"Tree Rings and Their Relation to Solar Variations and Chronology," *Ann. Rep. Smith. Inst.* (1931), 304–312, Washington (1932).

[4] Some of the doubtful dates obtained at this time later proved correct.

[5] The Pueblo Largo of N. C. Nelson, "Pueblo Ruins of the Galisteo Basin, New Mexico." *Anthro. Pap. Amer. Mus. Nat. Hist.*, **15** (1), 68 (1914).

[6] Nelson, op. cit., 59–63.

SOME OBSERVATIONS ON THE ARCHEAN METAMORPHICS OF THE GRAND CANYON

BY IAN CAMPBELL AND JOHN H. MAXSON

BALCH GRADUATE SCHOOL OF THE GEOLOGICAL SCIENCES, CALIFORNIA INSTITUTE OF TECHNOLOGY. PUBLICATION NO. 88

Read before the Academy, Monday, April 24, 1933

Although the rocks exposed in the inner gorge of the Grand Canyon present one of the best Archean sections in the United States, and although their occurrence has been known since the time of Powell's classic exploration in 1869 and 1874, relatively little attention has been given to their study. This may be due in part to the complexity and inaccessibility of the rocks themselves, and in part to what may have seemed the superior attraction of the later formations, exposed at higher levels in the Canyon walls.

The study of this terrane holds special interest, however, not only from the point of view of igneous and metamorphic petrology, but also from the fact that it involves problems concerning the early history of the globe. The writers are indebted to the Carnegie Institution of Washington and the U. S. National Park Service for the opportunity to undertake this study.

The purpose of this preliminary paper—preliminary because most of the data are based upon the field work alone, and not upon intensive laboratory investigations—is to present some of the more significant findings in regard to the metamorphic rocks, without attempting much general discussion of the relationships involved. Most of our present knowledge of the Archean is due to Noble[1] who described the principal rock types and indicated, in a broad way, their distribution.

This study has brought out new evidence which confirms the earlier judgments of Walcott[2] and of Noble concerning the sedimentary nature of the schists. Within the area studied, the writers have become convinced of the sedimentary origin of the great body of rocks to which the name "Vishnu Schist" (sensu strictu) may be applied. Summarized briefly, the evidence falls under two headings:

STRUCTURAL	PETROLOGIC
Cross-bedding	Quartzites
Stratification	Calcareous beds
Lenticular bodies	Iron formation

Thus in Lone Tree Canyon there is well exposed a section of quartz mica schists, in which such unequivocal sedimentary features as cross-bedding and quartzitic sandstone lentils are preserved. (See Figs. 1 and 2.)

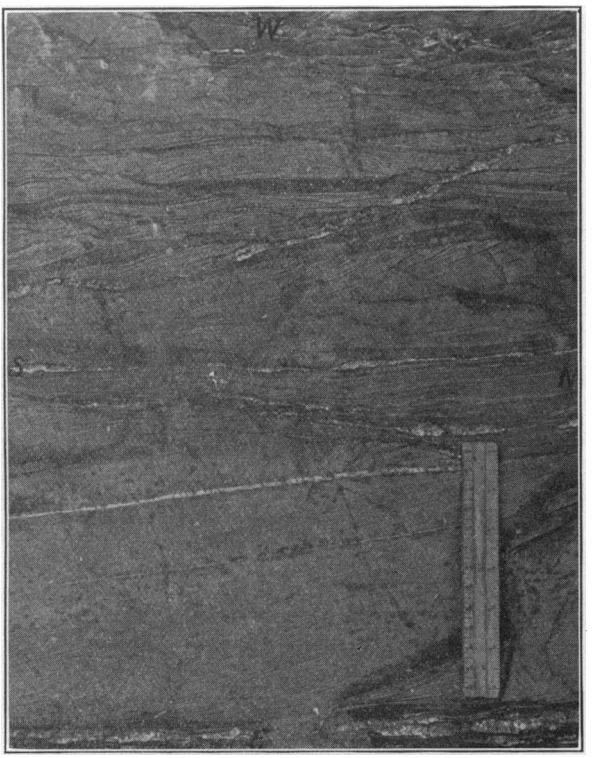

FIGURE 1

Quartz-sericite schist exposed in the floor of Lone Tree Canyon. In connection with the cross-bedding note that the sharper truncations are toward the west, indicating that the younger beds lie in that direction. The scale is six inches long.

It is interesting to note that within a few hundred feet of this least metamorphosed Archean exposure, there occurs a garnet-staurolite schist, associated with a granitic intrusion. This relationship is an indication that at least a part, and perhaps much, of the higher degrees of metamorphism found in the rocks in this area may be due to contact rather than to regional effects.

