# CALIFORNIA GEOLOGY

$1.00

NOVEMBER 1988

INSIDE:

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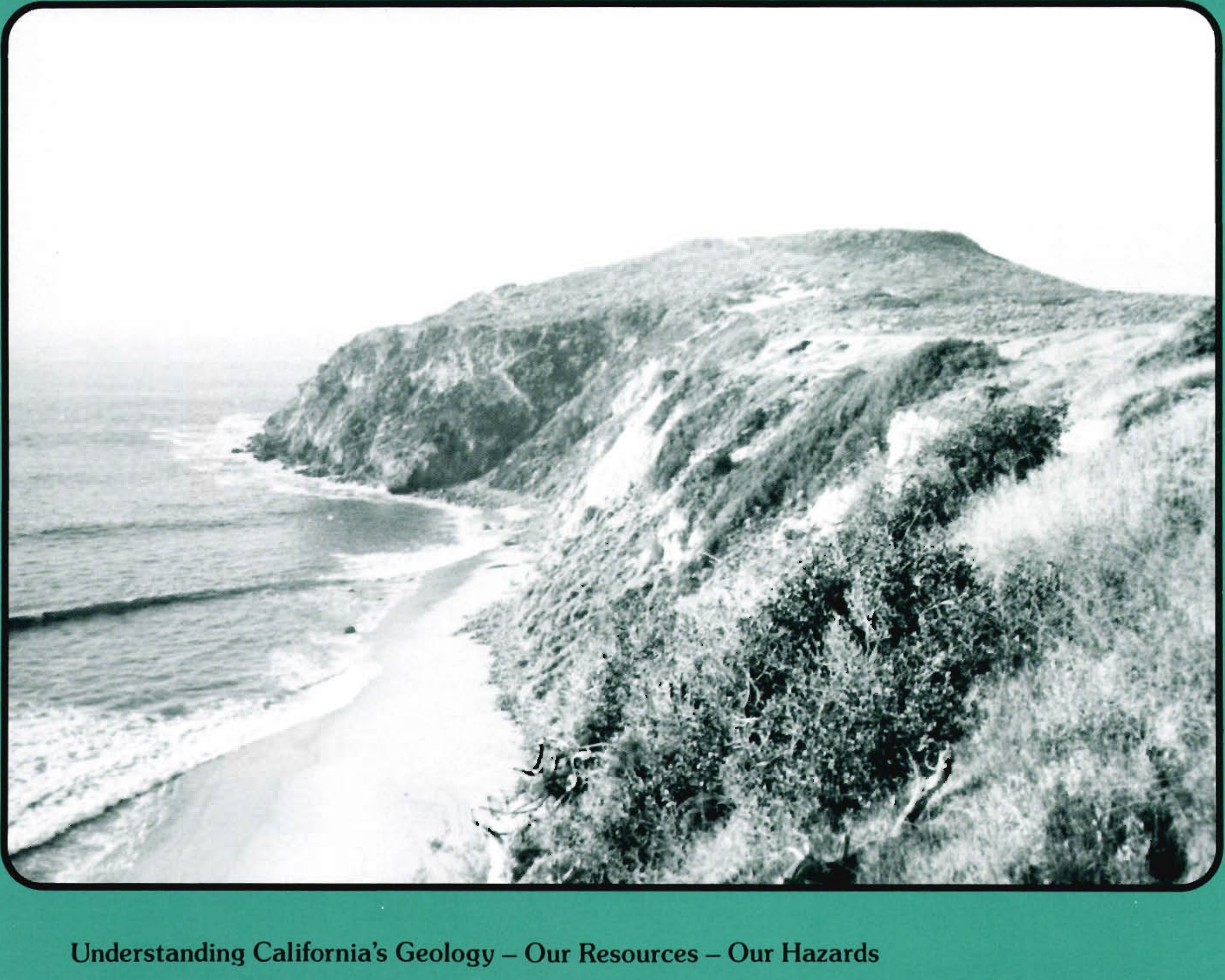
- Geologic Walkabout in Australia
- Volcanic Hazards at Mount Shasta
- Sedimentology of the Montgomery Creek Formation

## Paleomagnetism at Point Dume



Understanding California's Geology – Our Resources – Our Hazards

GORDON K. VAN VLECK, Secretary
THE RESOURCES AGENCY

GEORGE DEUKMEJIAN, Governor
STATE OF CALIFORNIA

RANDALL M. WARD, Director
DEPARTMENT OF CONSERVATION

CALIFORNIA GEOLOGY

A PUBLICATION OF THE
DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

State of California — GEORGE DEUKMEJIAN, *Governor*

The Resources Agency — GORDON K. VAN VLECK, *Secretary for Resources*

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*Printed:* Department of General Services
Office of State Printing

Division Headquarters: 1416 Ninth Street, Room 1341,
Sacramento, CA 95814
(Telephone: 916-445-1923)

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660 Bercut Drive, Sacramento, CA 95814
CALIFORNIA GEOLOGY: 916-445-0514;
Information: 916-445-5716

Los Angeles Office: 107 South Broadway, Room 1065,
Los Angeles, CA 90012
(Telephone: 213-620-3560)

Pleasant Hill Office: 380 Civic Drive, Suite 100,
Pleasant Hill, CA 94523
(Telephone: 415-646-5920)

CALIFORNIA GEOLOGY (ISSN 0026 4555) is published monthly by the Department of Conservation, Division of Mines and Geology. The Records Office is at 1721-20th Street, Sacramento, CA 95814. Second class postage is paid at Sacramento, CA. Postmaster: Send address changes to CALIFORNIA GEOLOGY (USPS 350 840), Box 2980, Sacramento, CA 95812-2980.

Reports concerning Division of Mines and Geology projects and articles and news items related to the earth sciences in California are included in the magazine. Contributed articles, photographs, news items, and geological meeting announcements are welcome.

THE CONCLUSIONS AND OPINIONS EXPRESSED IN ARTICLES ARE SOLELY THOSE OF THE AUTHORS AND ARE NOT NECESSARILY ENDORSED BY THE DEPARTMENT OF CONSERVATION.

Correspondence should be addressed to Editor, CALIFORNIA GEOLOGY, 660 Bercut Drive, Sacramento, CA 95814 (916) 445-0514.

Subscriptions: $7.00 per year. Single copies: $1.00 each. Send subscription orders and change of address information to CALIFORNIA GEOLOGY, P.O. Box 2980, Sacramento, CA 95812-2980.

November 1988/Volume 41/Number 11

CGEOA 41 (11) 241-264 (1988)

## In This Issue

Cover photo: Point Dume, Los Angeles County. During the past three decades paleomagnetic patterns in the earth's rocks provided scientists with a valuable tool for deciphering how continental plates have migrated, subducted, and collided to form the modern world topography. Within recent years scientists used paleomagnetic investigations to discover that the Transverse Ranges and portions of the continental borderland in southern California have rotated at least 80 degrees since the Miocene Epoch. Recent paleomagnetic investigations of the Miocene age Zuma Volcanics at Point Dume support that contention. An article about the methodology and the conclusions of paleomagnetic investigations at Point Dume starts on page 243. *Photo by J. C. Liddicoat.*

## Hazardous Materials Course

Findlay College of Ohio and the Association of Ground Water Scientists and Engineers, a division of the National Water Well Association, are offering a fifty-hour, five-day certificate program in the management of hazardous materials and hazardous wastes. The program will be held January 30 through February 3, 1989 in Findlay, Ohio.

The course is planned for technical and professional people working in the industry. Topics to be discussed include: the history of hazardous waste industry regulatory compliance, hazardous materials management, treatment technologies for hazardous waste, health and safety, toxicology, risk assessment, air and water quality, and consultant selection.

For additional information contact:

John Hosty
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1000 North Main Street
Findlay, OH 45840
(419) 424-4572

or

National Water Well Association
6375 Riverside Drive
Dublin, OH 43017
(614) 761-1711

## UNR Symposium

The Twenty-fifth Symposium on Engineering Geology and Geotechnical Engineering will be held March 20-23, 1989 at the University of Nevada-Reno. Topics will include: waste management and design for nuclear and chemical waste; geophysical and in-situ methods of site characterization; geotechnical applications of geostatistics and probability; engineering solutions to geologic hazards; earthquake and foundation engineering; highway materials and pavement design.

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# Paleomagnetism of the Zuma Volcanics
# POINT DUME
## Los Angeles County, California

By

EARTH SCIENCES BOARD
University of California, Santa Cruz

The earth's north and south magnetic poles migrate and reverse polarity over time. Paleomagnetism is the study of remanent magnetization in rocks containing iron-bearing minerals, such as hematite and magnetite, to determine past positions, intensities, and reversals in the earth's magnetic field. For example, as erupted lavas containing magnetite cool, the iron-bearing crystals become aligned parallel to the earth's magnetic field. The paleomagnetic record within those rocks is used by earth scientists to determine the geologic history of the earth's crust. This article reports a paleomagnetic investigation of the Zuma Volcanics which supports the contention that the Transverse Ranges and portions of the continental borderland in southern California have rotated 80 degrees clockwise during the past 16 million years . . . *editor.*

Photo 1. Point Dume, Los Angeles County. The rocks that make up the cliff face on the point are Miocene age Zuma Volcanics; the sea cliff in the foreground is the Monterey Formation. *Photo by J.C. Liddicoat.*

### INTRODUCTION

In recent years an interesting model has been developed for Neogene tectonic activity in southern California based on paleomagnetic data. In the model, dextral motion between the Pacific and North American plates produced clockwise rotation of tectonic blocks bound by pre-existing north-to-northeast trending normal faults (Kamerling and Luyendyk, 1979; Luyendyk and others, 1980; Hornafius, 1985; Kamerling and Luyendyk, 1985; Luyendyk and others, 1985; Terres and Luyendyk, 1985; Hornafius and others, 1986). These rotations are as much as 120 degrees in relation to a vertical axis and were accompanied by left-lateral displacement on the bordering faults. Using data collected from volcanic and sedimentary rocks, the realignment for the interval from 16 million years (m.y.) to 6 m.y. is presented in Figure 1 (Hornafius and others, 1986).

The paleomagnetic modeling data for the western Transverse Ranges are from the Miocene age Conejo Volcanics that are north of the Malibu Coast fault (Figure 2) (Kamerling and Luyendyk, 1979). The mean magnetic declination is anomalous by about 80 degrees in the clockwise sense. This declination should also be present in time-equivalent volcanic rocks south of the fault if the region between the Santa Ynez and Dume faults rotated as a whole (Figure 1). To explore that possibility, a paleomagnetic investigation was made of the Zuma Volcanics in the southernmost part of the general region between the Malibu Coast and the Dume faults.

### LITHOLOGY AND SAMPLE SITE

The Zuma Volcanics is early to middle Miocene in age and consists of basalt and andesite flows, breccias, pillow lavas, mudflow breccias, and aquagene tuffs* that are interbedded and overlain by the Monterey Formation (Photo 1) (Yerkes and Campbell, 1979). Locally the Zuma Volcanics contains siltstone and shale beds that are assigned to middle Miocene foraminiferal faunal stages (Relizian and Luisian stages) (Kleinpell, 1938). Fauna ages and a potassium/argon date of 14.6 ± 1 m.y. (Berry and others, 1976) from the southern tip of Point Dume place the Zuma Volcanics coeval with the Conejo Volcanics (Yerkes and Campbell, 1979).

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*An aquagene tuff is deposited in water and has an angular fragmentary texture.

Oriented hand samples of the Zuma Volcanics were collected at six sites along a 150 m transect on the southwestern end of Point Dume. No in-situ oriented cores were drilled because they would deface the sea cliff which is in the popular Point Dume State Beach. The purpose of this study was to document the presence or absence of a large-scale rotation of approximately 80 degrees similar to that known in the Conejo Volcanics north of the Malibu Coast fault as shown in figures 1 and 2. An estimated orientation error of 5 degrees in the horizontal plane and 10 degrees in the vertical plane seemed adequate for that purpose.

