GLOBAL TECTONICS, VIEWED FROM MANNED SPACECRAFT*

By

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Search and Discovery Article #30010 (2003)

Southwestern United States

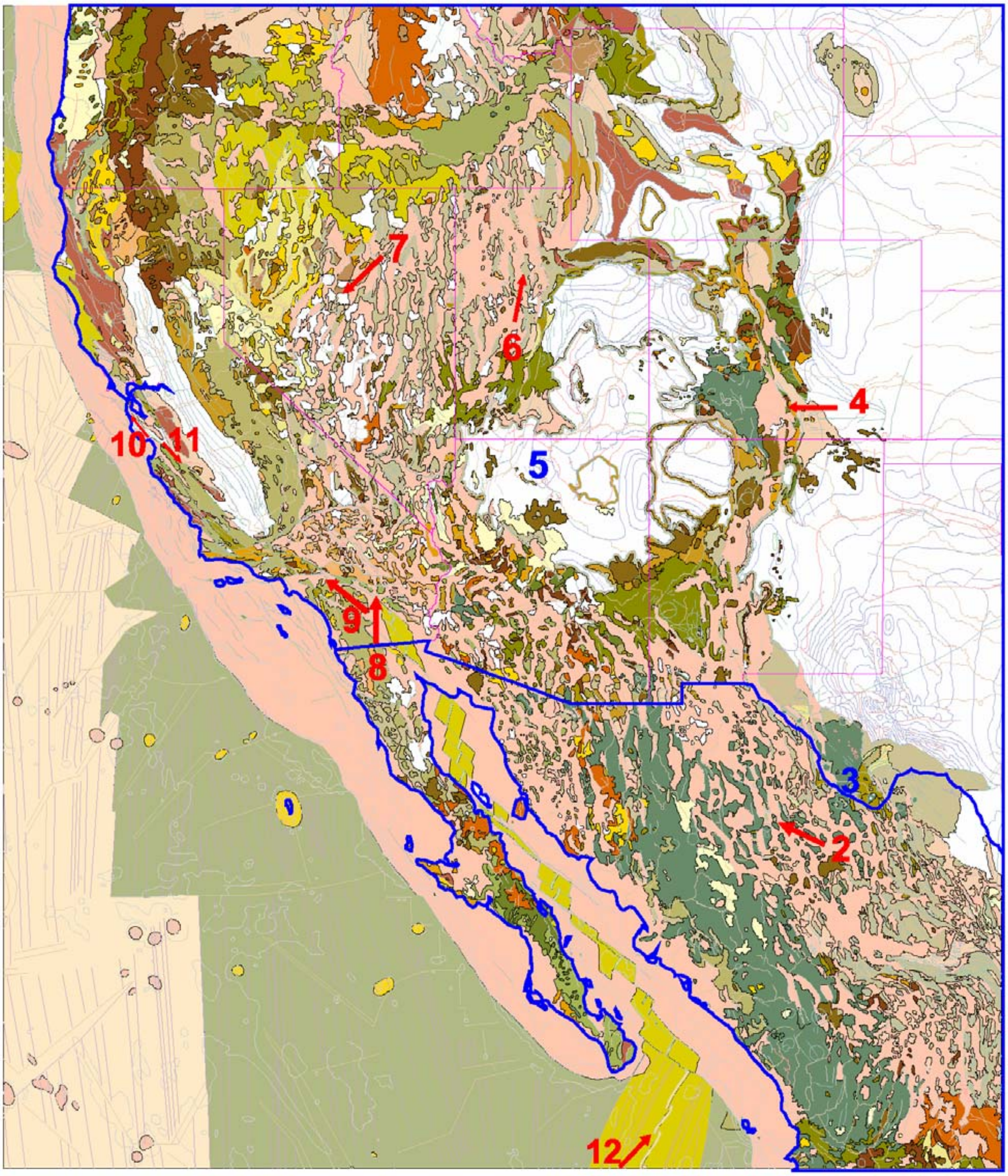

Figure 1. Tectonic map of Southwestern North America, as location map for Figures 2-12 (from Muehlberger, 1992, 1996).

The following 11 pictures illustrate major tectonic elements of the southwestern United States.

