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NEW HAVEN, CONNECTICUT
A. Composite spinel lherzolite/spinel-olivine pyroxenite/metagabbroid xenolith from Killbourne Hole, New Mexico.

This specimen (EP-3-162) was collected by Dale Jackson in February, 1972. The xenolith consists of interfingered spinel lherzolite, spinel-olivine pyroxenite, and metagabbroid (or pyroxene granulite) bands that range from 2 to 10 mm thick. The pyroxenite forms symmetrical borders on irregular and discontinuous bands of metagabbroid. The lherzolite bands do not contain plagioclase, nor is there any area in this specimen where the metagabbroid and lherzolite are in contact. All the rock types have dominantly polygonal texture.

The banded appearance of the specimen is due to sharp color contrasts between light-green lherzolite (light-green olivine > honey-brown orthopyroxene > bright-green chrome-diopside > red-brown spinel), dark olivine pyroxenite (brown orthopyroxene > yellow-green olivine > black aluminous augite > green-brown spinel), and the mainly light colored metagabbroid (brown orthopyroxene > yellow-green olivine > white plagioclase > black clinopyroxene > green spinel). The olivine pyroxenite has sharp contacts against the lherzolite but gradational contacts with the metagabbroid. It is inhomogeneous and tends toward olivine-websterite near the lherzolite contacts but grades into olivine-orthopyroxenite farther from the lherzolite bands.

Microprobe analyses indicate that the clinopyroxenes in the olivine pyroxenite and metagabbroid are identical in quadrilateral components (En$_{94}$ Fs$_{11}$ WO$_{5}$; Mg$_{9}$/Mg$_{8}$+Fe = 0.89) and have overlapping ranges of Na$_{2}$O and Al$_{2}$O$_{3}$. They differ in that the metagabbroid clinopyroxenes have higher TiO$_{2}$ (1.1 wt percent) and lower Cr$_{2}$O$_{3}$ (0.05 wt percent) than those of the olivine pyroxenite (TiO$_{2}$ 0.20-0.94 wt percent; Cr$_{2}$O$_{3}$ 0.12 wt percent).

Plagioclase occurs at the olivine pyroxenite/metagabbroid contacts as interstitial ovoid blebs (0.1-0.5 mm across). The grains become larger and more polygonal in shape as plagioclase increases in abundance with distance from the contact. Where plagioclase is most abundant, it occurs either in small patches of several grains that are interstitial to the mafic grains or in larger, commonly sealing, patches that surround the mafic phases. Twin lamellae and zoning are rare.

Both lherzolite and olivine pyroxenite contain large (1.5-5 mm) anhedral olivine and orthopyroxene porphyroclasts with strain lamellae. In the lherzolite the olivine porphyroclasts are commonly elongate and form a foliation in the plane of gneissic banding. The spinels in both lherzolite and olivine pyroxenite have holly-leaf shapes.
and also are elongate, forming a lineation in the foliation plane. The metagabbroid contains twinned clinopyroxene grains and other clinopyroxene grains that have exsolved spinel along cleavages; these features are relics of an earlier igneous texture and are not present in either the lherzolite or olivine pyroxenite.

The olivine pyroxenite and metagabbroid portions of this xenolith apparently are related to each other and may be differentiation products of a melt intruded into the lherzolite.

J. E. N. Pike

B. Composite spinel lherzolite/spinel-olivine websterite xenolith from Salt Lake Crater, Hawaii.

This specimen (73-SAL-1), collected by Dale Jackson in 1973, is a large xenolith (19.5 cm × 12.5 cm × 11.5 cm) composed of two ultramafic rock types imbedded in nephelinitic tuff breccia. One component of the xenolith is orthopyroxene-rich spinel lherzolite in the form of irregular, ovoid, and lensoid clasts ranging from 7.5 to 15 cm or less in maximum dimension. The other component is spinel-olivine websterite in irregular, anastomosing bands that partly or completely surround the lherzolite clasts. Thus, the structure of the specimen is that of "xenolith-in-xenolith."

The lherzolite clasts are composed of dominant pale brownish to light green olivine (up to 3 mm across), subordinate dark brownish orthopyroxene (up to 10 mm across), and sparse grains (1-2 mm across) of bright green chrome diopside and deep brown spinel. Olivine grains have widely-spaced internal tilt-boundaries, and some orthopyroxenes also contain strain features (such as patchy zones of undulatory extinction). The clinopyroxene occurs as interstitial grains or as blebs within the large anhedral orthopyroxene grains. Porphyroclastic texture is dominant in the lherzolite clasts, although locally there are elements of allotriomorphic-granular and mosaic textures. Discontinuous olivine-rich zones of variable thickness occur in the lherzolite clasts at contacts with websterite; the olivine in these zones is more brownish in color.

