is probably due to the presence of organic matter. Chloritoid is the most common accessory phase in studied rocks although other minerals like hematite, magnetite, and spinel can be observed as well. All rock-forming minerals show extremely fine grain size.

X-RAY DIFFRACTION

X-ray diffraction (XRD) has been employed as the main analytical method to obtain data on mineralogical composition of studied objects. This method requires only small amounts of material in comparison to other analytical techniques.

The rock fragments were homogenised by powdering in an agate cup. The measurement was conducted on DRON–2 difractograph (Institute of Geochemistry) with following measurement conditions: radiation CuKá, secondary monochromator, degree range 3° – 60° 2Θ, step 0.05° per 3 seconds, voltage 30 kV, current 20 mA. The raw data were processed by Bede ZDS 1.99 for Windows program (Ondruš 1997) employing diffraction pattern database PDF–2 (JCPDS 1999). The following ICDD cards have been used: 33-1161 (quartz), 34-0175 (muscovite), 12-0186 (paragonite), 9-0701 (clinochlore), 25-0177 (titanite).

RESULTS

Based on the mineralogical composition studied by XRD analysis, the samples can be subdivided into two major groups – quartz-muscovite-paragonite schist and clinochlore schist (Figure 3). Quartz-muscovite-paragonite schists contain small amounts of clinochlore. Variable colours from grey to black of this rock type indicate presence of organic matter. As there was not detected graphite by XRD, the organic matter is probably represented by less ordered or amorphous graphitised organic compounds. A second group of samples (namely A203332, A 14407 and A12108) was

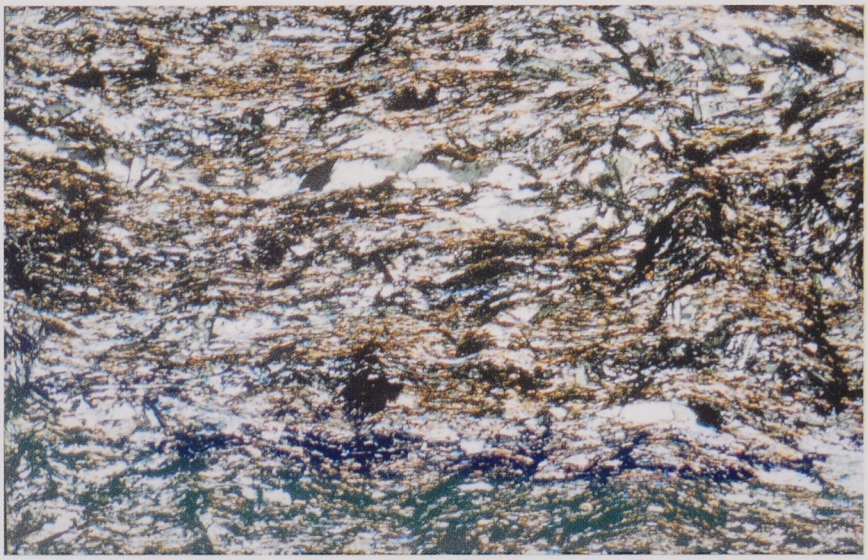

Figure 1. Microphotograph of sample A12121 showing characteristic metamorphic foliation. Crossed polarised light, magn. 50x.

Figure 2. Translucent areas of quartz and muscovite alter pale green-brown clinochlore and paragonite. Dark areas are due to the presence of amorphous graphite. The high relief rods are of chloritoid. Same sample as above. Plane polarised light, magn. 50x.

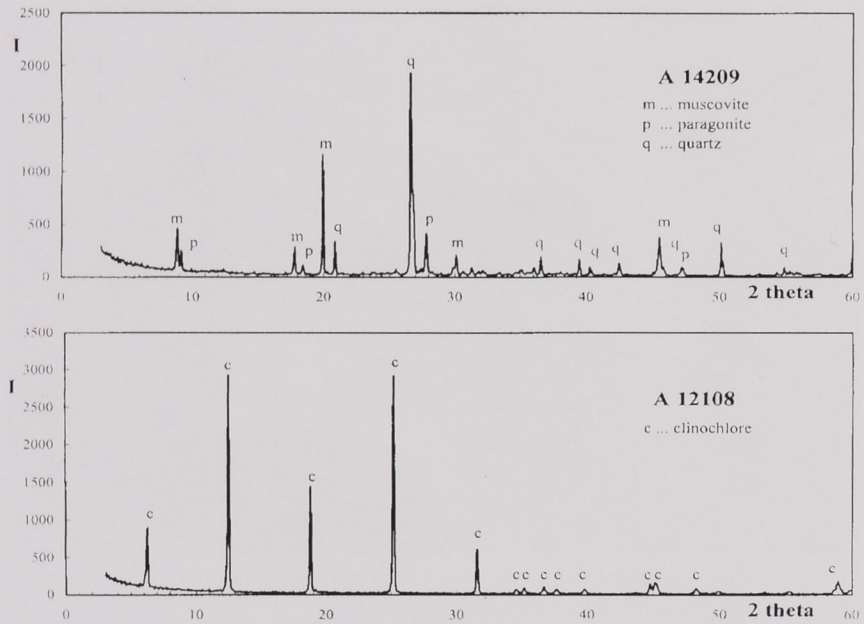

Figure 3. Typical XRD patterns representing two major group of rocks employed for Gandharan reliefs deposited at the Náprstek museum of Asian, African and American Cultures in Prague.

found to be clinochlore schists composed by monomineral clinochlore occasionally accompanied by titanite (sample A20332, Table 1). Presence of magnetite grains that were observed during macroscopic inspection of the samples (size up to 3 mm) was not confirmed by XRD.