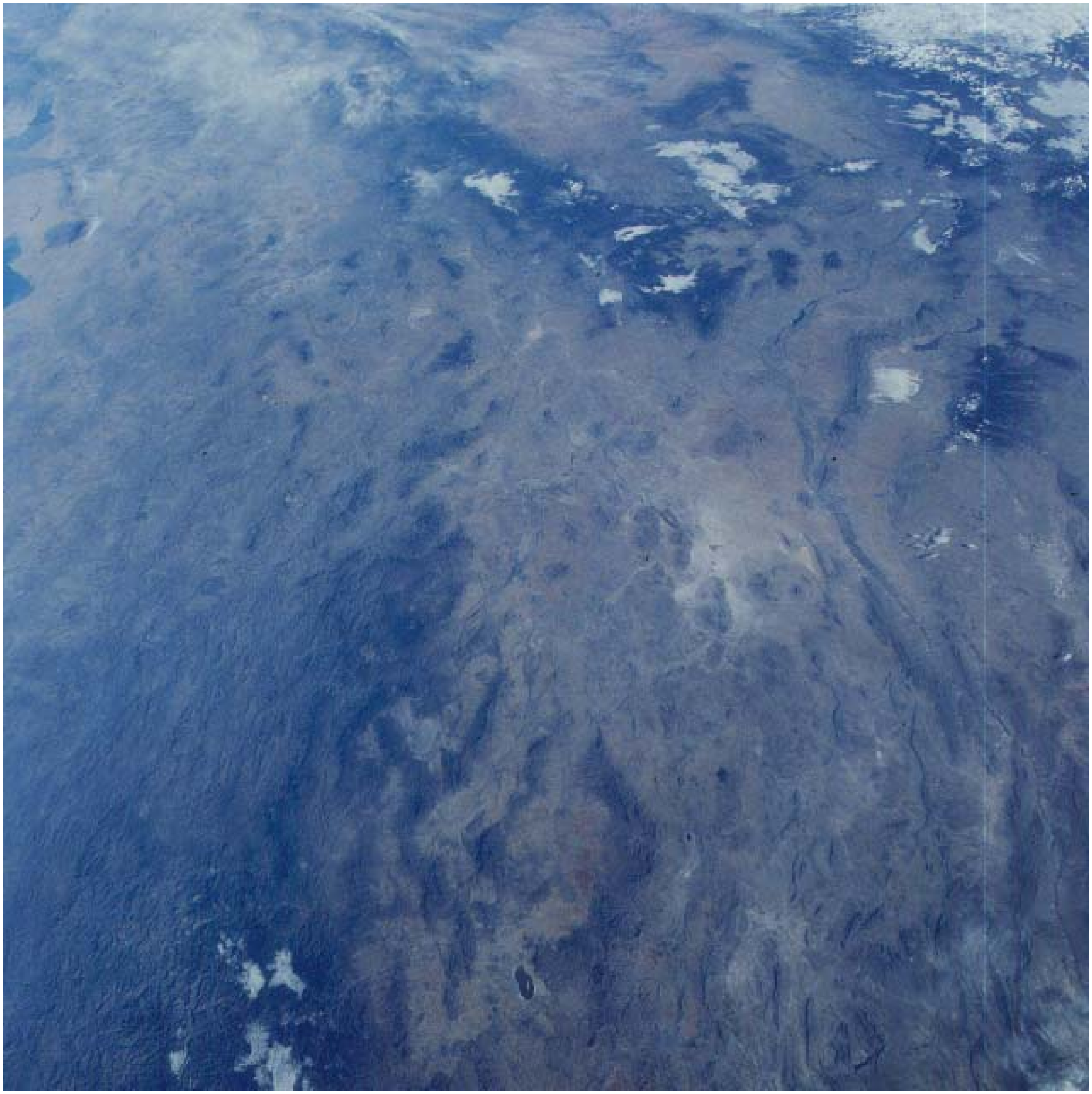

Figure 2. Photograph 31-77-070. View northwest across Chihuahua, Mexico to the Salton Sea (near upper left edge); Gulf of California (???water area on left edge); Mogollon Rim of central Arizona (upper middle); to White Sands (bright white spot near right edge); south to El Paso (where the dark mountains just to the left of the White Sands and the dark band to the west of that (the Rio Grande) join and turn toward the lower right). The Rio Grande extends down along the right edge to Presidio where the river bends right and leaves the frame.

This wide expanse was photographed on the mission that launched the Hubble Space Telescope at 240 miles up. That is the effective height that the Shuttle can go, it normally orbits at heights about one-half as high. This is one frame of a series taken on this orbit covering the band from the Pacific coast of Baja California east to northern Mexico and west Texas.

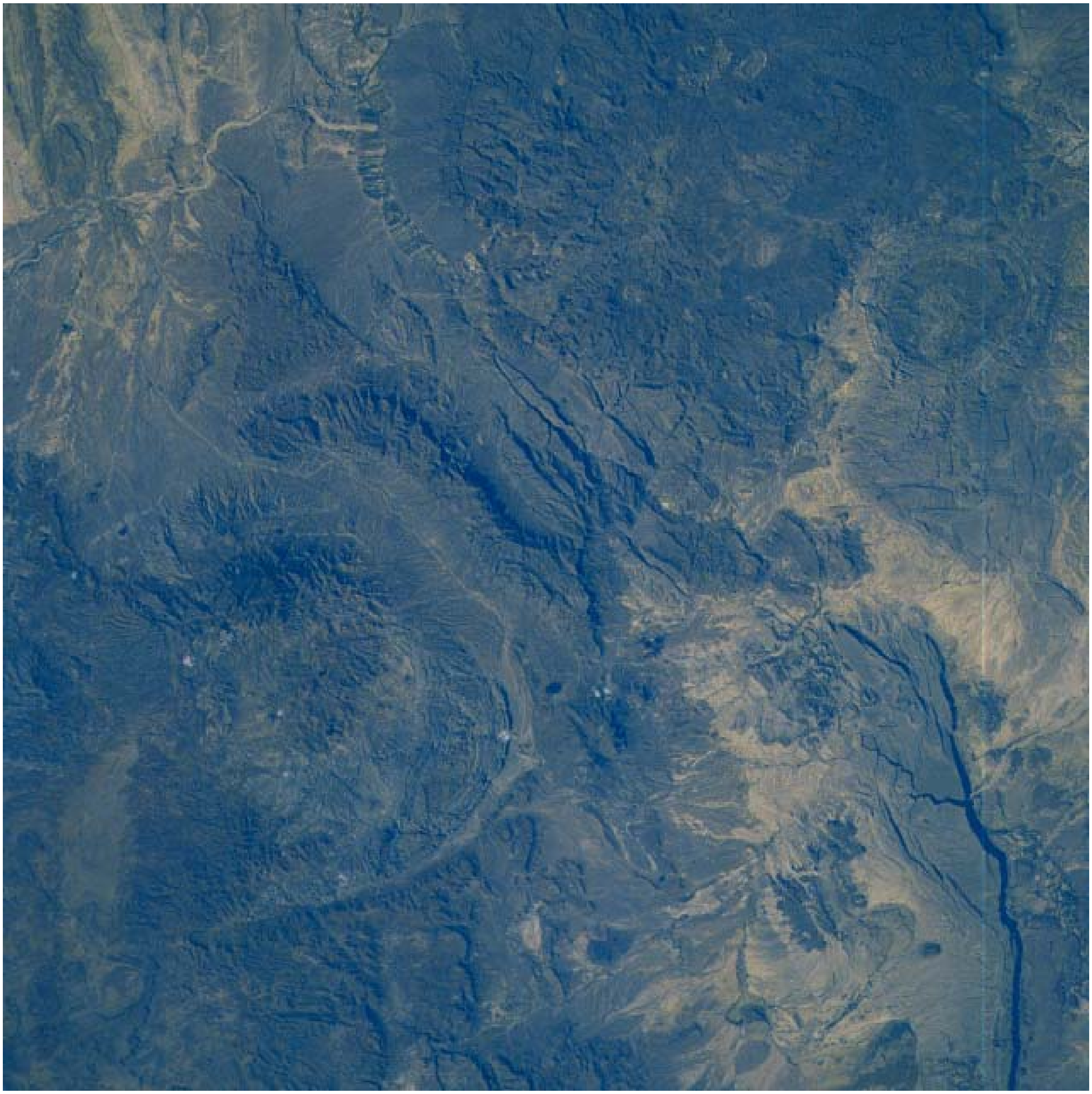

Figure 3. Photograph 34-74-095. Transfer zone between Presidio (upper left) and Big Bend National Park, Texas (lower right). The Rio Grande takes advantage of extension along the several faults in Colorado Canyon (center of frame) that drop that region down allowing the river to pass from the Presidio graben (upper left) to the Castolon graben (lower right) that occupies the western half of Big Bend National Park. Santa Elena Canyon is visible about one-third the distance along the tilted mesa that extends along the lower right edge of the photo. The large circular feature in the lower left is the Santana-San Carlos caldera. The circular feature along the upper right edge is the 5-mile diameter Solitario, a caldera on a laccolith.