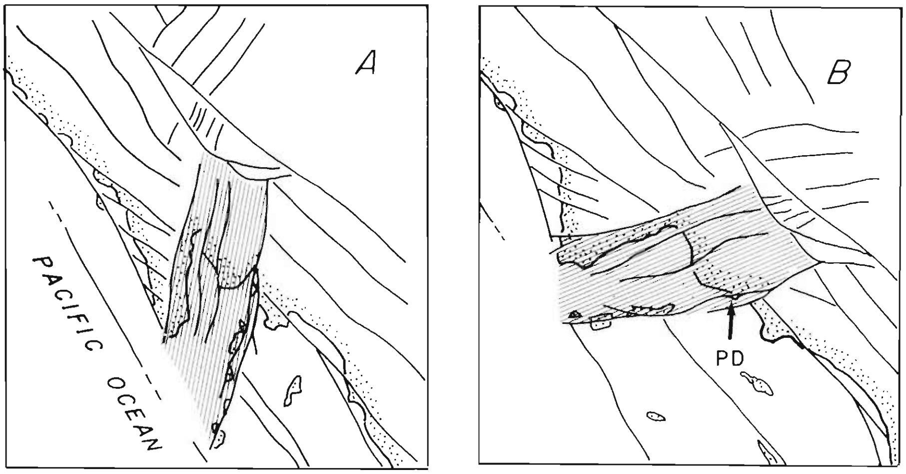
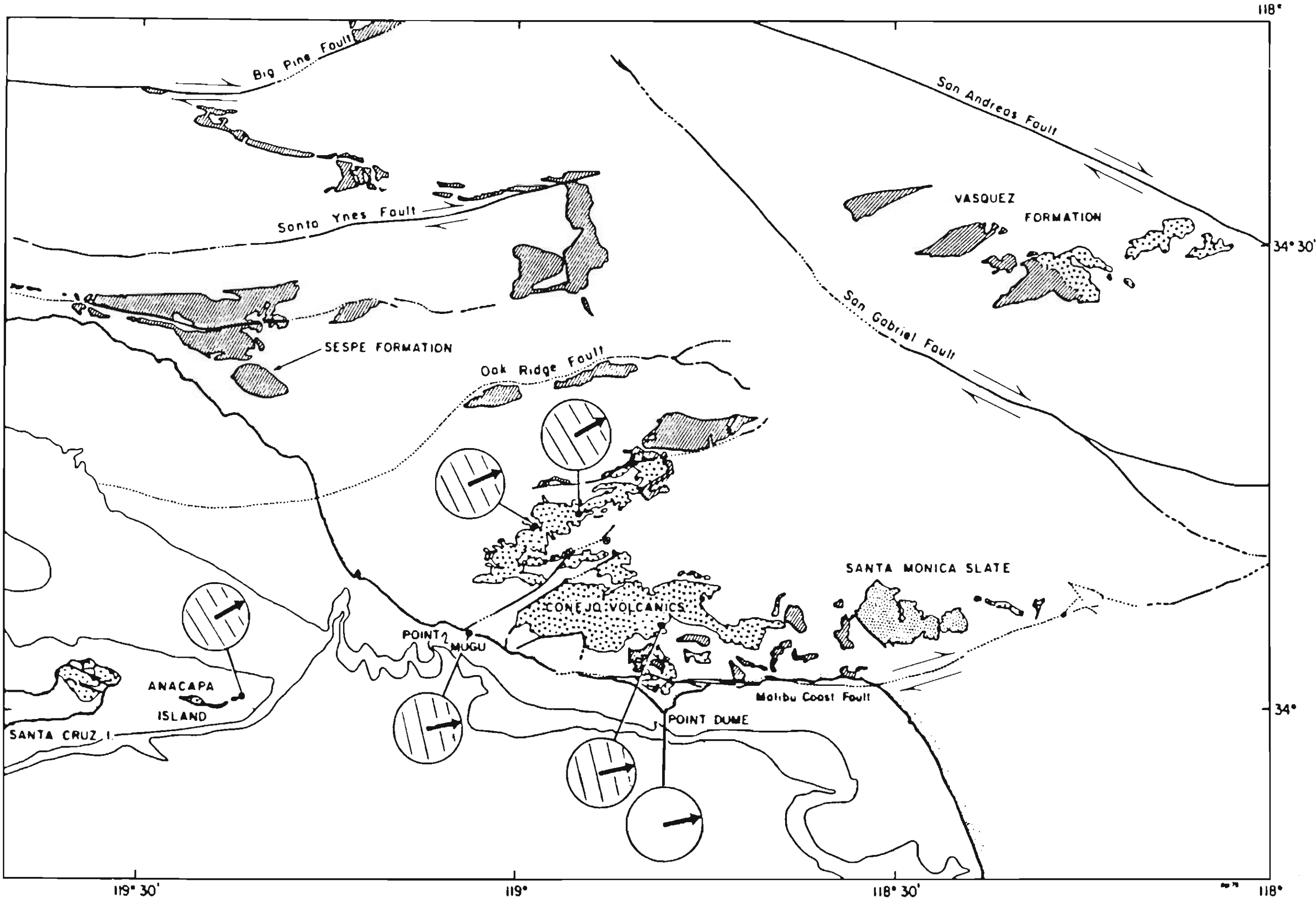


Figure 1. Configuration of southern California (A) 16 m.y. ago and (B) 6 m.y. ago as modeled by Hornafius and others (1986). In B, note the nearly 80 degree clockwise rotation of the tectonic block that is bordered on the north by the Santa Ynez fault and on the south by the Dume fault; it is the region highlighted by hachures. Point Dume (PD in B) is between the Malibu Coast fault and Dume fault. *Modified after Hornafius and others (1986).*

Figure 2. Map of western Transverse Ranges and continental borderland showing declination (arrows in shaded circles) in Miocene volcanics studied by Kamerling and Luyendyk (1979) and declination in the Zuma Volcanics at Point Dume (unshaded circle) from this report. Note the declination for the Zuma and Conejo volcanics is parallel and approximately 80 degrees clockwise from normal polarity; normal polarity closely parallels the present ambient geomagnetic field direction. *Modified after Kamerling and Luyendyk (1979).* ▼



## LABORATORY PROCEDURES

In the laboratory, 11-cubic-centimeter cores were measured in a cryogenic magnetometer. These specimens were subject to either alternating field demagnetization or thermal demagnetization in incremental steps to 999 oersteds (99.9 milliteslas) or 585 degrees centigrade, respectively (Figure 3). The specimens do not contain a secondary magnetization of importance, and a blocking temperature* of 585 degrees centigrade identifies magnetite as the primary source of the remanent magnetization.

Samples of the Zuma Volcanics were also sought south of the Malibu Coast fault. Outcrops of this unit are described in the literature (Yerkes and Campbell, 1979) and are on the geologic map of the east-central Santa Monica Mountains (Yerkes and Campbell, 1980). However, no other accessible localities were found where the volcanics are unweathered or unbrecciated. Exposures of the Zuma Volcanics at the eastern and southern ends of Point Dume are inaccessible by foot which prevented sample collecting at those localities. Therefore, sampling was confined to the southwestern end of the point.

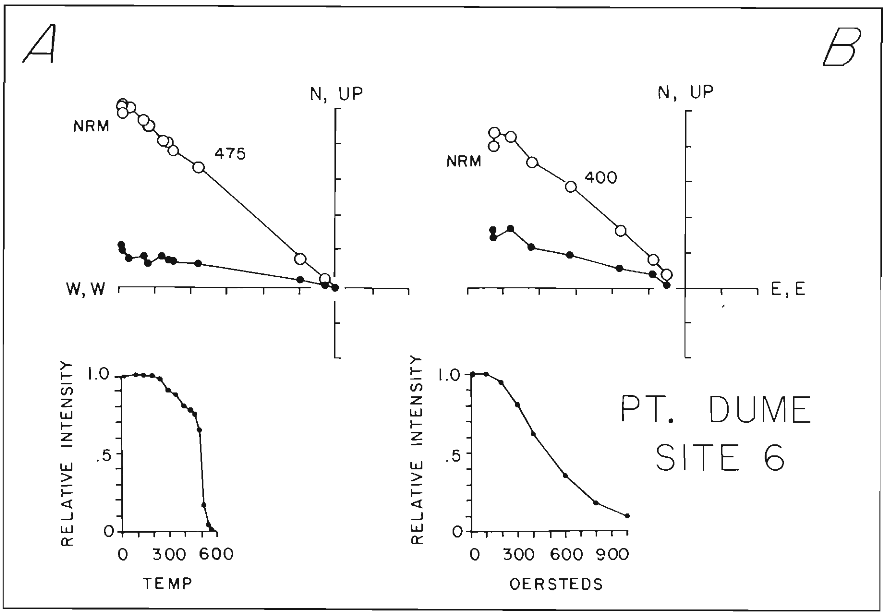


Figure 3. Vector diagrams and normalized intensity for specimens A and B from Site 6 in the Zuma Volcanics at Point Dume following (A) thermal demagnetization to 585°C, and (B) alternating field demagnetization to 999 oersteds. The specimens record reversed polarity and the blocking temperature in (A) is 585°C. In the vector diagrams, solid circles are projections on the NS-EW plane and open circles are projections on the EW-vertical plane. Divisions on the axes in the vector plots are 2.50 X $10^{5}$ electro-magnetic units/cubic centimeter and the numbers next to the dots are the level of demagnetization.

The Miocene age Monterey Formation in the sea cliffs adjacent to the Zuma Volcanics does not contain a clear primary magnetization. Specimens from a sample collected about 100 m northwest of Site 6 are weakly magnetized (undemagnetized natural remanent magnetism — NRM — is 5 × $10^{7}$ electro-magnetic units/cubic centimeter) and have paleomagnetic directions that are close to an axial dipole field before applying a bedding correction. Because of the ambiguous remanent magnetization in the Monterey Formation, we did not explore further the desirable possibility of recording tectonic rotation in igneous and sedimentary rocks of similar age from a single locality.

## PALEOMAGNETIC DATA INTERPRETATION

The collected specimens record reversed polarity and have a declination that is biased to the west (sites 1, 2, 5, and 6) or southwest (sites 3 and 4). Mean declination and the associated confidence levels of 95 percent (termed alpha-95s) (Fisher, 1953) for individual sites are plotted in Figure 4a. The mean paleomagnetic directions for all specimens (N = 45) is declination of 258.5 degrees and inclination of −43.3 degrees (Table 1).

TABLE 1. PALEOMAGNETIC DATA FOR THE ZUMA VOLCANICS, POINT DUME, CALIFORNIA.

| SITE | INCL | DECL | N | k | $\alpha^{95}$ | PLAT | PLONG | TEST |
|---|---|---|---|---|---|---|---|---|
| 1 | −25.5 | 287.1 | 7 | 55.5 | 8.2 | 6.2 N | 130.5 E | 30, 500° |
| 2 | −36.5 | 264.8 | 13 | 28.1 | 8.0 | 15.3 S | 136.8 E | 30 |
| 3 | −36.3 | 215.4 | 4 | 299.7 | 5.3 | 55.8 S | 165.8 E | 30, 500° |
| 4 | −58.3 | 217.6 | 10 | 84.3 | 5.3 | 59.5 S | 130.7 E | 30, 500° |
| 5 | −40.0 | 283.5 | 5 | 585.5 | 3.2 | 2.2 S | 125.0 E | 30, 500° |
| 6 | −38.9 | 257.7 | 6 | 20.6 | 15.1 | 21.9 S | 138.8 E | 30 |
| All Data | −43.3 | 258.5 | 45 | 10.7 | 6.8 | 22.8 S | 135.3 E | — |
| Sites 1, 2, 5, and 6 | −35.6 | 271.9 | 31 | 22.4 | 5.6 | 9.4 S | 133.7 E | — |
| Sites 3 and 4 | −52.0 | 216.8 | 14 | 39.7 | 6.4 | 59.4 S | 143.3 E | — |
| Sites means | −42.7 | 257.5 | 6 | 10.2 | 22.0 | 23.4 S | 136.2 E | — |

| | |
|---|---|
| SITE: | Site number |
| INCL: | Mean inclination (degrees) |
| DECL: | Mean declination (degrees) |
| N: | Number of specimens measured |
| k: | Fisher precision parameter |
| $\alpha^{95}$: | Alpha-95, radius (degrees) of circle of 95 percent confidence about the mean paleomagnetic direction |
| PLAT: | Latitude of virtual geomagnetic pole (VGP) |
| PLONG: | Longitude of VGP |
| TEST: | Level of demagnetization (milliteslas, degrees Celsius) used for the site mean paleomagnetic direction |

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*Blocking temperature is that temperature below which a rock has a stable remanent magnetization.

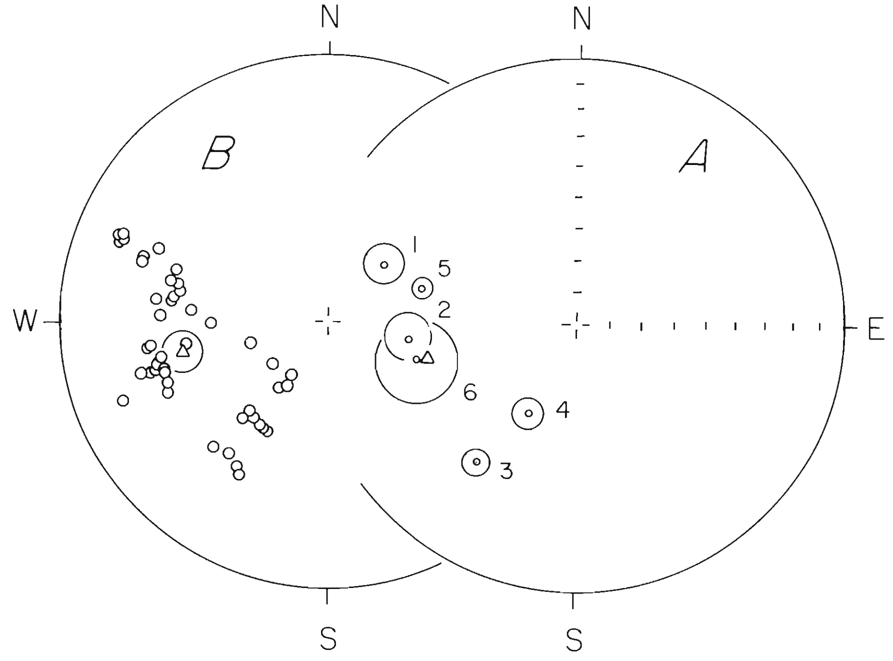

Figure 4. Equal-area plot of (A) site means directions and circles of 95 percent confidence for the Zuma Volcanics at Point Dume and (B) directions of individual specimens. The open triangle in (A) is the mean for the six sites and in (B) it is for all specimens (N = 45); the 95 percent circle of confidence is shown in B. The mean declination for the six sites is 257.5 degrees (77.5 degrees for normal polarity). All data are plotted on the upper hemisphere.