Based on this analysis, it is not possible to state firmly if these two groups represents two different source localities or just single source locality with two different types of material. This should be confirmed by detailed petrographical study of potential source locality(ies) in the future. Comparing our results to the previously published data the studied samples can be of the same provenance as carbonaceous quartz-chlorite-muscovite-chloritoid schists quarried in Swat area, north-west Pakistan (Cribb et al. 1992 and references therein).

ACKNOWLEDGEMENT

The support for this study was provided by the project MSM 113100005 "Material and energy flows in the upper parts of the Earth".

Appendix 2 Table. Mineralogical composition of studied objects based on XRD data. +++ is for major phase, ++ stands for minor phase and + for accessory phase.

sample	quartz	muscovite	paragonite	clinochlore	titanite
13 618	+++	+++	+	–	–
13 620	+++	+++	++	++	–
13 623	+++	+++	++	++	–
13 624	+++	+++	+	+	–
16 601	+++	+++	+	–	–
45 985	+++	+++	++	++	–
A 12108	–	–	–	+++	–
A 12121	+++	+++	++	++	–
A 14213	+++	+++	++	–	–
A 14407	–	–	–	+++	–
A 14408	+++	+++	++	–	–
A 14409	+++	+++	++	++	–
A 20331	+++	+++	++	–	–
A 25615	+++	+	–	++	–
A 13621	+++	+++	+	+	–
A 14210	+++	+++	++	–	–
43 526	+++	+++	++	–	–
A 14215	+++	+++	++	++	–
A 14209	+++	+++	++	–	–
A 20332	–	–	–	+++	++

Bibliography

Baïetto V., Villeneuve G., Schvoerer M., Bechtel F., 1999: Investigation of electron paramagnetic resonance peaks in some powdered Greek white marbles. *Archaeometry* 41(2): 253-265.

Barbin V., Ramseyer K., Decrouez D., Burns S. J., Chamay J., Maier J. L., 1992: cathodoluminiscence of white marbles: An overview. *Archaeometry* 34(2): 175-183.

Craig H., Craig V., 1972: Greek marbles: Determination of provenance by isotopic analysis. *Science* 176: 401-403.

Cribb J., Errington E., Claringbull M., (eds.) 1992: The Crossroads of Asia. Transformation in Image and Symbol in the Art of Ancient Afghanistan and Pakistan. Ancient India and Iran Trust, Cambridge, 306 p.

Herz N., 1985: Isotopic analysis of marble, in: Rapp G., Jr., Gifford J. A. (eds.), Archaeological Geology, Yale University Press, New Haven and London, pp. 331-351.

JCPDS., 1999: *Powder Diffraction File*, PDF-2, International Centre for Diffraction Data, Newtown, Pennsylvania, USA.

Lazzarini L., Moschini G., Stievano B. M., 1980: A contribution to the identification of the Italian, greek and Anatolian marbles through a petrological study and the evaluation of Ca/Sr ratio. *Archaeometry* 22(2): 173-183.

Mallory-Greenough L. M., Greenough J. D., Dobosi G., Owen J. V., 1999a: Fingerprinting ancient Egyptian quarries: preliminary results using laser ablation microprobe-inductively coupled plasma-mass spectrometry. *Archaeometry* 41(2): 227-238.

Mallory-Greenough L. M., Greenough J. D., Owen J. V., 1999b: The stone of predynastic basalt vessels: Mineralogical evidence for quarries in northern Egypt. *Journal of Archaeological Science* 26: 1261-1272.

Mallory-Greenough L. M., Greenough J. D., Owen J. V., 2000: The origin and use of basalt in Old Kingdom funerary temples. *Geoarchaeology* 15(4): 315-330.

Ondruš P., 1997: *ZDS – software for X-ray powder diffraction analysis*. ZDS Systems Inc., Prague.

Rapp G., Jr., 1985: The provenance of artifactual raw materials, in: Rapp G., Jr., Gifford J. A. (eds.), Archaeological Geology, Yale University Press, New Haven and London, pp. 353-375.

Renzulli A., Antonelli F., Santi P., Busdraghi P., Luni M., 1999. Provenance determination of lava flagstones from the Roman 'Via Consolare Flaminia' pavement (central Italy) using petrological investigations. *Archaeometry* 41(2): 209-226.

Schmid J., Ambühl M., Decrouez D., Müller S., Ramseyer K., 1999. A quantitative analysis approach to the discrimination of white marbles. *Archaeometry* 41(2): 239-252.

Willimas-Thorpe O., Webb P. C., Thorpe R. S., 2000: Non-destructive portable gamma ray spectrometry used in provenancing Roman granitoid columns from Leptis Magna, North Africa. *Archaeometry* 42(1): 77-99.