Figure 4. Photograph 90-750-035. View west across southern Colorado to northern Arizona. In the foreground is the Sangre de Cristo Mountains; beyond is the San Luis Valley (a basin of the Rio Grande rift; Alamosa, CO is in the center of it); beyond is the snow covered range of the Brazos Uplift and to the right and beyond are the San Juan Mountains. The open desert is the Colorado Plateau with the San Juan River flowing away from us to join the Colorado River just upstream from Lake Powell. Beyond that is the barely perceptible Grand Canyon. The Basin and Range country lies beyond the Plateau. Near the upper right corner the mountains drop off to Salt Lake City.

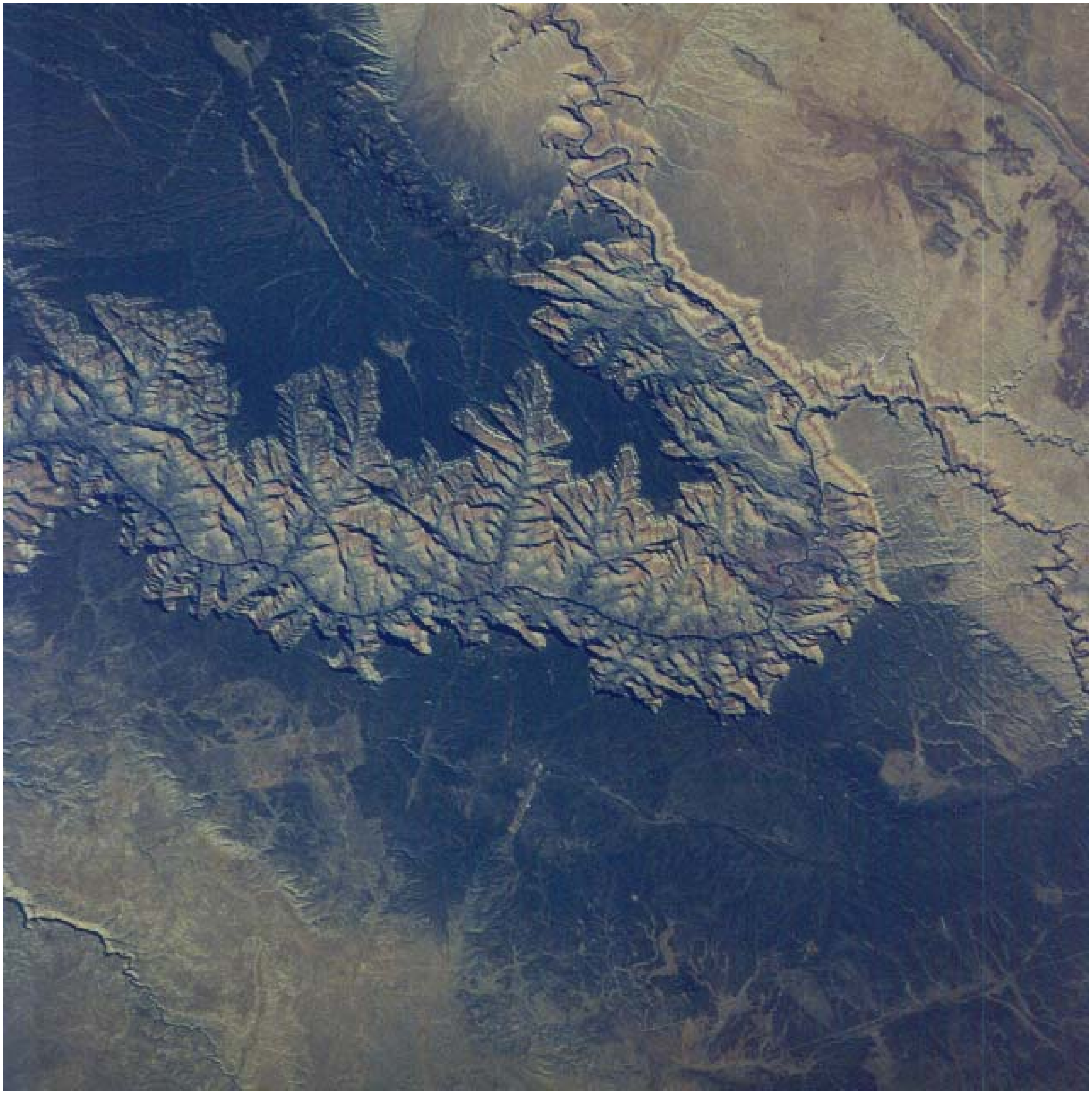

Figure 5. Photograph 34-72-056. “Tourist” Grand Canyon. View north at the main part of the Grand Canyon on a bright sunny afternoon. Bright Angel Creek is the straight valley in the center of the picture on the far side of the canyon. On the near side opposite Bright Angel are the hotels, restaurants and other tourist facilities. The Little Colorado River Canyon comes into the picture flowing north in the desert along the right edge and joins the Colorado after a sharp bend to the west (left).

Figure 6. Photograph 90-754-022. View north along the boundary of the Colorado Plateau (right) and the Basin and Range Province (left). The south half of Great Salt Lake is the dark water patch. The north half is the brown patch beyond the straight line edge that marks the railroad embankment across the lake. The tip of the Shuttle tail marks the Wasatch Mountains above Salt Lake City. Behind the tail are the Uinta Mountains. Beyond near the left base of the tail are the Black Hills in South Dakota.