Although the grouping of paleomagnetic directions for individual sites is quite good (except for Site 6 where alpha-95 is 15.5 degrees, the other sites have an alpha-95 of 8.2 degrees or less), there is considerable scatter in declination between sites. This might be attributed to poor sample orientation or could reflect secular variation if the volcanic rock was intrusive and cooled slowly. The latter possibility is favored because the field orientation for azimuth direction was done with care and did not exceed an orientation error of 5 degrees.

Inclination of an axial dipole (reverse) field for the locality is −53.5 degrees. This inclination is best approximated at Site 4 (−58.3 degrees) but is as low as −25.5 degrees at Site 1. Some of the nearly 10 degrees of discrepancy for all data (−53.5 degrees versus −43.3 degrees) might come from tilting of the volcanic rocks along the fault that separates them from the Monterey Formation (Figure 5).

The Zuma Volcanics at Point Dume is not a series of lava flows; therefore, an attitude (strike and dip) could not be measured. Tilting exposed in nearby cliffs and paralleling the bedding in the Monterey Formation which abuts Zuma Volcanics rocks was discounted. These sediments dip 30 degrees to the northeast around a strike of about 300 degrees. If this correction is applied to the volcanic rocks, the inclination would approach horizontal and be even more anomalous. For this reason, and because there is no evidence of a partial magnetic overprint in the volcanics that cannot be removed during demagnetization, it is likely that the shallow inclination results from a combination of secular variation and horizontal errors in the field and laboratory preparation of samples.

Another possibility is that the Zuma Volcanics was formed in a more southerly latitude (by about 10 degrees). The likelihood that this concept is applicable to this investigation should be viewed conservatively because only the locality at Point Dume is involved. This consideration, however, is supported by the hypothesis that the western Transverse Ranges and outer continental borderland originated west of Baja California (Crouch, 1979).

Kamerling and Luyendyk (1979) applied the hypothesis by Crouch (1979) that the western Transverse Ranges and the outer continental borderland formed west of Baja California, which would also place the Zuma Volcanics at a more southerly latitude. Kamerling and Luyendyk (1979) then proposed three pre-rotation positions for the region shaded in Figure 1 and put the southern boundary of the region at about 26.5 degrees north latitude. Interpretation aside, it is remarkable that the Zuma Volcanics and Conejo Volcanics have nearly identical mean inclinations: −43.3 degrees versus −44.8 degrees, respectively. The inclination for the Conejo Volcanics is from Table 1 in Kamerling and Luyendyk (1979).

## SUMMARY

The paleomagnetic data for the Zuma Volcanics from this investigation reinforce the conclusion of Hornafius and others (1986) that the position of southern California defined by the Malibu Coast fault and Dume fault has rotated clockwise by a minimum of 80 degrees since the middle Miocene. Possible evidence for such rotational motion in the Los Angeles Basin to the south might be found in the El Modeno (Yerkes, 1957) and Glendora (Shelton, 1965) volcanics of middle Miocene age that bracket the Whittier-Elsinore fault zone in the northern part of the basin. However, initial samples and paleomagnetic data collected from both formations do not show a rotation across the fault zone. That is contrary to paleomagnetic data for Pliocene-Pleistocene sediments (from the Imperial and Palm Springs formations) in the western Imperial Valley that show up to 35 degrees of clockwise rotation on the north side of the fault zone (Johnson and others, 1983).

## ACKNOWLEDGMENTS

This investigation was undertaken as a laboratory project for an undergraduate course in paleomagnetism at the University of California, Santa Cruz. Participants were L. Beil, G. Borsay, R. Burns, R. Burton, N. Callero, P. Chirinos Arias, L. Dion, C. Figler, J. Glen, M. Holden, D. Longstreth, G. Martindale, L. Meng, J. Park, P. Rankin, J. Schwartz, B. Smith, E. Smith, L. Solso, and C. Tang. Inquiries should be directed to J. C. Liddicoat, Earth Sciences Board, University of California, Santa Cruz, CA 95064.

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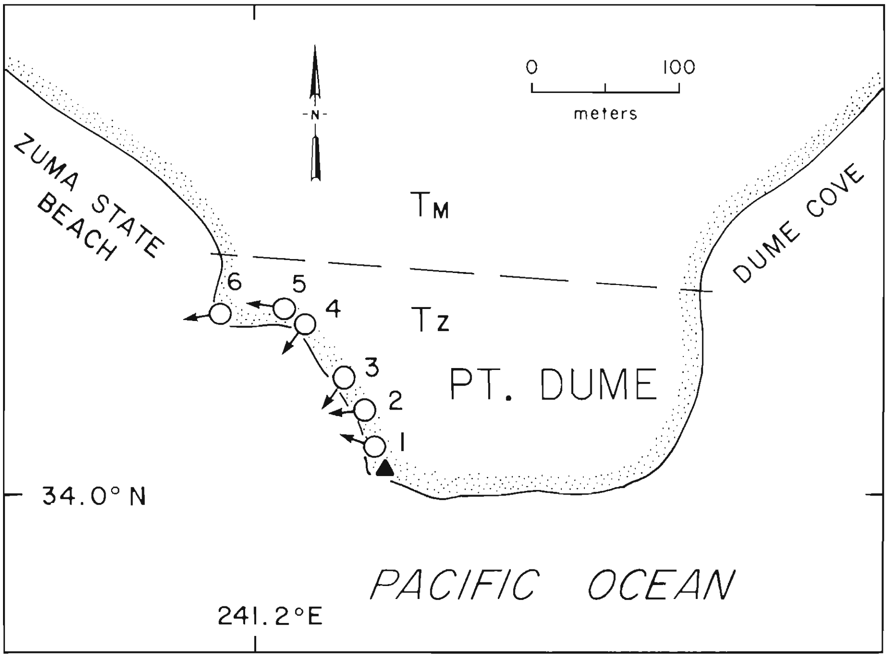

Figure 5. Generalized map of Point Dume showing the position of sites 1 through 6 and the azimuth (arrows) of the mean declination for each (Table 1). Dashed line is the inferred trace of the fault that separates the Zuma Volcanics (Tz) from the Monterey Formation (Tm). Note the two populations of declination — sites 1, 2, 5, and 6 to the west and sites 3 and 4 to the southwest. Solid triangle is the location of the potassium/argon date of 14.6 ± 1 m.y. (Berry and others, 1976). *Modified after Yerkes and Campbell (1979).*

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# Trivia

1. What was the most destructive historical earthquake?
2. What was the most destructive earthquake in this century?
3. What was the largest earthquake ever recorded?
4. What is the name of Alfred Wegener's book which presents the theory that all major continents on earth today were once united into a single landmass called Pangaea?

ANSWERS:

1. The most destructive earthquake, and the most destructive natural disaster, occurred in 1556 when a major earthquake collapsed thousands of loess cave dwellings in China's Shen-shu Province. Well-documented deaths exceeded 820,000.
2. The most destructive earthquake in modern times was the great T'ang Shan 1976 earthquake. On a rainy July morning two earthquakes of magnitude 8.0 and 7.4 devastated the industrial city of T'ang Shan located about 150 kilometers southeast of Beijing, China. The number of deaths is estimated at 655,000. The high population density, the mud-brick title-roofed buildings, and the fact that the first quake struck when most of the people were indoors sleeping greatly contributed to the enormity of the tragedy.
3. The largest earthquake observed to date was the great Chilean earthquake of 1960. Because the Richter scale does not adequately measure very large earthquakes, the Chilean earthquake has been estimated at 9.5 on the *Moment magnitude scale.* For comparison, the 1906 San Francisco earthquake was estimated at 7.9 on the *Moment magnitude scale.*

   Moment magnitude is based on the *seismic moment* - a product of the area faulted, the fault slip and displacement, and the shear modulus (rigidity) of the rock medium at the quake source. The upper limit of earthquake magnitude is open. The faulted area from the Chilean earthquake was about 1.6x10$^5$ km$^2$, and the fault displacement was about 20 meters. For comparison, the faulted area for the 1906 San Francisco earthquake was about 6.45x10$^3$ km$^2$, and the fault displacement was 5 to 7 meters.
4. In 1915 Wegener's book, *On the Origin of Continents and Oceans (Die Eustehung der Kontinents und Ozeane)*, was published. Wegener (pronounced *vag-ah-ner)* a German meteorologist, presented the theory of continents breaking off from a supercontinent he called Pangaea. It was not until 30 years after he died that the plate-tectonic concept supported his theory of continents moving laterally for enormous distances.

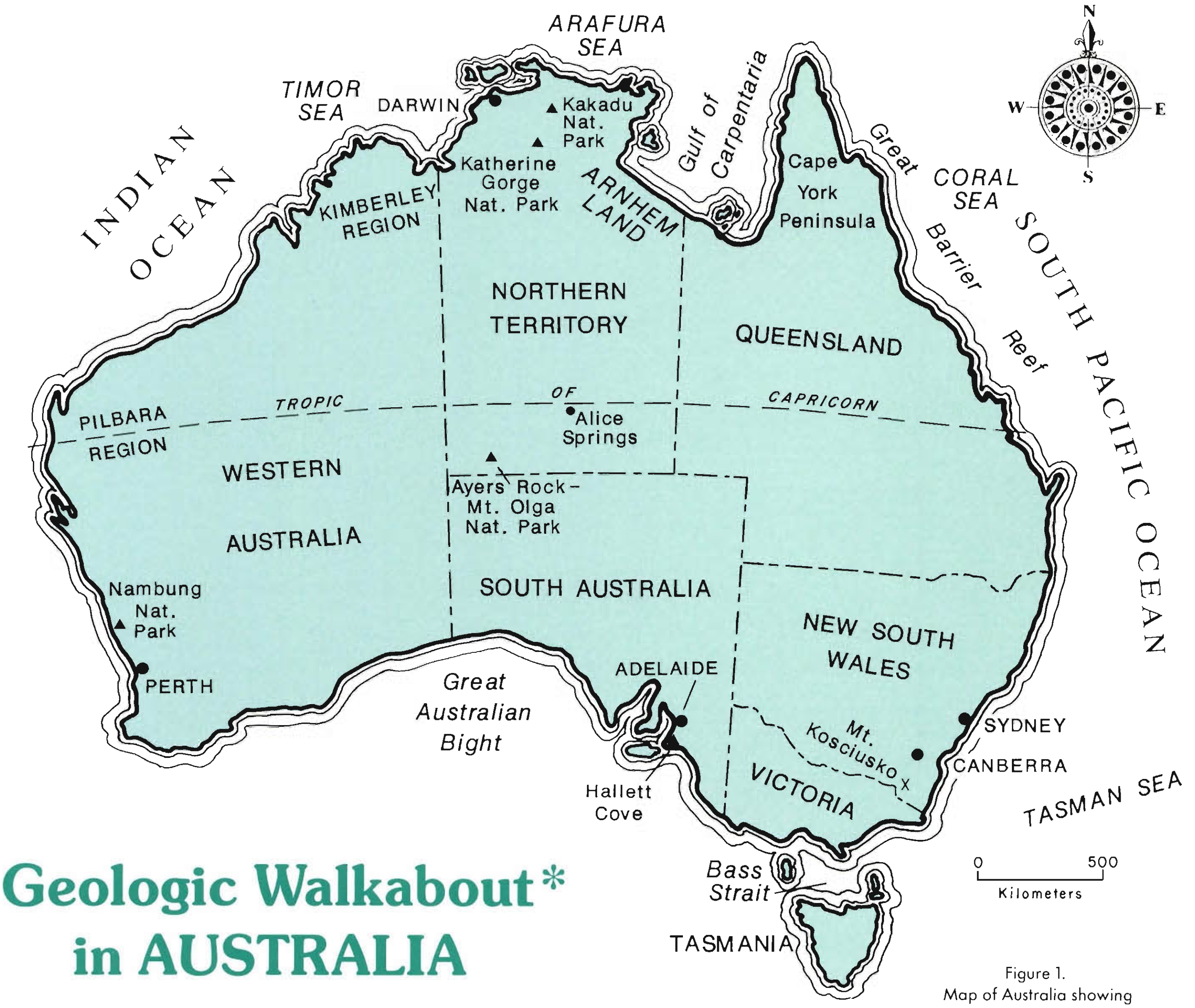

Figure 1.
Map of Australia showing localities mentioned in text.

# Geologic Walkabout* in AUSTRALIA

By

Mary C. Woods, Geologist
Division of Mines and Geology

During 1988 Australians are celebrating the 200th anniversary of the settlement of the island continent by Europeans. The Latin term "terra australis incognita" (unknown southern land) was used by cartographers and seamen on early maps as a generic name for a land mass that was thought to exist in the vast void of the southern Pacific Ocean. In 1770 when Captain James Cooke discovered the land he named it New South Wales (Butts, 1970).

The continent of Australia covers 2,867,741 square miles in the southern hemisphere between the Indian Ocean on the west and the South Pacific Ocean on the east (Figure 1). It is approximately the size of the continental United States.

Australia is the flattest, driest, oldest, most isolated geographic land mass, and one of the least populated continents. Only about 10 percent of the land is arable. About 20 percent of the land is hilly or mountainous. The highest point is Mount Kosciusko, which is 7,316 feet in elevation.

The majority of the approximately 16 million people of Australia live in subtropical to temperate regions along coastal areas in the east, the southeast, and the southwest.