The websterite is finer grained than the lherzolite and is composed of dominant brownish orthopyroxene, abundant dark green clinopyroxene, minor (~ 5 percent) brownish-green spinel and yellowish-green olivine, and very minor sulfide, brown amphibole, and interstitial secondary carbonate. There is a heterogeneous distribution of pyroxene grain sizes, and the texture ranges from porphyroclastic to polygonal mosaic. Large orthopyroxene grains (up to 3 mm across) tend to be concentrated toward the centers of the websterite bands. Both pyroxenes contain exsolution lamellae, and some of the larger orthopyroxenes are poikiloblasts enclosing grains of olivine, clinopyroxene, and spinel. Nearly all the olivine occurs as rounded grains within orthopyroxene and a polycrystalline inclusion composed of two grains of olivine, one of clinopyroxene, and one of spinel was noted. Most of the spinel (and associated sulfide) forms irregular, interstitial grains between the pyroxene grains.

The colors of the minerals in the lherzolite clasts are somewhat darker than is typical of Cr-diopside group peridotites, and the colors of minerals in the websterite appear to be intermediate between those of the Cr-diopside and Al-augite groups. Microprobe analyses show that the pyroxenes in the websterite have lower Mg/Mg+ΣFe and Cr/Ti than the corresponding pyroxenes in the lherzolite clasts. Average TmO₂ contents of clinopyroxene and orthopyroxene in the websterite are 0.67 and 0.16 wt percent, respectively, compared with 0.88 and 0.05 wt percent, respectively, in the lherzolite. Corresponding average Cr₂O₃ contents of clinopyroxene and orthopyroxene are 0.40 and 0.23 wt percent, respectively, compared with 0.81 and 0.41 wt percent, respectively. Microprobe traverses show that the Cr content of spinel decreases systematically across contacts between lherzolite and websterite in the same manner observed for other composite xenoliths.

The structural and chemical relationships in this sample suggest that the lherzolite clasts represent pieces of reacted wall rock intruded and engulfed by magma from which the websterite subsequently crystallized. As proposed for other Salt Lake Crater xenoliths, the pyroxenes of the websterite may have crystallized originally as a single phase subcalcic augite, which recrystallized to two pyroxenes upon cooling at depth.

J. E. N. Pike
A. J. Irving

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Editors' Preface

We conceived the idea of a volume in honor of Dale Jackson in January 1978 when Dale was seriously ill with cancer. We shared with many the great sense of loss when, after an encouraging remission, he succumbed on July 28, 1978. Dale was told about this volume several days before his death, and he expressed his deep gratitude for the tribute. The contents of this volume reflect very well how major lines of petrologic research on mafic and ultramafic rocks over the past 20 years have been shaped by Dale's remarkable insight and energy. Four areas of his most significant research are well-represented here — layered intrusions, ophiolites, mantle xenoliths, and Hawaiian volcanism. The contributing authors include both Dale's contemporaries and younger scientists, many of whom benefitted especially from Dale's unselfish guidance and advice during his visits to their field areas in the United States and abroad.

The preparation and timely publication of a volume such as this requires the assistance and cooperation of many individuals. We particularly wish to extend our appreciation to the reviewers for their prompt and critical evaluations. We thank the Editors of the American Journal of Science for the opportunity to make this volume a reality and we are especially grateful to Marie Casey for her patient and seemingly tireless efforts. We also appreciate the generous support provided by the Lunar and Planetary Institute, the Institute for the Study of Earth and Man of Southern Methodist University, and the National Science Foundation, without which this volume could not have been published.

We hope that the papers assembled here serve as a lasting tribute to Dale, whose quiet enthusiasm and scientific vision affected so many of us.

Anthony J. Irving
Michael A. Dungan

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Hunt's Hole, New Mexico, 1972.
FOREWORD

Everett Dale Jackson was born in Fresno, Calif. in 1925. After completing high school at Fresno, he entered the Marine Corps in World War II. He returned to Fresno State College after the war but then transferred to the University of California, Los Angeles, in 1947, where he was first introduced to geology. Dale had signed up for the first-year psychology course but took introductory geology instead when he found the psychology course to be filled. With that course, Dale became an enthusiastic geology major. He was considered by some of the faculty, which included Cordell Durrell, James Gilluly, and Dan Axelrod, to have been their best student. In the summer of 1948, Dale worked as a field assistant to Paul Bateman of the U.S. Geological Survey, mapping part of the Big Pine quadrangle in the Sierras in lieu of UCLA’s summer field requirement.