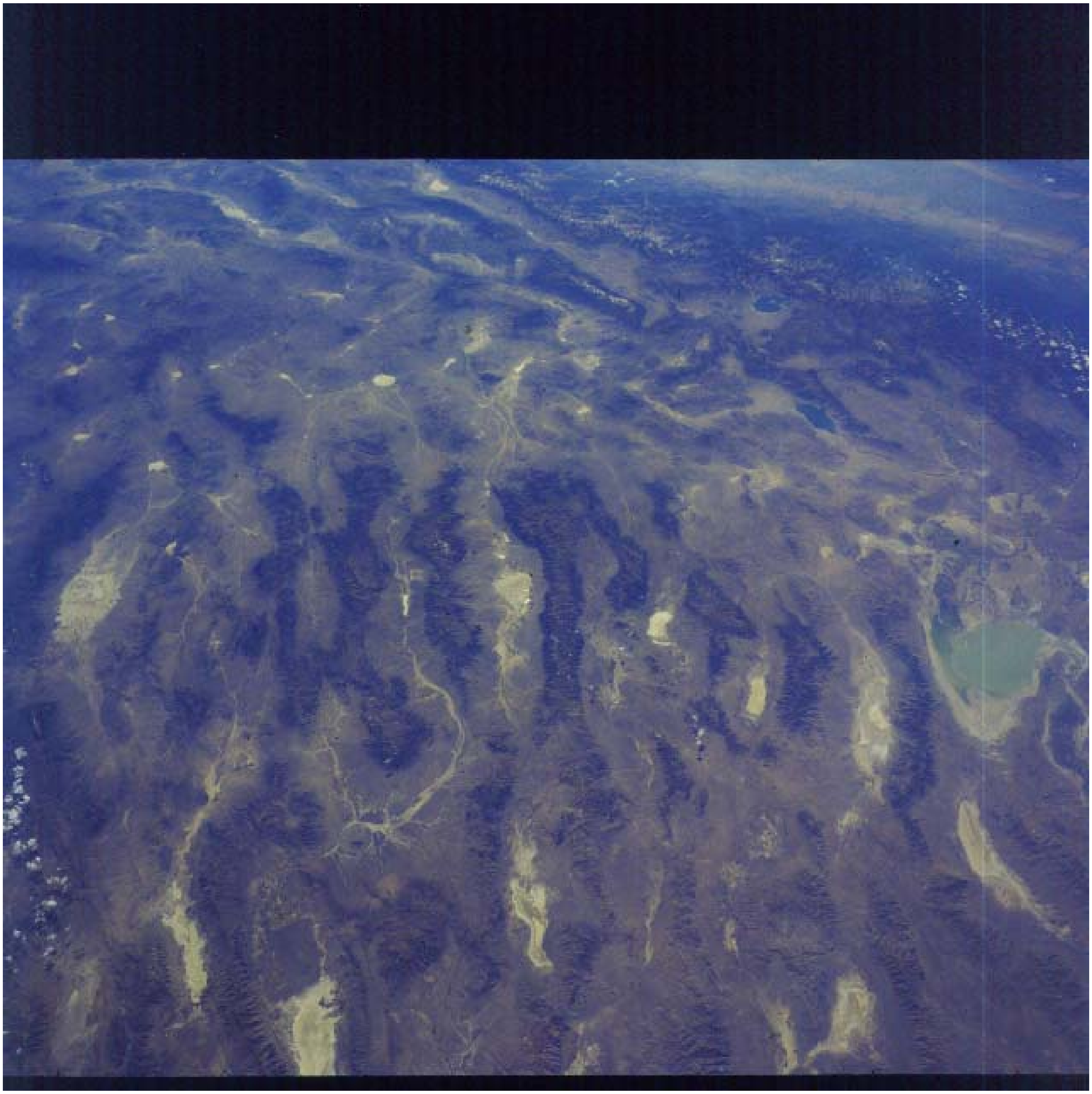

Figure 7. Photograph 17-121-184. Southwest across Nevada showing typical basin and range topography in foreground. South-trending ranges (mostly horst blocks) and intervening valleys (mostly graben) alternate as extension pulls them apart. Beyond they terminate against the Walker Line, a boundary that extends from Las Vegas to Reno. This marks the eastern boundary of a large triangular wedge. The western boundary is along the base of the Sierra Nevada (in the distance) and the Garlock fault (off the frame to the left) is the southern boundary. This triangular wedge has faults that move the far (west) side north parallel to the San Andreas fault (near the skyline) as well as normal faults that extend the region parallel to the Basin and Range Province faults. Mono Lake is nearly circular and lies at the base of the Sierra Nevada. Walker Lake lies to the right and in a valley closer to us.

Figure 8. Photograph 37-83-54. View north across the Mojave Desert to the Sierra Nevada (covered with snow). The Salton Sea lies in a depression where the San Andreas (at the foot of the mountains on its right) steps west (left) and cuts through the Imperial Valley irrigation district into Mexico (foreground). The San Andreas fault continues northwest between the snow-capped ranges (San Gabriel on the left, San Bernardino on the right), then along the southern margin of the Mojave Desert to where it crosses the Tehachapi Mountains and lies just west of the San Joaquin Valley. Las Vegas is the green patch in the brown valley at the right edge of the photo. Death Valley lies near the right center of the frame and extends away from the viewer. Circular Mono Lake lies just beyond the far end of the straight Owens Valley along the east base of the snow-capped Sierra Nevada.

Figure 9. Photograph 51F-38-0043, The San Andreas fault extends straight away from us in this beautiful view of Southern California (Even the smog is relatively light and concentrated in two patches- one near Riverside {close to us} and the other in the San Fernando Valley. The fault cuts through the mountains (San Bernardino on the right, San Gabriel on the left) , then along the southern edge of the Mojave Desert and beyond along the west side of the San Joaquin Valley and northward along the east side of Monterey Bay (near top right??? edge).

The offset of the San Gabriel Mountains (left) from the San Bernardino Mountains (right) was long thought to be the offset of the San Andreas fault. The paper by Mason Hill and Tom Dibblee (1953) showed that was wrong! The tan-colored valley in the center foreground is bounded on the right (east) by the San Jacinto fault, which splays from the San Andreas in Cajon Pass (above the smog band), and by the Elsinore fault on the left (west). Both of these faults are right-handed strike-slip faults. The Elsinore fault makes a right-step that formed a pull-apart basin, now occupied by Lake Elsinore. They run into the Santa Monica and San Gabriel faults that lie at the base of the east-trending mountain ranges of the same name.

The Mojave Desert is bounded on the north side by the Garlock fault which marks the southern end of the Sierra Nevada and continues east off the view to the southern end of Death Valley.

Figure 10. Photograph 61A-46-039. View northeast across San Francisco Bay. The San Andreas fault can be traced south from Tomales Bay (near upper left edge), to the entrance of San Francisco Bay to back on land in South San Francisco (color line from dark closer to us to lighter [all houses]), and continuing along the color break southeast to where it leaves the picture in the lower right side. San Jose occupies the valley south of the bay. The Hayward fault lies at the base of the mountains along the east (far) side of the bay. The football stadium of the University of California at Berkeley straddles this fault. Another splay (Calaveras fault) diverges to the north and lies on the east side of the Hayward Hills.