The vast interior (called the outback or bush) is mainly desert where there are few roads or populated areas. The Top, as the northern area is called, has a hot, humid subequatorial climate and semidesert conditions inland. The largest city in the northern area is Darwin (Butts, 1970).

## GEOLOGIC FEATURES

This vast craton is the oldest of the continents. It came into being as an island continent in the Triassic Period (255 million years ago) during the gradual break up of the ancient Gondwanaland landmass, which was the parent land of Australia, Antarctica, South America, and Africa. The boundary of the Australian plate is some distance away from the continent and the center of the area (Australia) is stable. There are no active volcanoes in Australia and seismic activity is relatively lower than it is at plate margins; however, some damaging earthquakes have occurred in Australia.

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*refers to the nomadic life of the Aborigines as they wandered about the land seeking food.

Glacial striations on Precambrian rock, Hallett Cove, South Australia. *Photo by Marjorie J. Duffy.*

### Hallett Cove Conservation Park

Some clues to the close ties between Australia and Antartica are found at Hallett Cove on the Fleurieu Peninsula south of the city of Adelaide, South Australia.

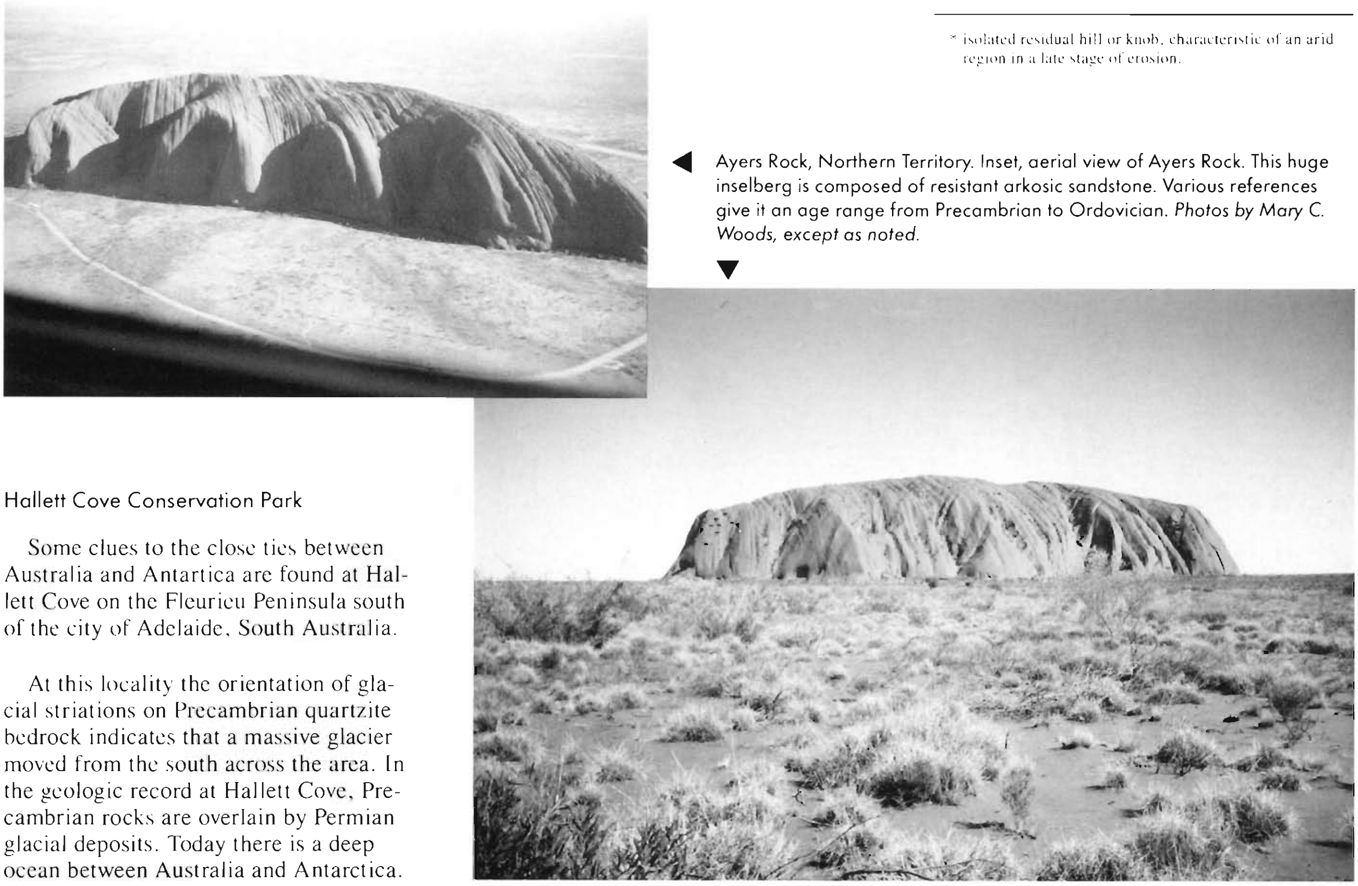
At this locality the orientation of glacial striations on Precambrian quartzite bedrock indicates that a massive glacier moved from the south across the area. In the geologic record at Hallett Cove, Precambrian rocks are overlain by Permian glacial deposits. Today there is a deep ocean between Australia and Antarctica.

In Permian time the parent land mass was still intact and glaciers covered most of the southern land. The Permian glaciers left their mark on the land that broke off during drifting of the continents (Cooper, and others, 1976).

### Ayers Rock – Mount Olga National Park

Ayers Rock in the Northern Territory is a mammoth inselberg* of Precambrian arkosic sandstone rising abruptly 1,143 feet above the desert floor in central Australia. It has been an object of wonder since humans first saw it. The Aborigines have lived on the continent for 40,000 years; they consider it a sacred spot. The native name for the rock is Uluru. European settlers and others from many countries find it equally fascinating. Uluru — the subject of mythology, folk-tales, and scientific investigations — is a focal point of Uluru-Mt. Olga National Park.

In Precambrian time the area was a vast sea where thick sequences of sediment accumulated in horizontal layers. Over geologic time the sand was compressed into sandstone. The strata were tilted almost vertically by regional tectonic movement about 500 million years ago (during the Ordovician Period).



◀ Ayers Rock, Northern Territory. Inset, aerial view of Ayers Rock. This huge inselberg is composed of resistant arkosic sandstone. Various references give it an age range from Precambrian to Ordovician. *Photos by Mary C. Woods, except as noted.* ▼

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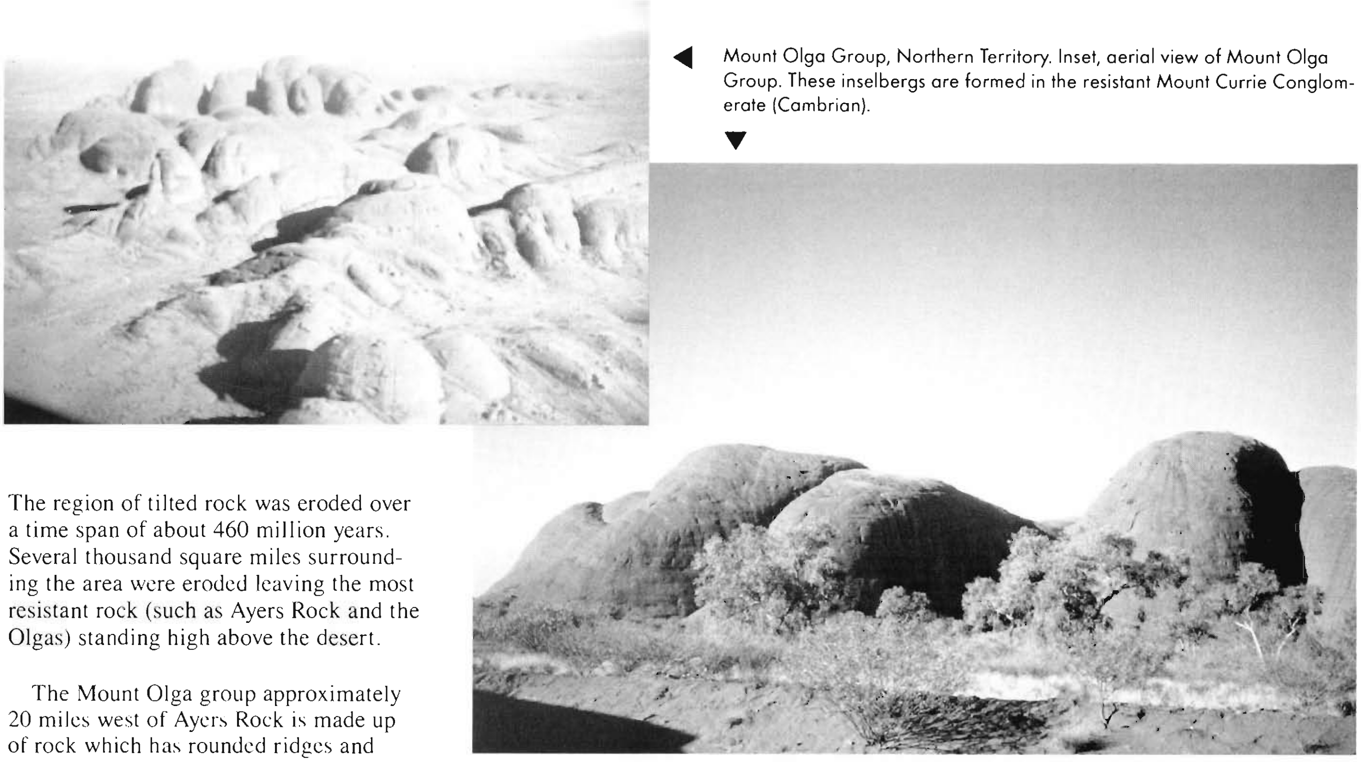
* isolated residual hill or knob, characteristic of an arid region in a late stage of erosion.



Mount Olga Group, Northern Territory. Inset, aerial view of Mount Olga Group. These inselbergs are formed in the resistant Mount Currie Conglomerate (Cambrian).

The region of tilted rock was eroded over a time span of about 460 million years. Several thousand square miles surrounding the area were eroded leaving the most resistant rock (such as Ayers Rock and the Olgas) standing high above the desert.

The Mount Olga group approximately 20 miles west of Ayers Rock is made up of rock which has rounded ridges and domes that appear to be giant caterpillars huddled together. The native name for the Olgas is Kata Tjuta. The rocks are 1,000 feet high and are composed of a massive conglomerate facies of Cambrian sandstone. Conglomerate clasts of the Mount Olga Group range from pebbles to boulders (Wooley, 1977).

During Tertiary time the inselbergs were islands in an extensive lake. The bedrock in this area is about 200 feet below the sand and clay deposited by lacustrine processes in the surrounding area.

The appearance of ribs on Ayers Rock is due to weathering of the tilted stratified sandstone. The rounded surface of the rock is the result of spalling, a weathering process that causes flakes or plates to slough off the homogeneous surface. The sandstone mass of Ayers rock has almost no planes of weakness (joints or faults).

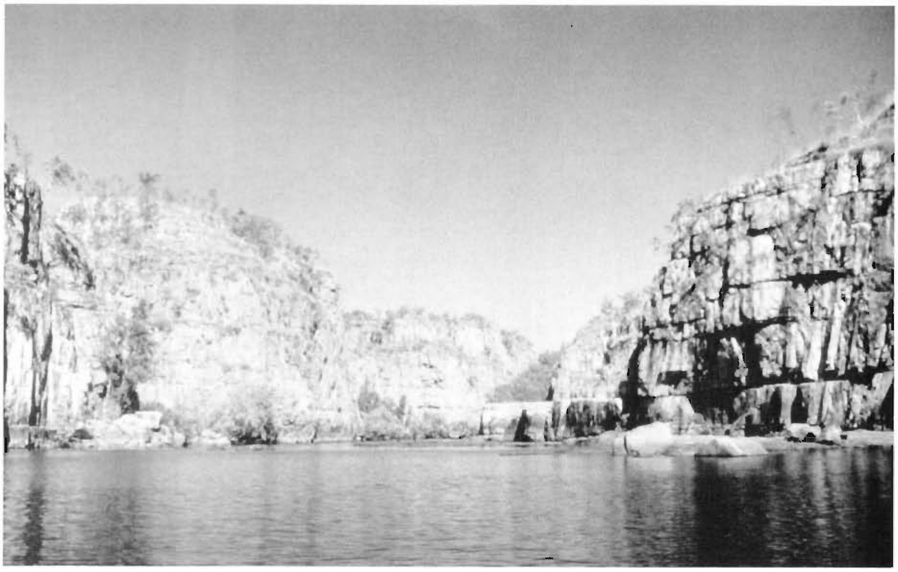
The massive conglomerate of Mount Olga has nearly horizontal bedding with vertical joints. Erosion along the joints has formed ridges and hills separated by steep sided valleys (Ollier, 1980). Iron oxides give the red color to the rocks and surrounding soils.

### Katherine Gorge National Park

A thick sequence of sedimentary and volcanic deposits of Precambrian age (1800-2200 million years old) occurs in the Arnhem Land Plateau near Darwin, Northern Territory. The drainage of the Katherine River developed in joints in the massive siltstone and sandstone deposits. The river cut down into the joints as the land was uplifted forming steep sided cliffs (Walpole and others, 1968). This scenic area is a national park and contains ancient rock art of the Aborigines.