After graduating magna cum laude in 1950, Dale married Josephine Arburua. He then entered graduate school at UCLA while Jo began a career in social work. After a year of graduate school, Dale was offered a job by the U.S. Geological Survey mapping in the Stillwater Complex in Montana. It was an opportunity too good to turn down. From 1951 to 1959, Dale carried out the textural study of the Stillwater ultramafics that led to the publication in 1961 of his Professional Paper (no. 358), “Primary textures and mineral associations in the Ultramafic zone of the Stillwater Complex, Montana.” This work is one of the classics of modern geological literature. Our current model for the textures, mineral associations and stratigraphy of layered ultramafic cumulates rests on the foundation laid by Dale in his brilliant analysis of the Stillwater rocks.

He returned to graduate school at UCLA in 1959 and, using the Stillwater work as the basis for his dissertation, completed his Ph.D. in the enviably short time of 2 yrs. Even in his brief stay in Los Angeles, Dale influenced other graduate students, both toward investigations of
ultramafic rocks and eventually toward careers in the U.S. Geological Survey. We were attracted not only by Dale’s personal qualities, his energy, and warmth, but by the notion that the Survey offered the possibility of such thorough and rewarding immersion into scholarly work.

In 1962, Dale, Jo, and their family went to Washington where he was to be staff deputy to Wayne Hall, the Chief of the subdivision of Geochemistry and Geophysics. It became clear before long that the qualities of intellectual curiosity and drive that characterized Dale’s research were not applicable to staff work with his usual enthusiasm. In 1968, following a request for aid in training astronauts to become part-time geologists, Dale was seconded to NASA for the job. Although their geological training may have seemed initially to be a distraction, the astronauts were soon converted by Dale’s professionalism and his ability to transmit his own enthusiasm for his science to others. Ultimately, first as a co-investigator on the samples from the Apollo 11 and 12 missions, then as a member of the live-time mission advisory team, Dale left a profound mark on the Apollo program. In 1973, he was awarded NASA’s Exceptional Scientific Achievement Medal.

During this period, after leaving the astronaut training program, Dale became interested in the ultramafic xenoliths found in late-stage Hawaiian extrusives. He was quick to perceive that the kind of systematic mapping, petrological and textural description, and classification that had proved so necessary in the Stillwater Complex would be required to understand the origins of these rocks. Before long, he had begun to bring order out of chaos, demonstrating a relationship between the compositions of xenoliths relative to the positions of the major eruptive centers. The xenoliths clearly were fragments of the mantle, more or less depleted in their basaltic components, depending on their distance from the shield volcanoes.

Like other great geologists, Dale’s career came into full flower as he reached middle-age. From the mid-1960’s until his death, he produced a flood of geologic literature of a really astonishing variety. The study of xenoliths and his professional associations in Hawaii led to papers on the origin of dike swarms on the flanks of shield volcanoes. From such a commonplace source as an airlines map of the Pacific, he developed with others a theory of the origin of the Pacific line islands. This led to his extensive involvement with the Deep Sea Drilling Program, where he and others established the progressive chronology of the Emperor-Hawaiian island chains. During this period, he drew heavily on his Stillwater gestation period, applying his unique knowledge of cumulus textures to studies of ultramafic massifs around the world. Between 1970 and 1978 Dale was an author or co-author of fifty published articles on everything from the mineralogy of chrome spinels to discussions of the origins of stress fields in the Pacific Ocean plate.

In addition to the NASA medal, Dale was recognized for his accomplishments by an array of appointments, lectureships, and awards. He
was a fellow of the American Geophysical Union, American editor of the
Journal of Petrology, co-chief scientist on legs 33 and 55 of the Deep
Sea Drilling Project, recipient of the Geological Society of America's
special commendation award in 1973, to name only a few.

In 1976, Dale spent a semester lecturing at Princeton University
where appropriately enough, he sat at the desk formerly used by Harry
Hess. Dale taught well, perhaps even better through tutorials than lec-
tures. He was a good listener, being both stimulating and easily stimu-
lated himself. He carried his vast petrological knowledge so lightly that
students or colleagues were never intimidated by him.

To work closely with Dale on a research problem, an experience
shared by many of us, was both a challenge and a pleasure. Never one
to ruminate passively while others worked, he rarely allowed the reverse
to happen either. Dale worked hard and had an awesome persistence so
that, once begun, a published result was assured. He set high standards,
however, and many of us have had to revise our own standards upward
after such an exercise.

There are few scientists who have set their mark so firmly in their
chosen field as Dale has. He displayed a scholarly thoroughness and
originality that is remarkable not only for its rarity but for the very large
numbers of papers it characterizes. Those of us fortunate enough to have
been his colleagues are the beneficiaries of more than the great scholarly
output of this creative and energetic man, however. We have been in-
delibly enriched by contact with a warm, generous, and proud human
being whose commitment to his vision of scientific research will not fade
from our memories.

C. B. Raleigh

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