The delta region of the San Joaquin and Sacramento Rivers at the west edge of the Great Valley of California has been extensively modified into agricultural land.

The Sonoma and Napa Valley wine country lies along the top edge of the picture.

Figure 11. Photograph SL3-121-2375. View south down the San Joaquin Valley to Los Angeles and on to Baja California. The San Andreas fault lies between the brown mountains and surrounding land and the green valleys near Monterey Bay (lower right). The fault extends southward to where it makes a sharp bend to the left and continues along the southern margin of the Mojave Desert (triangular brown area), through the mountains to the left side of the Salton Sea, where it makes a right step and disappears into the northern end of the Gulf of California (top center).

This picture was taken from Skylab 3 during the summer of 1973. Comments by astronauts who have flown during this period and later during the Shuttle era say the sky is murkier now than it was at that time.

Figure 12. Photograph 81-711-049. View northeast into the Gulf of California. The 165 mile offset along the San Andreas fault is the distance between the south tip of Baja California and the Isla Marias (center at mouth of gulf).

For those interested in viewing more of California, I have selected 17 of the best for a CD-ROM that is in the pocket of the Geological Society of America Special Paper 338 (1999).

Middle East, Adjacent Africa, and Southwestern Asia

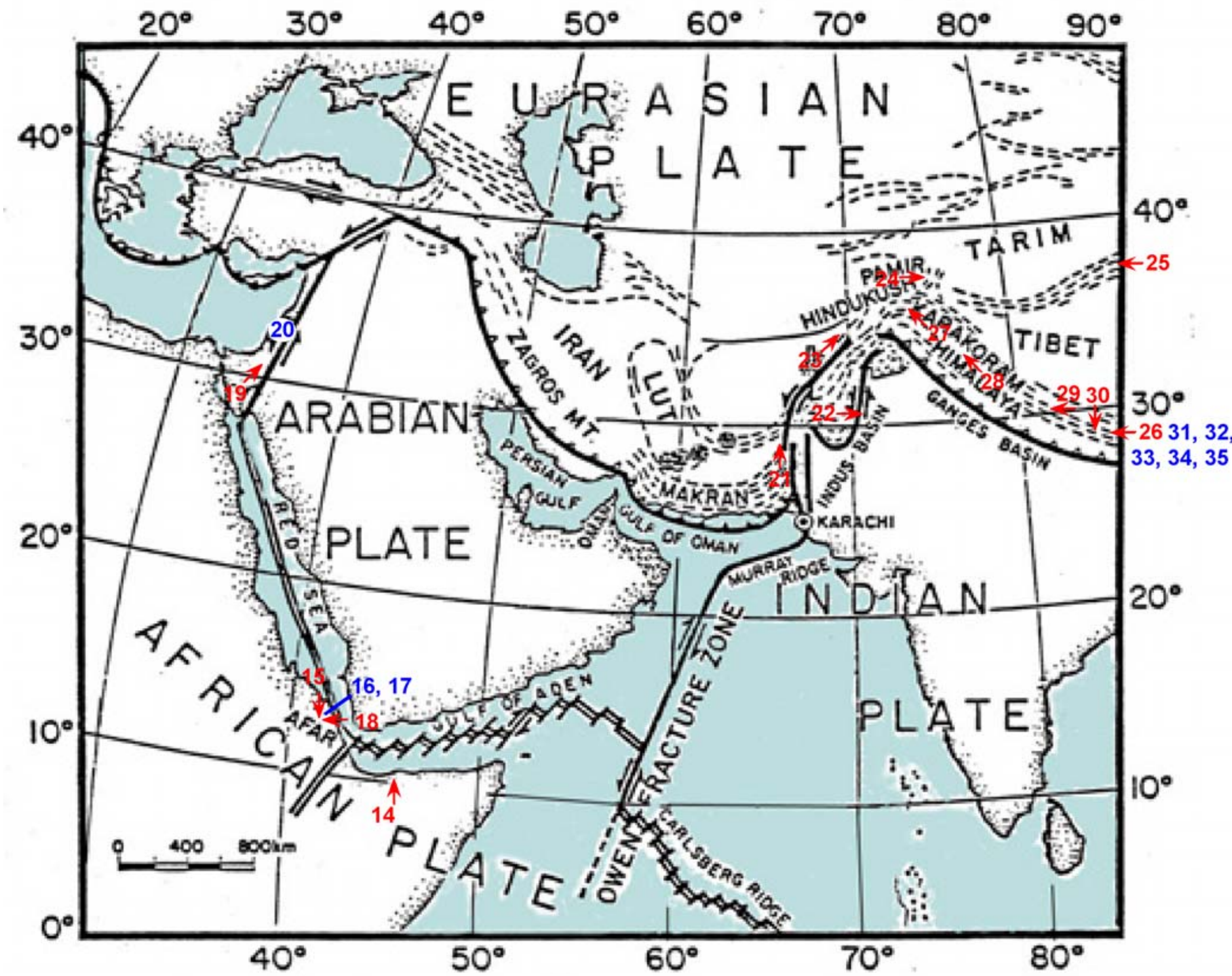

Figure 13. Map of African, Arabian, Indian, and Eurasian plates, as location map for Figures 14-34 (from Muehlberger, 2001).