### Kakadu National Park

The Arnhem Land Escarpment and Plateau are the outstanding topographic features in this park which was established in 1979. The area is inhabited by about 150 Aborigines who combine their ancient stone-age culture with that of modern times. In this area of 6,600



Katherine Gorge. The Katherine River has cut through the Arnhem Land Plateau along joints in the massive sandstone. *Photo by Marjorie J. Duffy.*

square miles there are about 5,000 rock-art sites sacred to the Aborigines. Some of the rock art is reported to be 20,000 to 35,000 years old (Breeden, 1988).

This vast park of floodplains, tidal flats, and billabongs* (marshy areas formed by cutoff segments of meandering streams) is noted for the great variety of wildlife present in the area — 50 species of mammals, 75 species of reptiles (including man-eating salt-water crocodiles), 275 species of birds, and many other forms of fauna as well as flora.

There are mineral deposits present in the park and uranium is mined at one site in the park.

### Nambung National Park

The Pinnacles Desert is a geological curiosity in the Nambung National Park on the coast north of Perth, Western Australia. The resistant rock columns known as the Pinnacles are in the Pleistocene Tamala Limestone, a formation composed of lime and quartz sand. The columns range from a few inches to about 15 feet in height. They were formed by water percolating downward into the limestone over thousands of years. As the water seeped downward it dissolved the lime and deposited it as calcite along the root systems of plants and in fractures and channels in the sediments, forming an irregular surface below the leached sand. Over time erosion removed the soft sediments and left the more resistant columns formed by the leaching process (Playford and others, 1976).

Billabong, a marshy cutoff segment of a river meander, Kakadu National Park. The wetland forms the habitat for numerous fauna and flora. *Photo by Marjorie J. Duffy.*

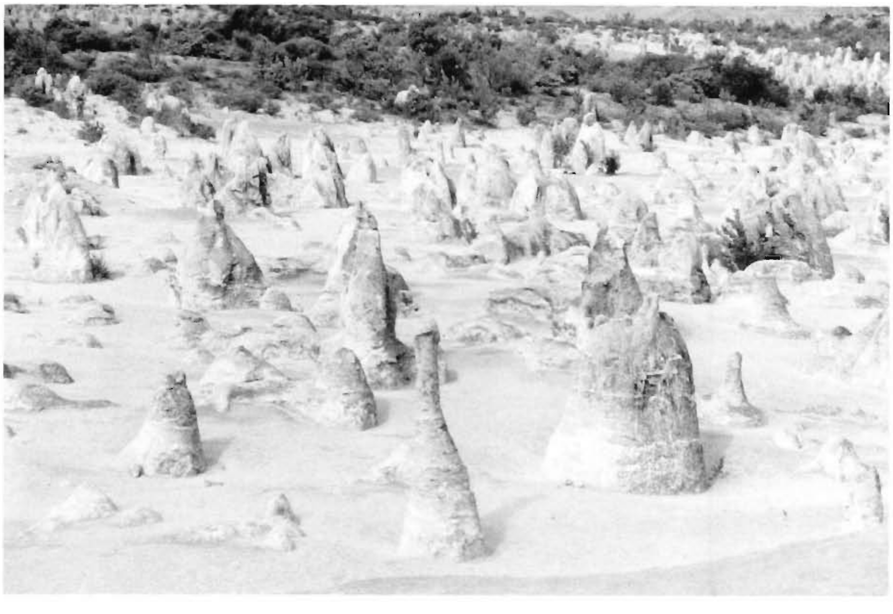
## MINERAL RESOURCES

Mining is a major industry. Mineral resources include iron, lead, zinc, copper, silver, gold, uranium, nickel, coal, oil and gas, and bauxite. The bauxite deposits on Cape York Peninsula are the largest in the world (Butts, 1970). Australia provides roughly 70 percent of the petroleum used in the country and it produces nearly 18 percent of the world's uranium.

Australia ranks second in iron ore production. Iron ore is found in Precambrian sedimentary rocks that were deposited 2000 million years ago. Iron deposits are widespread in Precambrian and Paleozoic rocks of western and central Australia. The Precambrian Brockman Formation is extensive in the Pilbara and Hamersley ore provinces of Western Australia (Fairbridge, 1975).

The Mount Isa copper-silver-lead-zinc deposit in Queensland is one of the largest lead-zinc producers in the world. The richest silver-lead-zinc mine is located at Broken Hill, New South Wales (Jensen and Bateman, 1981).

Australia supplies about 90 percent of the world's opals, which are highly prized for their vivid fire. Rare black opals are found at Lightning Ridge, New South Wales and Coober Pedy, South Australia. At Coober Pedy in the Stuart Range, the largest opal producing area, the matrix in which the opal occurs is leached sandy claystone. The sediment was deposited in a marine environment during the Cretaceous Period. The rocks were subsequently deeply weathered during the Tertiary Period. Opal also occurs at various other localities in Precambrian, Paleozoic, and Tertiary sediments (Jensen and Bateman, 1981).



◀ Pinnacles, Nambung National Park, Western Australia. These limestone columns are erosional features developed in the Pleistocene Tamala Limestone. *Photo by Marjorie J. Duffy.*

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*native name meaning "dead river."

Aerial view of an eroded anticline with meandering river cutting across the eroded surface, western Macdonnell Ranges southwest of Alice Springs, Northern Territory. Oil and gas deposits occur in the general area.

In 1979 diamonds were discovered in the remote Kimberley area of northwestern Australia. Diamonds from the Argyle kimberlite are popular for the range of color which grades from white to champagne to cognac. Based on the volume of diamonds (30 million carats per year), the Argyle mine is the largest diamond mine in the world. The diamonds are produced from the kimberlite pipe and from alluvial gravels downstream from the pipe. About 5 percent of the Argyle diamonds are gem quality; 40 percent are industrial quality; and 55 percent are in intermediate categories (Suttill, 1987).

The bulk of the Argyle diamonds are very small (1 mm to 3 mm) and unique x-ray fluorescent sorters were developed to separate the diamonds from the crushed waste matrix (Suttill, 1987).

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# Volcanic Hazards at Mount Shasta

New information on potential volcanic hazards at Mount Shasta in Siskiyou County, California, has been prepared as a cooperative effort between the U.S. Geological Survey, the California Department of Conservation, Division of Mines and Geology, and the Governor's Office of Emergency Services. *Volcanic hazards at Mount Shasta* describes the potential location of hazard zones and outlines emergency procedures for residents of the area.

Mount Shasta — a long-dormant volcano in northern California — is the largest of the Cascade Range volcanoes, towering to 14,162 feet above sea level and rising almost two miles above the communities of Weed, Mount Shasta, McCloud, and Dunsmuir. It is a stratovolcano, which means it is a massive cone built of alternating layers of lava and fragments of volcanic debris.

More than 500,000 years ago Mount Shasta began forming, and it has been repeatedly active during the last 10,000 years. Although the mountain does not erupt at regular intervals, its geologic history indicates that it erupts on an average of about once each 250 to 300 years. The last eruption was in 1786.

Even though the volcano has not been active for two centuries, Mount Shasta is like Mount St. Helens before 1980 and almost certainly will erupt again. The potential types of volcanic activity expected at Mount Shasta, based on what has occurred in the past, include both explosive and non-explosive eruptions. Explosive eruptions can produce volcanic ash, pyroclastic flows (fast-moving streams of hot volcanic ash and rock fragments mixed with hot gases), and lateral blasts. Non-explosive eruptions can form lava domes inside the volcanic crater and lava flows down the side of the mountain. In addition, both explosive and non-explosive eruptions can cause mudflows down local drainageways. Both types of activity often are accompanied by emissions of gas.

Low cone-shaped hills in Shasta Valley resemble volcanic vents. These features are erosional remnants of a 300,000-year-old debris avalanche from Mount Shasta. View north of Grenada, Siskiyou County. *Photo by C. W. Chesterman.*

All volcanic events at Mount Shasta within the last 1,000 years occurred on the northern and eastern flanks of the volcano, and this is where the next eruptive activity is most likely to occur. Although scientists cannot yet accurately predict when Mount Shasta will erupt again, a future eruption is likely to be preceded by repeated earthquakes, venting of gases, and swelling of all or parts of the volcano. No single precursor is a reliable guide for forecasting the exact time, place, and scale of an impending eruption.

Currently, there is no sign of volcanic activity at Mount Shasta and no indication of when the mountain might become active again. Instruments designed to detect any precursory activity are monitored by the U.S. Geological Survey. This would allow scientists to alert state and local officials to activate existing emergency response plans.

Single copies of *Volcanic hazards at Mount Shasta, California* are available free from: Books and Open-File Reports, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80025. The booklet is based on USGS Bulletin 1503, *Potential hazards from future eruptions in the vicinity of Mount Shasta volcano, northern California*, by C. Dan Miller. ⚒

# Sedimentology of the MONTGOMERY CREEK FORMATION

## Shasta County, California

By

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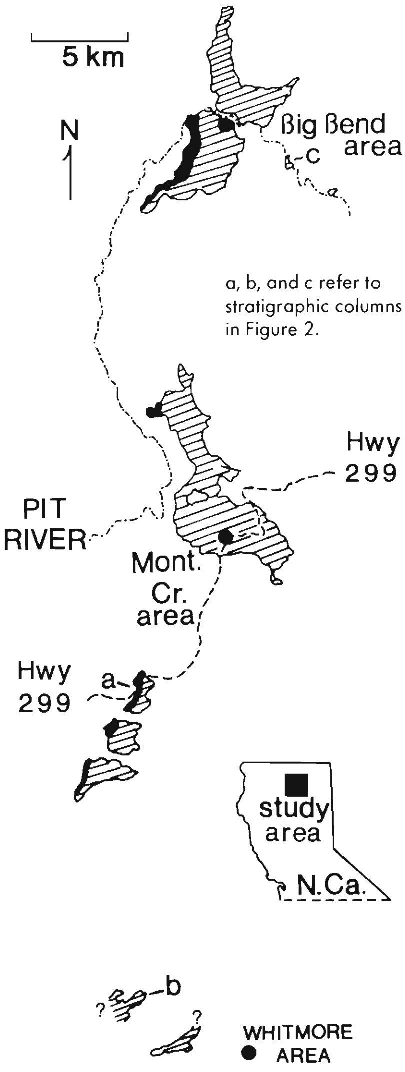
In this article the author presents new information about paleocurrents and the origin of sediment within the Late Cretaceous to Eocene age Montgomery Creek Formation exposed northeast of Redding. This formation is nonmarine and the lithology is predominately conglomerate, arkosic sandstone, and shale. The type locality is on the north side of Montgomery Creek, about 2½ miles east-northeast of the town of Montgomery Creek, Shasta County. A previous article about the Montgomery Creek Formation was in the June 1987 issue of CALIFORNIA GEOLOGY . . . *editor.*

### INTRODUCTION

Recent sedimentological studies of the Montgomery Creek Formation provide insight on the tectonic origins of the Klamath and Cascade mountains. The older eastern Klamath Mountains border this formation on the west and the Cascade Mountains overlie it on the east. In this article investigations of paleofluvial data in the stratigraphically thick Montgomery Creek Formation are examined.

The entire Montgomery Creek Formation was deposited in a fluvial system and, for purposes of study, the Montgomery Creek Formation was divided into a basal member composed chiefly of Late Cretaceous to Paleocene (?) age conglomerate, and an Eocene age upper member composed chiefly of pebbly sandstone, sandstone, mudstone, and low-grade coal. Although the contacts between these two members of the Montgomery Creek Formation are conformable and are well exposed, disconformities within each unit are common. Considerable portions may have been reworked by shifting river currents during the deposition of this formation. Such intensive reworking would be plausible because of its extensive age range (from Late Cretaceous to Eocene age). The age ranges for these units are similar to those reported by Higinbotham (1987) and are based on independent palynological studies (J.C. Young, 1985, personal communication) of 16 samples collected by the author.



a, b, and c refer to stratigraphic columns in Figure 2.

Figure 1. Location map showing the Big Bend, Montgomery Creek, and Whitmore study area. Town names are indicated by solid circles. The basal member of the Montgomery Creek Formation is shown in black. The upper member of the Montgomery Creek Formation is shown with cross-hatchure. More detailed geologic maps of the northern areas are in Higinbotham (1987).

### STRATIGRAPHY

#### Basal Conglomerate Member

The basal member of the Montgomery Creek Formation consists of massive to crudely stratified cobble and boulder conglomerate that rests unconformably upon older formations. From north to south this lower conglomerate member thins from 90 m to less than 50 m. In the extreme southwest of the southern Montgomery Creek area (Figure 1) approximately 10 m of poorly sorted pebble-conglomerate intercalated with lenses of micaceous sandstone disconformably overlies fossiliferous marine sandstone of the Upper Cretaceous Redding Formation. This pebble conglomerate unit could be the Oak Run conglomerate member defined by Haggart (1986). This unit, in turn, is unconformably overlain by Tertiary age Cascade volcanic rocks. The basal contact was not observable in the Whitmore area (Figure 1).

Basement rock underlying the Montgomery Creek Formation in the Big Bend, Marble Creek, and northern Montgomery Creek areas and along the Pit 5 Powerhouse Road consists of the Jurassic age Bagley Andesite. In the southern Montgomery Creek area along Cedar Creek, Clover Creek, and Highway 299, the basement unit consists of metasedimentary rock of the Triassic age Pit Formation. Abundant angular boulders of slate and metagraywacke can be seen in the basal Montgomery Creek Formation in this area. The size and angularity of these clasts suggest they were locally derived.