Quartzites occur at many places in the section, and while the majority are very thoroughly recrystallized, some preserve evidence of stratification.

An interesting discovery is that of thin beds and small lentils of a lime-silicate rock, composed of garnet, diopside, epidote and calcite—an as-

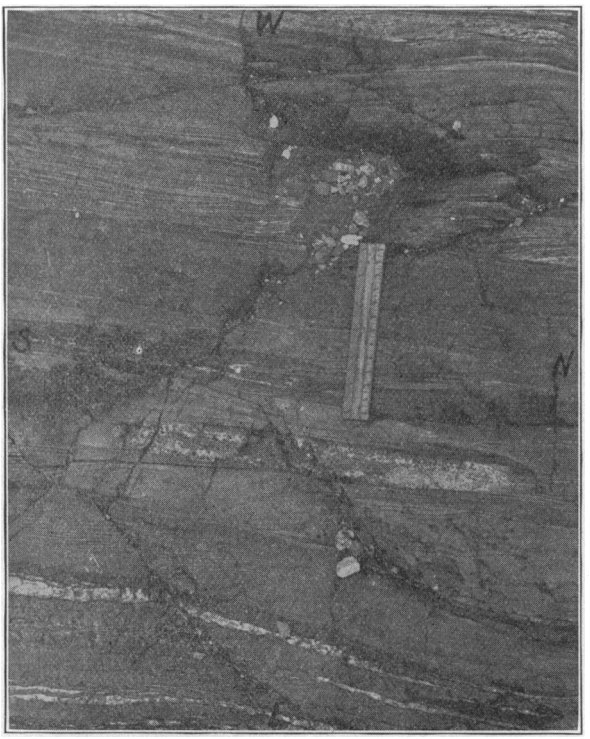

FIGURE 2

Another view of the quartz-sericite schist in Lone Tree Canyon, showing sandstone lentil below the rule. Note that schistosity generally parallels the bedding. The white streaks are quartz veinlets. The scale is six inches long.

semblage typically developed in the metamorphism of impure calcareous rocks. These occurrences, which are found in both Horn and Pipe Canyons, probably represent original calcareous lenses of a shale.

Also in Pipe Canyon, there is a rock classed as "iron formation" which on analysis is seen to be very similar to itabirite, the ferruginous quartzite of Pre-Cambrian age forming the iron ores of Minas Geraes.

There can be no question as to the original character of the types just mentioned. But the origin of many of the schists might be obscure, were

it not for their association and inter-bedding with the types of undoubted sedimentary character, for igneous invasions have greatly complicated the picture. Thus not infrequently it is possible to trace, by almost imperceptible gradations, a quartz-mica paraschist into a typical granite. In these cases the grain of the schist becomes gradually coarser, the mica orientation tends to disappear and the proportion of feldspar increases. It is difficult, if not impossible, in such cases, to mark a contact or to assign relative proportions to the two end types. Certainly the processes of assimilation, replacement, granitization, etc., have played a major rôle in the development of many of the types here found, and even in the case of the most typical Plutonic igneous rocks, there is the possibility that much of their substance has been derived from earlier sediments.

Assuming a sedimentary origin for the Vishnu schist, it is natural to inquire next into the general conditions of its formation—its environment of deposition. Not much data applicable to this question have yet been accumulated. A few facts are pertinent, however. First, there is the apparent absence from the section of conglomerates on the one hand, and limestones on the other. Second, there is the great thickness of the section. It is entirely possible that the distance now measured across the strike will have to be reduced considerably, if either isoclinal folding or reverse faulting, with duplication of portions of the section, can be proved. But even if the section were to be reduced one-half (an extreme figure) it would still be measured in tens of thousands of feet. Third, throughout this thick section, sedimentation appears to have been rather uniform. The sediments were dominantly sandy clays. Fourth, the few examples of cross-bedding observed indicate marine rather than aeolian or fluviatile deposition. All things considered, therefore, these Archean sediments may be assumed to have been laid down in a shallow, subsiding geosyncline. They are accumulations of the neritic zone, and may perhaps be compared to the arenaceous shales of the Belt series of the northern Cordillera or even—to bring the comparison closer—to the non-calcareous sediments of the overlying Grand Canyon series (Proterozoic) represented by such formations as the Shinumo quartzite and the Hakatai shale.

[1] Noble, L. F., "A Reconnaissance of the Archean Complex of the Granite Gorge, Grand Canyon, Arizona," *U. S. G. S.*, Prof. Paper 98–I (1916).

[2] Walcott, C. D., "Pre-Carboniferous Rocks in the Grand Canyon, Arizona," *Amer. Jour. Sci.*, **26**, 437 (1883).