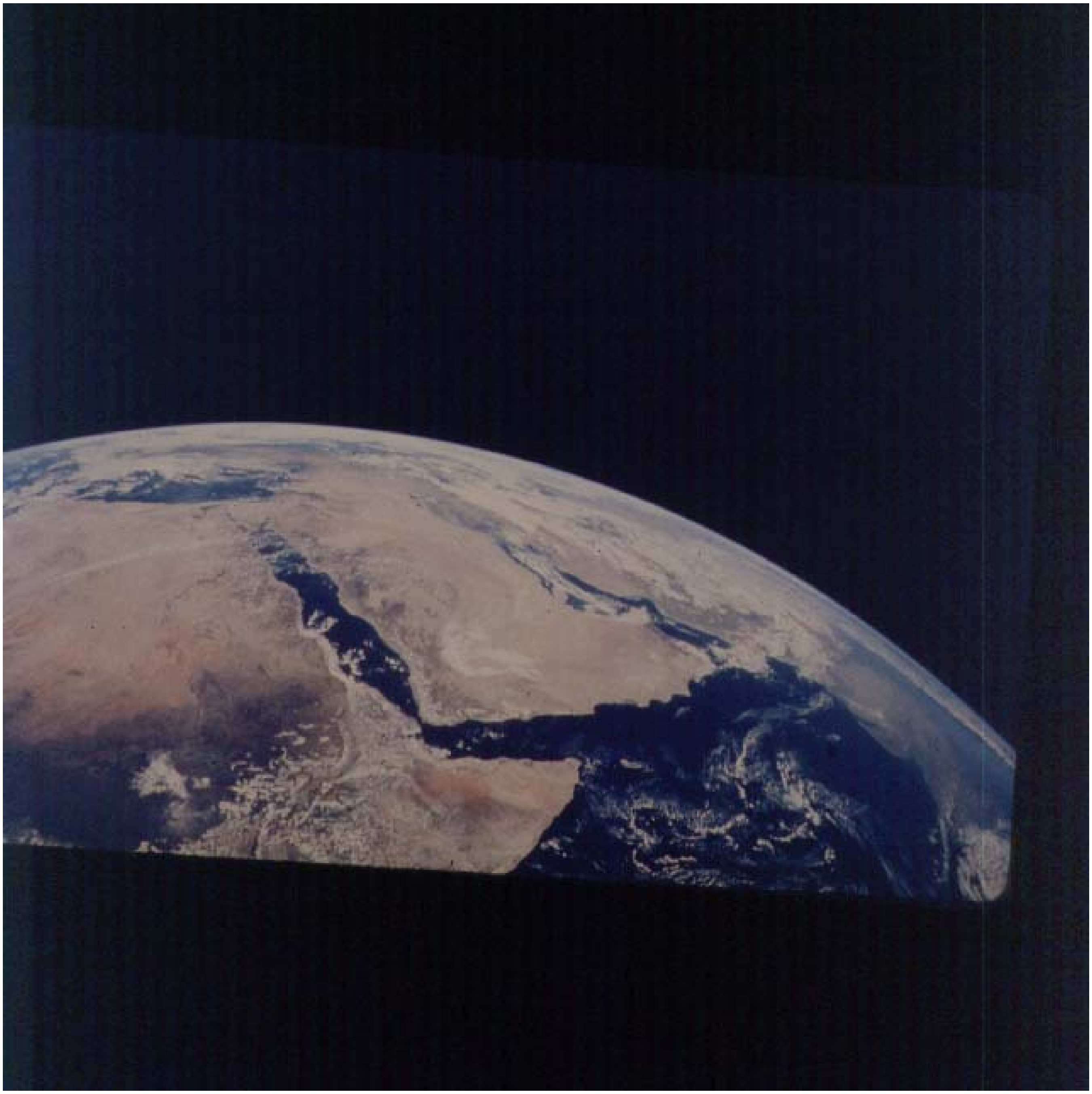

Figure 14. Photograph A17-148-22718. Taken on the way to the Moon, December 1972 on Apollo 17. View of the Arabian Peninsula and adjacent Africa and Asia. The spreading centers of the Red Sea, Gulf of Aden and East Africa come together in the Afar Triangle (light-colored triangular wedge of land at the south end of the Red Sea). This low-lying region is a complex of tectonic and volcanic features that reflect the ongoing regime of sea-floor spreading.

Afar Triangle

The next four slides illustrate some of these features of the Afar Triangle region.

Figure 15. Photograph 17-32-012. View south along the length of the Afar Triangle. The Red Sea spreading center dies out under the sea at the left and steps over to continue south under the giant volcanoes on the right at the base of the escarpment bounding the Ethiopian Highland (averaging 11,000 feet whereas the dry valleys at the base of the volcanoes are below sea level). In the far distance is the Somali escarpment bounding the Afar Triangle on the south. The East African Rift Valley enters from the upper right (light-colored area).

Beyond the three giant volcanoes is a region of extensive faulting marking the spreading between the southern continuation of the Red Sea system and the northward-propagating Gulf of Aden spreading center. These features are seen in the next frames.

Figure 16. Photograph 17-32-014. Near vertical view on Erta Ale, a giant shield volcano in the northern Afar Triangle. North is at bottom of the picture. The lake at the north base of Erta Ale (3372 ft) is 410 ft below sea level. Volcanoes abound to the south where the spreading center jumps eastward (left???) to the base of the Ethiopian escarpment. Erta Ale is about 50 miles long.