Based on the abundance of plant fossils and sedimentary characteristics, previous workers ascribed a nonmarine fluviatile origin for the coarse clastic rocks of the Montgomery Creek Formation (Diller, 1906; Sanborn, 1960; MacDonald and Lydon, 1972; Higinbotham, 1987).

TABLE 1. LITHOFACIES SCHEME FOR FLUVIAL DEPOSITS. From Miall, 1978.

| Facies Code | Lithofacies | Sedimentary structures | Interpretation |
|---|---|---|---|
| *Gms* | massive matrix supported gravel | none | debris flow deposits |
| *Gm* | massive or crudely bedded gravel | horizontal bedding, imbrication | longitudinal bars, lag deposits, sieve deposits |
| *Gt* | gravel, stratified | trough cross-beds | minor channel fills |
| *Gp* | gravel, stratified | planar cross-beds | linguoid bars or deltaic growths from older bar remnants |
| *St* | sand, medium to very coarse, may be pebbly | solitary (theta) or grouped (pi) trough cross-beds | dunes (lower flow regime) |
| *Sp* | sand, medium to very coarse, may be pebbly | solitary (alpha) or grouped (omikron) planar cross-beds | linguoid, transverse bars, sand waves (lower flow regime) |
| *Sr* | sand, very fine to coarse | ripple marks of all types | ripples (lower flow regime) |
| *Sh* | sand, very fine to very coarse, may be pebbly | horizontal lamination, parting or streaming lineation | planar bed flow (lower and upper flow regime) |
| *Sl* | sand, fine | low angle (<10°) cross-beds | scour fills, crevasse splays, antidunes |
| *Se* | erosional scours with intraclasts | crude cross-bedding | scour fills |
| *Ss* | sand, fine to coarse, may be pebbly | broad, shallow scours including eta cross-stratification | scour fills |
| *Sse, Sne, Spe* | sand | analogous to *Ss, Sh, Sp* | eolian deposits |
| *Fl* | sand, silt, mud | fine lamination, very small ripples | overbank or waning flood deposits |
| *Fsc* | silt, mud | laminated to massive | backswamp deposits |
| *Fcf* | mud | massive, with freshwater molluscs | backswamp pond deposits |
| *Fm* | mud, silt | massive, desiccation cracks | overbank or drape deposits |
| *Fr* | silt, mud | rootlets | seat earth* |
| *C* | coal, carbonaceous mud | plants, mud films | swamp deposits |
| *P* | carbonate | pedogenic features | soil |

* Seat earth is a British term for strata underlying a coal seam. The strata represents an ancestral soil that supported the vegetation from which the coal was formed.

The lithofacies code scheme (by Miall, 1978) shown in Table 1 and used in Figure 2 describes and interprets the various rock types within the Montgomery Creek Formation.

The basal member of the Montgomery Creek Formation consists chiefly of massive or crudely bedded gravel (labeled facies *Gm* in Table 1). An imbricate structure within this conglomerate member exhibited by flat and elongate clasts indicates the paleoflow direction. Upwards within this member, clast size diminishes and stratification becomes more apparent as exhibited by incised channels that are filled with gravelly trough cross-beds or planar cross-beds, and sandstone lenses (Photo 1). Clasts are concentrated along laminated foreset beds or are suspended in the coarse micaceous sandstone that constitutes the matrix of all conglomerate beds.

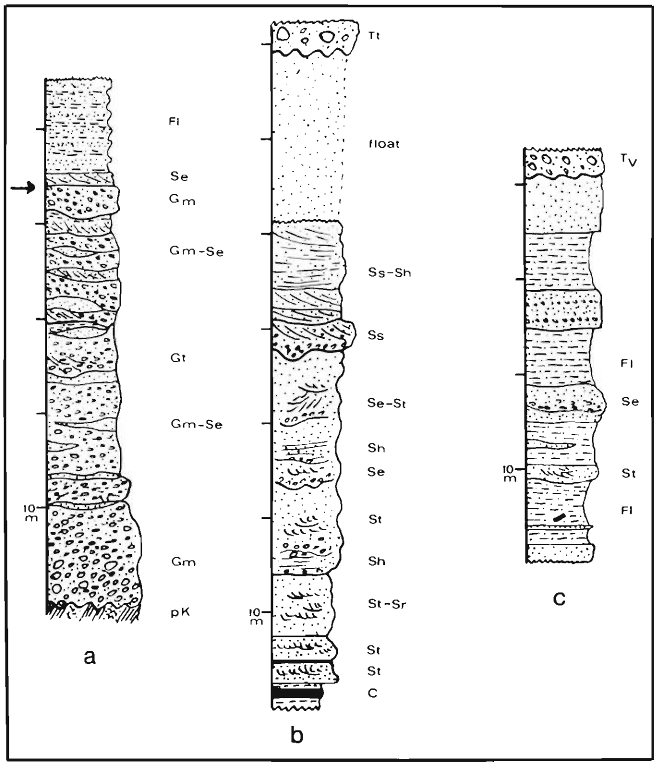


Figure 2. Stratigraphic sections representative of the basal and upper members of the Montgomery Creek Formation. The locations of the stratigraphic columns are on Figure 1. Column (a) is a section of the Highway 299 area in the Montgomery Creek region. Arrow indicates the base of the upper member (SE ¼ of section 21 to NW ¼ of section 22, T34N, R1W). Column (b) is a section of the Lawrence Basin in the Whitmore area (center of the SE ¼, section 4, T32N, R1W). Column (c) is a section of Kinner Falls in the Big Bend area (center of section 5, T36N, R1E). Letter symbols to the right of the columns refer to lithofacies described in Table 1. Tt = Pliocene age Tuscan Formation, Tv = Tertiary volcanic rock, and pK = pre-Cretaceous rock.

Photo 1. Sandstone lens (at top) and organic-rich clay drape (above the half-meter long ruler) in a gravelly facies of coarse imbricated conglomerate *(Gm)* of the Montgomery Creek Formation basal member exposed along the Pit 5 Powerhouse Road. *Photos by Ken Aalto.*

Some conglomerate beds grade upwards into coarse sandstones within beds that are from ½ m to 2 m thick. Sandstone within such sections commonly has horizontal laminations or exhibits planar or trough cross-bedding. At a few sites this coarse sandstone fines upwards into rippled cross-stratified medium sandstone or into intercalated rippled sandstone and mudstone. Pebbly sandstone is also present in lenses filling channels cut into conglomerate beds and may exhibit crudely developed low-angle forset laminations and mudstone rip-up clasts or well-developed trough cross-bedding. Uncommon basal member lithologies include clay drapes in channels and carbonized plant fragments in mudstone lenses (Photo 1).

### Upper Member

The upper member of the Montgomery Creek Formation consists primarily of abundant sandstone and mudstone and lesser amounts of conglomerate and coal (Photo 2). The contact between the basal and upper members is well exposed along the Pit 5 Powerhouse Road and along Highway 299 (Figure 2A). At both locations the contact is conformable (in the context of fluvial systems) and reflects a change in coarseness of sediment supply. Along the Pit 5 Powerhouse Road the contact is marked by the cessation of conglomerate deposition and the appearance of small channels of trough cross-bedded sandstones and planar cross-bedded sandstones. These channels have cut into gravel conglomerate facies, and one such channel contains carbonized plant fragments that contain Eocene age palynomorphs.

Along Highway 299 the contact between the basal and upper members of the Montgomery Creek Formation is marked by the appearance of crudely cross-stratified sandstone facies overlain by thick, interbedded rippled sandstone and mudstone facies.

Because of the poor, discontinuous exposure and the likelihood of the Montgomery Creek Formation section being repeated by Basin and Range faulting, the thickness of the upper member is difficult to determine. From a generalized geologic cross-section of the Big Bend area a maximum section thickness for the upper member of the formation was calculated to be approximately 875 m (Higinbotham, 1987).

In the Montgomery Creek area, a maximum thickness for the upper member of the Montgomery Creek Formation was calculated to be 380 m. This thickness was based on the topographic position of the last major conglomerate unit in the formation and the upper unconformity with younger Tertiary age volcanic rocks located at the southernmost exposure of the Montgomery Creek Formation.

Upper member sandstone units within the Montgomery Creek Formation chiefly display grouped trough and planar cross-bedding facies (Table 1, Figures 2B, 2C). Channeling occurs among trough cross-bedded units and the beds average ½ m to 1 m in thickness. Upwards within this member, large sand-filled channels with eta cross-stratification,* crudely stratified pebble-cobble conglomerate and parallel-laminated sandstone facies become abundant. Facies with cross-bed sets (Table 1) are several meters thick (Figure 2B). Conglomerate occurs in channel fills and as ½ m to 1 m thick tabular layers that commonly grade upwards into parallel-laminated sandstone. Conglomerate clasts are lubricated. Mudstone in these coarse intervals occurs as clay drapes in channels and discontinuous lenses intercalated with uncommon rippled sandstone.

Coarse intervals of the upper member are intercalated with laminated to massive mudstone facies and coal beds that are commonly less than ½ m thick (facies *C*). Siliceous concretions are common in carbonaceous sediment. In the Whitmore area (Figures 1, 2b) coal is present in several coarsening-upwards cycles that range from 30 cm to 50 cm in thickness. The layers containing pure coal are in sharp contact with the underlying sediment and grade upward into a medium-gray, organic-rich claystone.

Finer sediments are more abundant in the lower portion of the upper member of the Montgomery Creek Formation, and coarser sediments are more abundant higher in the section. Coarser intervals of the lower portion may be arranged in fining-upwards sequences (Higinbotham, 1987). Those sediments higher in the section commonly lack well-defined size trends, but may contain several meter-thick lithofacies cycles that consist of massive or crudely bedded sandstone facies followed by planar and trough cross-bedding facies or rippled cross stratified sandstone facies (Table 1). In the Whitmore area similar cycles in sandstones include sandstone facies with crude cross-bedding and ripple marks (Table 1).

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* Eta cross-stratification is a plunging, broad shallow scour filled with cross-strata with foresets oriented subparallel to the scour surface.

Photo 2. The upper portion of the upper member of the Montgomery Creek Formation exposed along Highway 299 east of the town of Montgomery Creek. Note the intertonguing of the conglomerates and sandstones.

## DEPOSITIONAL SETTING

The basal member of the Montgomery Creek Formation was deposited in a "Scott-type" gravelly braided river system (Higinbotham, 1987). This type of river system is characterized by a high sediment yield, high relief, and/or great seasonal discharge fluctuations (see Miall, 1977, 1985 for descriptions of braided river systems).

Features of Scott-type river deposition include longitudinal gravel bars built during high water discharge by aggradation within major channels. Such bars contain crude horizontal stratification and clast imbrication (seen in facies *Gm*). Gravelly planar and trough cross-beds (seen in facies *Gp* and *Gt*) develop along bar margins as sediment accumulates and builds lateral channels. During waning flow, sand may be deposited on bar crests and develop an overall fining upwards sequence within the bar. Varying flow velocities result in the formation of bedding structures (such as sand waves, dunes, and flat, even plane beds), and account for bedding features observed in lower member sandstones of the Montgomery Creek Formation. Also within a Scott-type river depositional system, clay is deposited as drapes in inactive channels or as overbank sediment away from the main channel area. This type of high energy braided river model explains the variety of sedimentary features observed in the basal member of the Montgomery Creek Formation.

The lower part of the upper member of the Montgomery Creek Formation is dominated by finer facies commonly ascribed to floodplain sedimentation (seen in facies *Fm*, *Fl*, and *C*). Fining-upwards sequences in this interval are ascribed to sand deposition within point bars in a meandering river system (Higinbotham, 1987). Sandstone and conglomerate become more abundant higher in the section. The prevalence of one to several meter-thick repetitions of fining-upwards cycles within many of the uppermost coarse sections indicates aggradation of channel systems by deposition of gravel in longitudinal bars, and deposition of sand in channels and on longitudinal bar crests during waning flood conditions. Sedimentary features of the upper part of the upper member are much like those of the "Donjek type" sandy braided river system (Miall, 1977). Apparently, during the deposition of the Montgomery Creek Formation the energy level of the fluvial system greatly diminished, then increased. These changes could reflect climatic change, tectonic activity, or both.

## PALEOCURRENT ANALYSIS

Arranging flow indicators in a hierarchy that reflects their likelihood of showing true downvalley trends is important to determine paleocurrent flow directions. This method is preferred over the method of determining the diverse flow orientations of second and third order channels* because local flow in second and third order channels may be contrary to the actual downvalley flow. The best paleocurrent flow indicators are those whose true geometry can be recognized in the field and which reflect sedimentation during maximum discharge in major channel areas. These criteria are displayed by the imbricate structure of clasts within facies of the gravelly conglomerates deposited in longitudinal bars. Orientation of foreset lamination is less reliable for determining paleocurrent flow direction because it is difficult to acquire data about foreset bedding orientation from poor exposures and because much of the cross-bedding was developed in second and third order channels.

The direction of paleoflow as reflected in clast orientation within the gravelly conglomerates *(Gm)* was obtained by measuring the plunge directions of short and long axes of clasts that were at least 8 cm in length. Short axis plunge data includes that for disc and blade shaped clasts. Long axis plunge data includes that for prolate (roller) and blade shaped clasts. Flow direction was determined from cross-bedding for each facies. Clast orientation data for each facies was plotted on stereonets; summaries for the data are shown on the contoured stereonets of Figure 3. Data from the analyses of clast axis and imbrication indicate the general paleocurrent flow direction was towards the south-southwest.