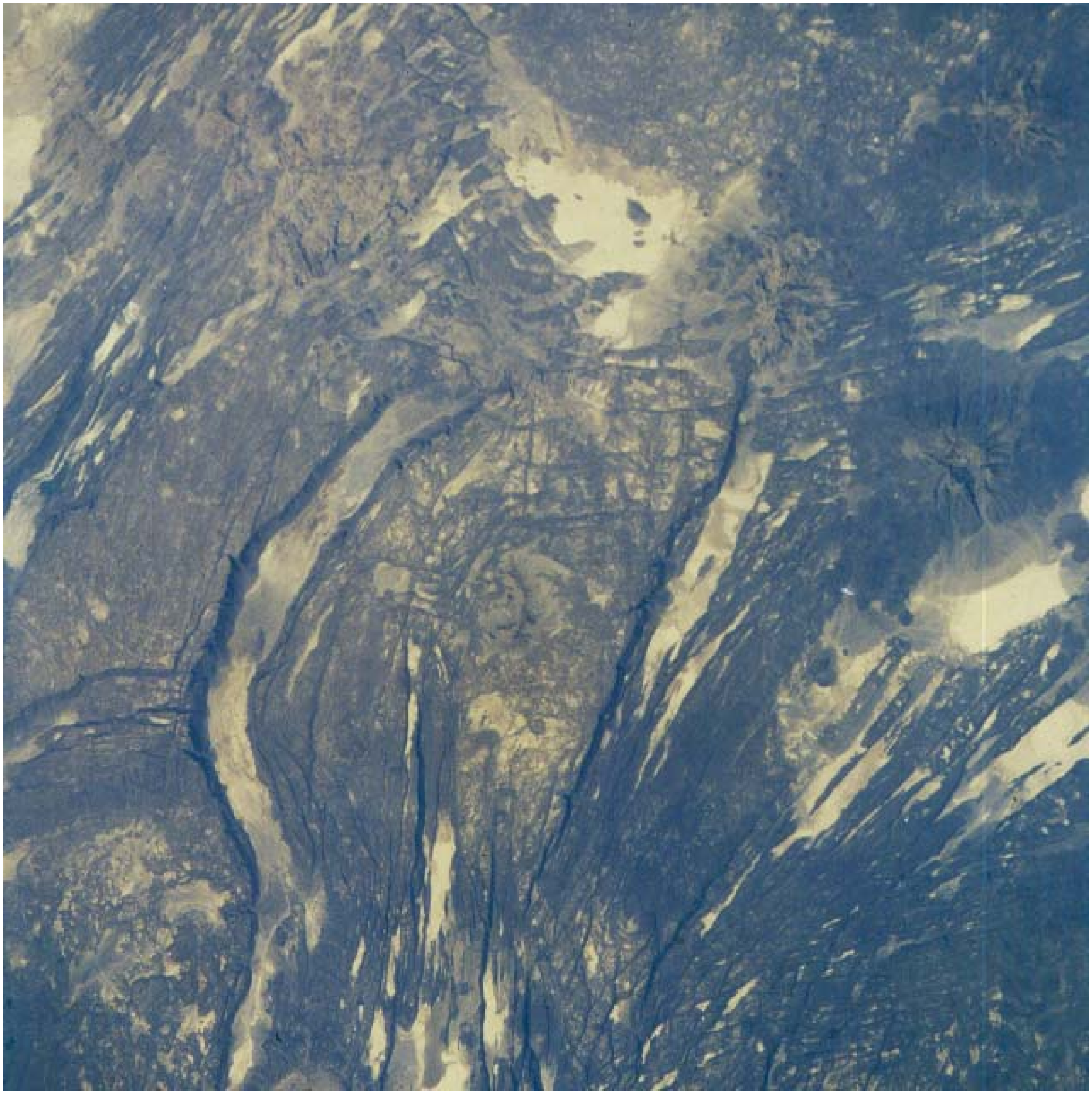

Figure 17. Photograph 61A-36-094. Near vertical view on the central Afar Triangle fractured zone. North is near top of picture. Field of view is about 60 by 60 miles. Gulf of Aden spreading center (propagating nearly north) lies off the frame to the right (east). The Red Sea spreading center (propagating nearly south) lies off the frame to the left (west). The structural lows (grabens) are light colored because of the accumulation of fine material dropped by the rare floods that collect into ephemeral lakes.

Figure 18. Photograph 17-35-104. West into Gulf of Tadjoura (westernmost extension of the Gulf of Aden spreading system). The spreading center extends from the Gulf of Tadjoura northwestward into the Lake Asal basin (509 ft below sea level; about 5 miles across). Recent volcanism forms the land bridge separating the ocean from the salt lake. This spreading center is nearly a duplicate of the Mid-Atlantic spreading center in size and structural relief. To the right of Lake Asal the spreading center makes a series of right steps. The shadows beautifully outline the rapid changes in structural relief along strike.

Sinai – Dead Sea

Figure 19. Photograph 43-94-78. View north across the Sinai Peninsula, along the Dead Sea fault to Syria. Shows the contrasting structures of the rifted Gulf of Suez (left) and the transform fault of the Dead Sea fault (105 km left slip; two-thirds of the length of the Gulf of Aqaba). The Dead Sea fault makes left steps under the Gulf that opens the gulf to the sea. The Dead Sea beyond lies in another left step.

Mt. Sinai lies in the center of the Precambrian basement exposures in the near field of the Sinai Peninsula. Beyond, the sedimentary cover of Nubian Sandstone (ruddy color) and the overlying limestones form the cap of the peninsula.

In the upper right can be seen the smoke plume from the burning oil wells of Kuwait, August 1981.

Figure 20. Photograph 17-120-056. Near vertical view of the Dead Sea segment of the Dead Sea fault. North is to the top of the frame. The Dead Sea occupies the current basin with the only significant drainage coming in from the north- the Jordan River. South of it is the salt-filled earlier basin. Further south is the fluvial filling (extends beyond the frame) of the first episode of faulting.

About 40 miles separates Jerusalem (gray area to the west of the north edge of the Dead Sea) and Amman, Jordan (gray area to northeast of the north end of the Dead Sea). Beirut, Lebanon fills the peninsula on the Mediterranean Sea shore near the top of the picture. Damascus, Syria lies to the east of the tan mountains and in the midst of the dark, irrigated area fed from springs along the base of the mountains. Jericho is the dark patch just north of the Dead Sea and on the west side of the valley that extends north to the Sea of Galilee. The Sea of Galilee marks another left step in the Dead Sea fault. Another left step to the north is followed northward by a strong bend to the east into the Bekaa Valley.