Paleocurrent flow directions within the Montgomery Creek Formation change in the lower member and the upper member and from one region to another. In the Big Bend area, data for the lower member conglomerate indicate a west-southwest paleocurrent flow. Cross-bedding data for the upper member indicate a southerly paleocurrent flow direction. Data from the Montgomery Creek area indicate the general paleocurrent flow direction for the lower member ranged from the southeast to the southwest. Cross-bedding data for the Whitmore and Montgomery Creek areas indicate the paleocurrent flow direction shifted from the southwest towards the southeast during the deposition of the Montgomery Creek Formation.

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* Second and third order channels are smaller, higher channels that are occupied only during floods.

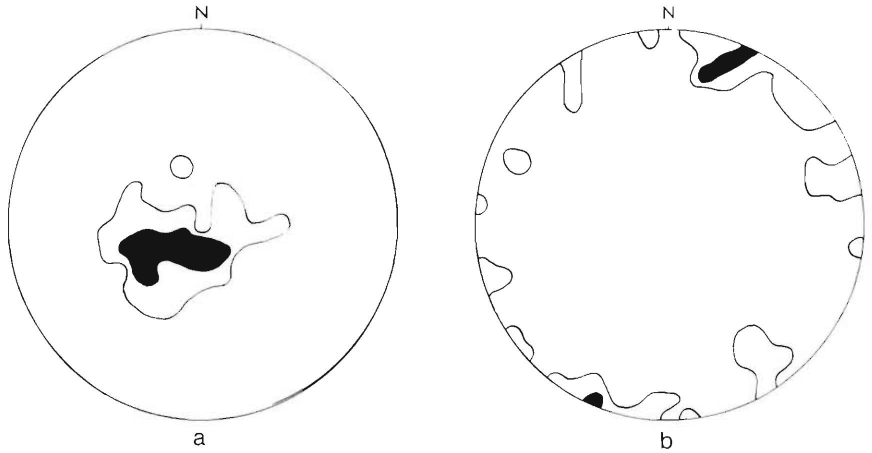

Figure 3. Summary of clast orientation data for conglomerate of the Montgomery Creek Formation. Lower hemisphere equal-area plots depicted are: (a) short axis plunge directions for disc and blade shaped clasts (n = 255), and (b) long axis plunge directions for prolate and blade shaped clasts (n = 141). In both diagrams the contours depict three percent (open field) and six percent (blackened field) of the data per unit area.

## CONGLOMERATE AND SANDSTONE PETROLOGY AND PROVENANCE

Conglomerate clasts consist chiefly of gray to tan quartzite, gray slate, and porphyritic volcanic rocks that range in composition from basalt to dacite. Minor constituents include granite, diorite, gabbro, vein quartz, and gray to black chert. Five pebble counts of an average of 90 clasts each give an average conglomerate composition of 37 percent metasediment clasts, 50 percent metavolcanic clasts, 6 percent plutonic clasts, 3 percent chert clasts, and 3 percent vein quartz clasts. No significant petrologic differences exist within the formation or throughout the region. Pre-Cretaceous basement rocks of the area can logically account for the majority of clasts present (Sanborn, 1960).

Sandstone composition was determined by point counts of 300 grains per thin section. These thin sections were stained for both potassium feldspar and plagioclase feldspar. The Gazzi-Dickinson counting method was used to minimize the effect of grain-size differences among the samples for composition (Ingersoll and others, 1984). In this method, monomineralic crystals and other grains of sand size that occur within larger rock fragments are classified in the category of the crystal or grain composition, rather than in the category of the larger rock fragment. The diagram format, provenance fields, and methods used are those of Dickinson and others (1983).

Most sandstones that were counted are either lithic arkoses or feldspathic litharenites (terminology of Folk, 1974). Quartzose grains include both monocrystalline and polycrystalline varieties. Most grains exhibit deformation bands, segmented undulosity, and strongly undulose, irregular crystallites that indicate a metamorphic source terrane (Young, 1976). However, nearly every thin section has a fair proportion of clear euhedral grains with embayments, negative inclusions, and hairline cracks that are characteristic of volcanic (beta) quartz. Feldspar grains include both twinned and untwinned plagioclase, orthoclase, microcline, and perthite. Many crystals are subhedral to euhedral and exhibit oscillatory zoning. Volcanic rock fragments include chiefly those with microlitic and lathwork textures suggesting intermediate to basic volcanic sources (terminology of Dickinson, 1970).

Sedimentary rock fragments within the sandstones include mudstone with widely varying proportions of silt and clay. Metamorphic rock fragments are chiefly phyllitic. Detrital biotite is more abundant than muscovite and chlorite. Accessory minerals, especially abundant in calcareous concretions, include clinopyroxene, epidote, actinolite, hornblende, zircon, tourmaline, zoisite, apatite, and sphene.

Sandstones are texturally immature to submature with angular to subangular, poorly sorted grains in 14 to 39 percent of the mud matrix, calcite, and/or iron oxide cement. Most matrix is detrital and unrecrystallized, although some basal conglomerate member sandstones contain extensive diagenetic chlorite and numerous squashed volcanic and sedimentary rock fragments. Feldspar in these sandstones contains abundant pumpellyite. Other common alteration products include calcite, epidote, sericite, and iron oxide. One upper member sandstone contains laumontite precipitated in pores and as expitaxial overgrowths on feldspar grains and volcanic rock fragments.

Ternary diagrams of detrital compositions indicate a transitional to dissected volcanic arc source for most sandstones. Although possible stratigraphic trends exist for sandstone composition, no significant regional differences were found. The ternary diagrams for total quartzose feldspar and aphanitic lithic grains (QtFL), and for monocrystalline quartz, feldspar, and aphanitic lithic grains (QmFLt) in Figure 4 show upsection increases in quartzose grains and depletion of lithic grains. The ternary diagram for monocrystalline quartz, plagioclase, and potassium feldspar grains (QmPK) in Figure 4 shows similar increases in the quartzose fraction for upper member sandstones that occur along with a diminishing proportion of plagioclase. These changes probably reflect deep dissection of a volcanic arc. They may also reflect increased sediment recycling that would logically relate to the history of diminishing relief followed by source area rejuvenation during the depositional period of the Montgomery Creek Formation.

The increase in quartzose grains may also reflect erosion of an older volcanic carapace and greater exposure of metasedimentary rocks of the Pit Formation, a logical source for much of the strained quartz grains* seen in thin section. The eastern Klamath Mountain basement provides a logical source of Montgomery Creek Formation sediment, and there is no evidence for increased volcanic material towards the top of the section.

## CONCLUSIONS

Paleocurrent flow data indicate a northern source for Montgomery Creek Formation sediment. This material was most likely derived from a basement source terrane in the Klamath Mountains area that is presently covered by late Cenozoic volcanic rocks. The source area of the Montgomery Creek Formation initially had high relief, but by Eocene time had been lowered so that coarse-bedload sedimentation of a braided river system was succeeded by meandering river and floodplain sedimentation. A return to sandy sedimentation by a braided river system very likely reflects source area rejuvenation towards the end of the Eocene.

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* Strained quartz grains exhibit dislocations in their crystal lattices as seen when viewing their optical properties.

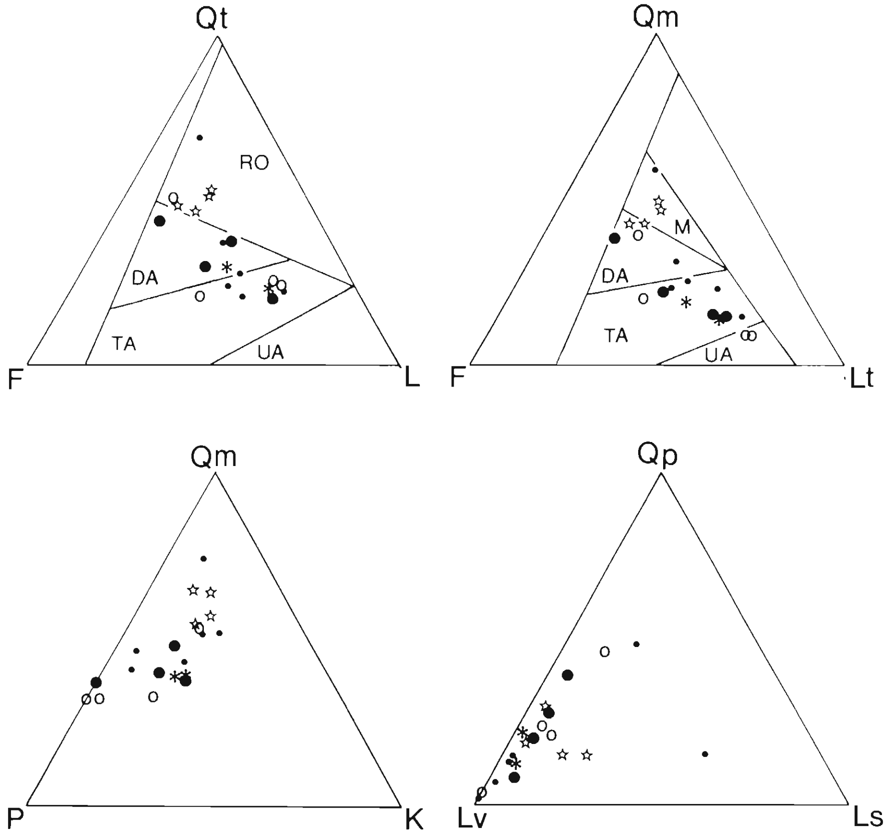

Figure 4. Ternary diagrams depicting detrital modes for Montgomery Creek sandstones. Grain parameters and provenance fields are from Dickinson and others (1983). Data are given for the Montgomery Creek Formation, Big Bend area lower member (asterisks) and upper member (open stars), Montgomery Creek area lower member (circles) and upper member (large dots), and the Whitmore area upper member (small dots). Grain parameters are defined as follows: Qt = total quartz grains (monocrystalline and polycrystalline, including chert); Qm = monocrystalline quartz grains, Qp = polycrystalline quartz grains (including chert); F = total feldspar grains; P = plagioclase grains; K = potassium feldspar grains; Lt = total aphanitic lithic grains including chert; L = total aphanitic lithic grains excluding chert; Lv = total aphanitic volcanic lithic grains including metavolcanic grains (such as greenstone); Ls = total aphanitic sedimentary and metasedimentary lithic grains (chiefly mudstone and phyllite); (more simply Qt = Qm + Qp, F = P + K, Lt = L + Qp = Ls + Lv + Qp, L = Ls + Lv). UA = undissected arc, TA = transitional arc, DA = dissected arc, RO = recycled orogen, and M = mixed provenance.

This change was accompanied by (1) increased sediment recycling, (2) dissection of the ancestral Klamath arc, and (3) a shift in sediment transport towards the southeast. The Montgomery Creek Formation may underlie late Cenozoic volcanic rocks of the Cascade arc and Modoc Plateau.

From Cretaceous time to the present, the Klamath Mountains have intermittently shed sediment to surrounding areas (Jones and Irwin, 1971; Ingersoll, 1983; Nilsen, 1984). Periodic tectonic rejuvenation of the Klamath Mountain province and nearby regions during the Cenozoic is reflected in the late Oligocene to early Miocene fluviatile sedimentation of the Weaverville Formation (MacDonald, 1910; MacGinitie, 1937; Barnett, 1982; Schweickert and Irwin, 1986) and the late Miocene to recent uplift of the Klamath peneplain (Diller, 1902; Mortimer and Coleman, 1984). Further sedimentary investigations of Cenozoic Era cover rocks in the Klamath Mountains province may shed light on the style and mechanism of regional uplift.

## ACKNOWLEDGMENTS

This study was funded by Sun Exploration and Production Company under professional services contract #CS 90-3305P. I thank Sun Exploration and Production Company, Tenneco Exploration and Production Company, and Sohio Petroleum Company for permission to publish these results. I also thank J. C. Young, Don Davis, and Larry Higinbotham for help in locating outcrops suitable for sedimentological analysis.

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4. Complete Mailing Address of Known Office of Publication
1721 20th STREET, SACRAMENTO, CA 95814

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Publisher (Name and Complete Mailing Address)
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1416 Ninth Street, ROOM 1341, SACRAMENTO, CA 95814

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# USGS Experimental 7.5 Minute Quadrangle Reference System

The U.S. Geological Survey (USGS) has proposed converting its primary 7.5 minute topographic map series to a new datum, called the North American Datum 1983 (NAD 83). The new datum is a revised astronomic latitude and longitude on which horizontal controls on maps are computed. An experimental edition of the San Rafael, California 7.5 minute quadrangle was printed with the older North American Datum 1927 (NAD 27) and the new North American Datum (NAD 83) back-to-back so that users can graphically compare the differences.

The experimental NAD 83 quadrangle map is a more accurate cartographic representation of the region than the existing NAD 27 quadrangle map.

The actual shape of the earth must be considered to precisely locate the latitude and longitude of points on the surface of the earth. The shape of the earth more closely approximates an oblate spheroid that is flattened at the poles and bulges at the equator rather than a perfect sphere. The existing U.S. Geological 7.5 minute quadrangle series is based on an ellipsoidal determination that was adopted by the U.S. Geological Survey in 1927 as NAD 27.

In 1980 the Geodetic Reference System (GRS 80) was adopted by the federal government as a best fit to the shape of the earth's geoid. The geoid is an equipotential surface of the earth's gravity field. It can be thought of as a continuous sea-level surface extended beneath the continents. GRS 80 was based on the compilation of geodetic, gravimetric, astrodynamic, and astronomic data collected by modern equipment. The GRS 80 representation was adopted to produce the NAD 83. Because the older NAD 27 map surface deviates from the NAD 83, the computed position of points determined using the two reference shapes are different. For example, the experimental NAD 83 San Rafael, California 7.5 minute quadrangle map area differs from the existing NAD 27 area by approximately 8 meters in latitude and 96 meters in longitude.

Conversion of the existing NAD 27 maps to the new NAD 83 reference system is important because there is an increasing reliance on satellite-derived data that is based on the Global Positioning System (GPS). The GPS more accurately correlates to the NAD 83 reference system than it does with the older NAD 27 reference system. There are 55,000 USGS 7.5 minute topographic maps based on the NAD 27 system.

The map is available for $2.50 from the U.S. Geological Survey, Public Inquiry Office, 345 Middlefield Road, Menlo Park, CA 94025. Make check payable to the U.S. Geological Survey. Specify MAP# 37122-H5-TF-024: Experimental Edition, San Rafael, California Quadrangle on North American Datum 1983 (NAD 83) and North American Datum 1927 (NAD 27), published 1988. ⚒

# BOOK REVIEWS

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Geographic Map

HIGH SIERRA. By Bill Guyton. 1988. 1072 Verde Drive, Chico, CA 95926. Scale 1:333,500. 23 inches by 35 inches. $8.00, includes tax, shipping, and handling.

The Sierra Nevada of California has been called the "Range of Light," the "Gentle Wilderness," and the "High Sierra." This four-color map covers that area of the Sierra Nevada that is predominantly above 9,000 feet. Thirty-three U.S. Geological Survey 15-minute quadrangle maps were used to compile the High Sierra map. There is an index of these quadrangle maps for those wishing to examine specific areas in more detail. The High Sierra map identifies highways, roads, trails, lakes, rivers, creeks, passes, mountains, and corners where quadrangles meet. In addition geomorphic features such as drainage basins and divides are included.

This map is of interest to backpackers, fishermen, mountain climbers, geologists, geographers, and others who enjoy exploring the High Sierra.

Marine Topography

UNITED STATES BATHYMETRIC AND FISHING MAPS Including Topographic/Bathymetric Maps. Free catalog available from Distribution Branch N/CG33, National Ocean Service, 6501 Lafayette Avenue, Riverdale, MD 20737. (301) 436-6990.

Bathymetric maps illustrate the geomorphology of the sea floor, portraying the shape, size, and distribution of underwater features. Through the use of depth contours and other bathymetric data, these 1:250,000 scale maps provide geographically detailed information about submarine topography. Topographic/bathymetric maps contain both land and submarine topography. These maps are available at scales of 1:24,000, 1:100,000, and 1:250,000.

Bathymetric and topographic/bathymetric maps are basic tools for performing scientific, engineering, marine, and marine environmental studies required in the development of energy and marine resources. They are valuable to land-use planners, conservationists, surveyors, geologists, and oceanographers.

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### Mineralogy

GEMSTONES. By Christine Woodward. 1988. Sterling Publishing Co., Inc., 2 Park Avenue, New York, NY 10016. 59 p. $9.95 ($13.50 in Canada), paper cover.

Abundant color photos capture the beauty of gemstones in both their natural and cut states in this introductory volume. The text details popular and lesser-known gems, and discusses such factors as their special attributes, mineral properties, formation, and mining. A short section focuses on how gems are identified, where gems are found, and the origin of many kinds of gemstones.

The book is published in cooperation with the British Museum of Natural History.

### Northern Sierra Nevada

GEOLOGIC HISTORY OF THE FEATHER RIVER COUNTRY, CALIFORNIA. By Cordell Durrell. 1987. University of California Press, 2120 Berkeley, CA 94720. 337 p. $40.00 hard cover, $17.95 paper cover.

This book is a geologic history of the Northern Sierra Nevada — that part of the range north of Interstate 80. For the most part, it focuses on Plumas, Sierra, and Butte counties, parts of Lassen County, and the counties south of the North Fork of the Yuba River. The author (now deceased) began to study the area in 1939 and returned there for many years. During this time Durrell became very interested in the geologic history of the Feather River area, which is reflected in this detailed account of investigation. The volume is written for the layman; however, it is a study which would be of value to geologists.

Included are an introduction to the science of geology and the 400 million year history of the Sierra Nevada, the events leading to the ancestral Sierra Nevada, and the Sierra Nevada after the Nevadan Orogeny. Geological terms and concepts are explained within the text.

### Physical Geology

ROADSIDE GEOLOGY OF U.S. INTERSTATE 80 BETWEEN SALT LAKE CITY AND SAN FRANCISCO: The Meaning Behind the Landscape. By W. Kenneth Hamblin, J. Keith Rigby, John L. Snyder, and William H. Matthews, III. 1975. Varna Enterprises, P.O. Box 2216, Van Nuys, CA 91404. Available from American Geological Institute, 4220 King Street, Alexandria, VA 23302. 51 p. $3.00 soft cover. Write to AGI for discount information.

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Interstate Highway 80 between San Francisco and Salt Lake City is remarkable for the scenic beauty and geologic interest in the landscape. Many travelers need a guide to appreciate the geologic history behind the many structural features, landforms, and outcrops of igneous, sedimentary, and metamorphic rocks. This publication provides the reader with a brief overview of what geology is and how geologists have interpreted the landscape.

The book is organized by highway segments between specific towns, so that one can understand the geological story of portions of the route at a time. Information and a map are provided for each segment. Reference is made by numbers and/or letters to specific localities described in the text, and located on the maps. Photographs are used throughout the text to help the traveler recognize geologic features.

In addition, the reader will find information about historical events, abandoned mines, ghost towns, and rock, mineral, and fossil collecting localities. The publication is useful to professional geologists, geology students, rock hounds, and interested laymen.

Sedimentary Petrology

CARBONATE ROCK DEPOSITIONAL MODELS: A Microfacies Approach. By Albert V. Carozzi. 1989. Prentice Hall, Englewood Cliffs, NJ 07632. 604 p. $68.00, hard cover.

Carbonate rocks contain more than 50 percent by weight carbonate minerals such as calcite, dolomite, and siderite. Understanding how these rocks form can lead to more efficient methods of petroleum exploration. Microfacies analysis techniques can be used as a method of predicting models of sedimentation for carbonate rocks. Microfacies in carbonate rocks can be seen clearly only in thin sections under a microscope. Thin section analysis of carbonate rocks is a tool that can be used to understand depositional environments, diagenetic evolution of carbonate rocks, and the formation of porosity and permeability in carbonate rocks.

The use of microfacies analysis techniques is applied to understanding the origin and formation of carbonate ramps, carbonate platforms, and carbonate slopes and basins. This book will be of interest to students and professionals concerned with the disciplines of sedimentary petrology, sedimentology, petroleum geology, and palentology.

Structural Geology

GEOLOGICAL STRUCTURES AND MOVING PLATES. By R.G. Park. 1988. Chapman and Hall, 29 West 35th Street, New York, N.Y. 10001-2291. 337 p. $45.00 soft cover, $95.00 hard cover.

Geological structures are interpreted in terms of plate tectonics in this volume. Topics covered include the lithosphere, plate movement and plate boundaries, mechanical properties of plates, the source of distribution of stress in the lithosphere, and structures and plate movements in different tectonic regimes. Case studies are included with specific examples from Phanerozoic and Precambrian orogenies.

This book was written for advanced undergraduate and postgraduate students. It is a useful reference for geoscientists.

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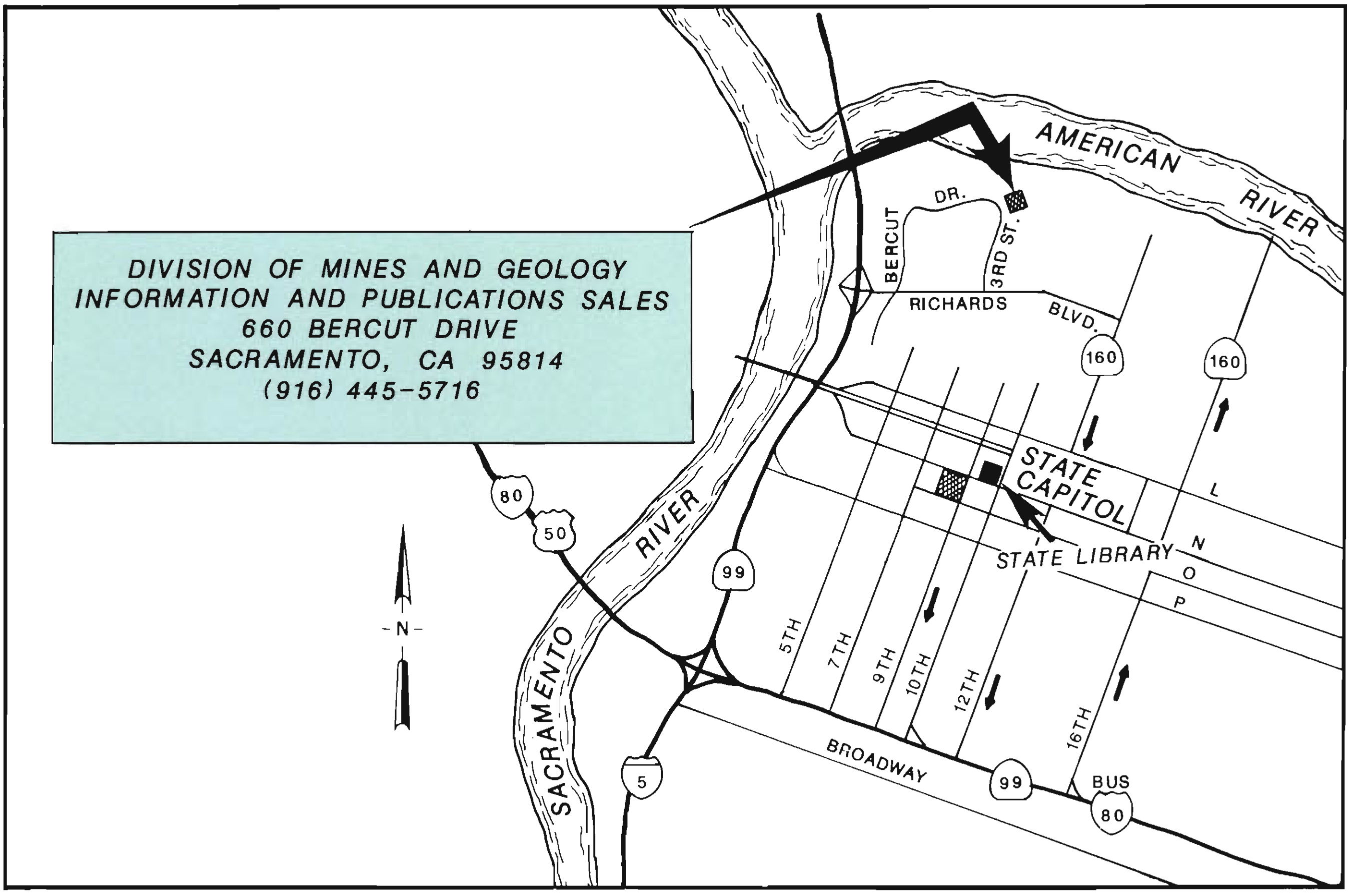

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## SPECIAL REPORT 143

MINERAL LAND CLASSIFICATION OF THE GREATER LOS ANGELES AREA, PART VII, Project Description: Classification of Sand and Gravel Resource Areas in the San Bernardino Production-Consumption Region. By Russell V. Miller, 1987. 50 p., 10 figures, 5 tables, 45 plates. $10.00

The San Bernardino area as defined in this report covers 1,098 square miles and includes the large urbanizing portion of southwestern San Bernardino County and northwestern Riverside County. Although substantial portions of this region have been developed, urbanization is still rapidly occurring.

In any urban development it is important that land-use decisions are made with full recognition of the natural resources of the area. Mineral resources, including aggregate, are limited resources within a given area. To help those who make land-use decisions, this report presents aggregate resource information for the region, including the expected aggregate resource needs over the coming decades.

For many years the San Bernardino area has been fortunate to have adequate quantities of relatively low-cost aggregate materials available locally. However, as more and more areas become urbanized, suitable sand, gravel, and stone deposits are being lost through urban development and are being diminished yearly by mining.

The principal objective of this report is to classify land in the San Bernardino area into Mineral Resources Zones, based on guidelines adopted by the California State Mining and Geology Board. This classification project, as mandated by the Surface Mining and Reclamation Act of 1975, will assist the Board in designating lands that are needed for their mineral content. This designation process, in turn, has been designed to assist and guide local lead agencies in preserving essential mineral resources for future use through proper zoning ordinances.

Classification of aggregate materials in other parts of the greater Los Angeles area is currently underway.

This report may be purchased at Division offices in Los Angeles, Pleasant Hill, and Sacramento, or it may be ordered by mail from the Division of Mines and Geology, P.O. Box 2980, Sacramento, CA 95812-2980. ⚒