Makran – Afghanistan – Pakistan

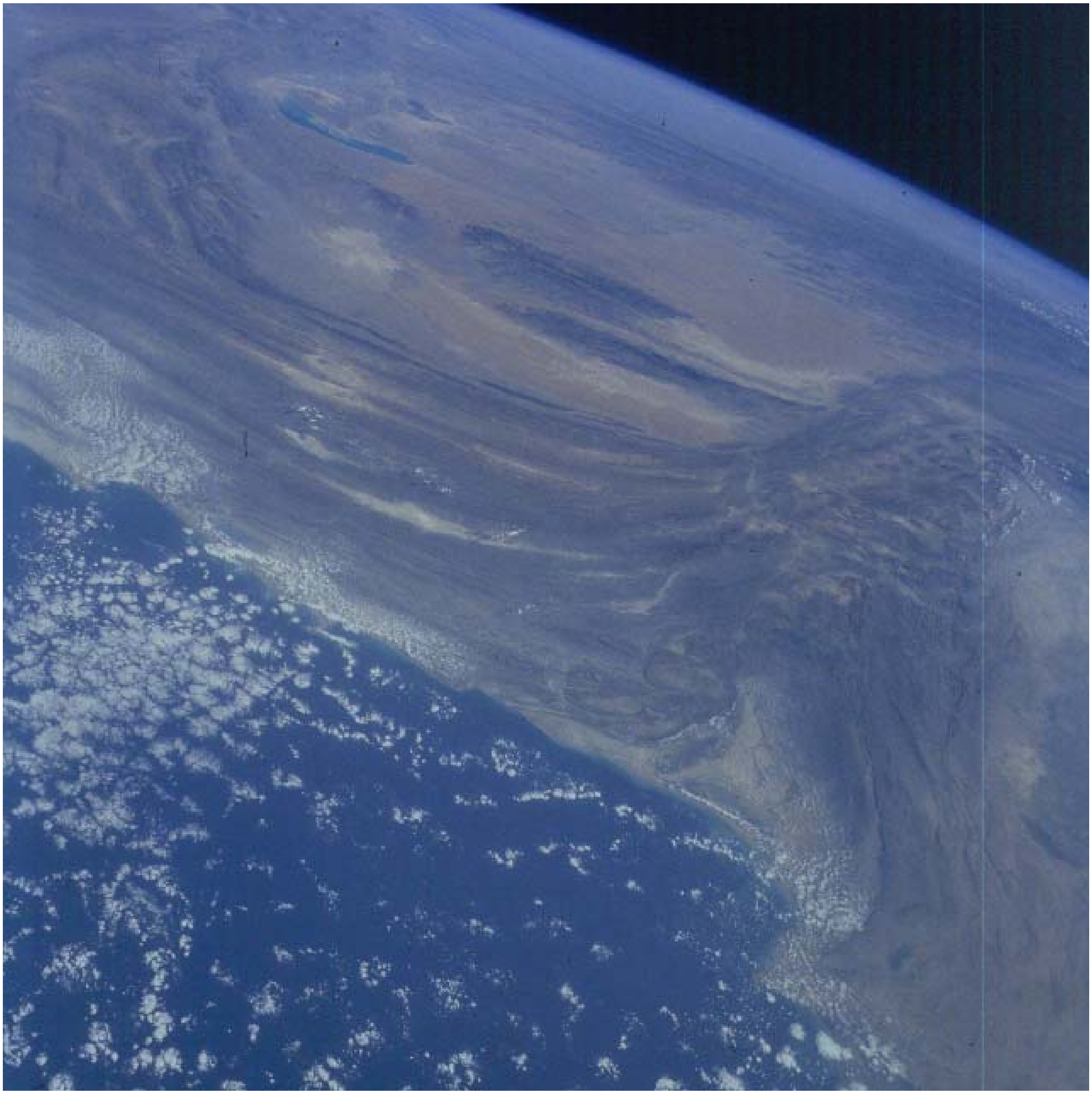

Figure 21. Photograph 57-87-050. View north to Afghanistan across western Pakistan. The Makran (center foreground) is an accretionary prism formed as the Indian Ocean floor subducted under the Asian continent. In the middleground is the volcano line (far inland compared to many subduction systems because the subducting plate is going under at a very shallow dip). Beyond is the continental Helmand Block (the desert region) that extends into the high mountain ranges of central Afganistan.

The Indian Plate, at the right edge, is moving away from us and drags the Makran layers against the plate boundary Chaman fault.

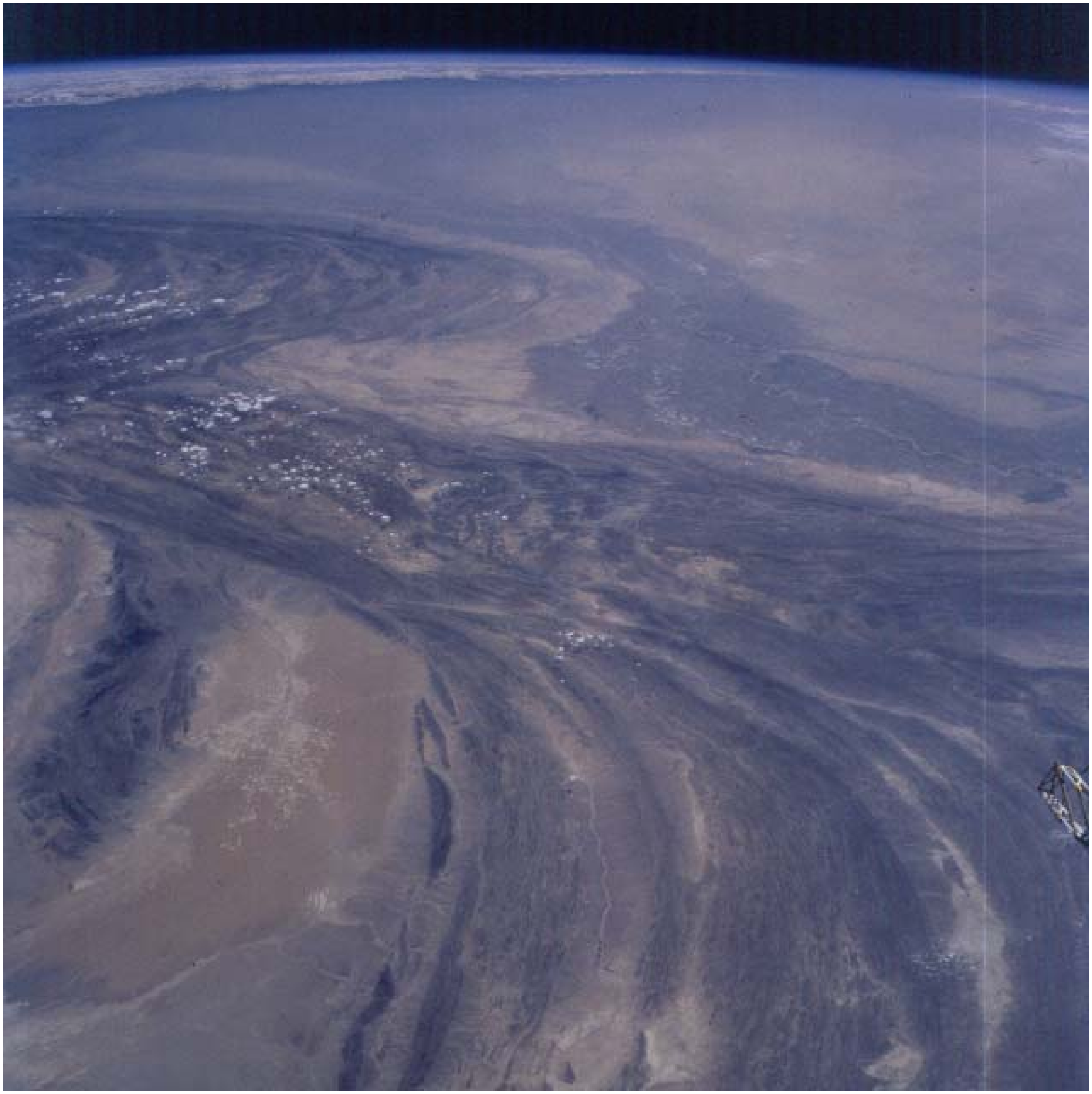

Figure 22. Photograph 84-701-050. View east across the Helmand block and Makran beds showing the drag along the transform faults marking the boundary between the Eurasian and Indian Plates. In the middle distance is the big arc of the Suleiman Ranges in Pakistan. The Himalayas hide under the clouds on the skyline.

The next picture is to the left of this scene. The dark, massive mountain range on the left side (the volcano line) that is truncated at the far end by the Chaman fault, the transform boundary between the Eurasian and Indian Plates, will be an easy landmark for the next picture.

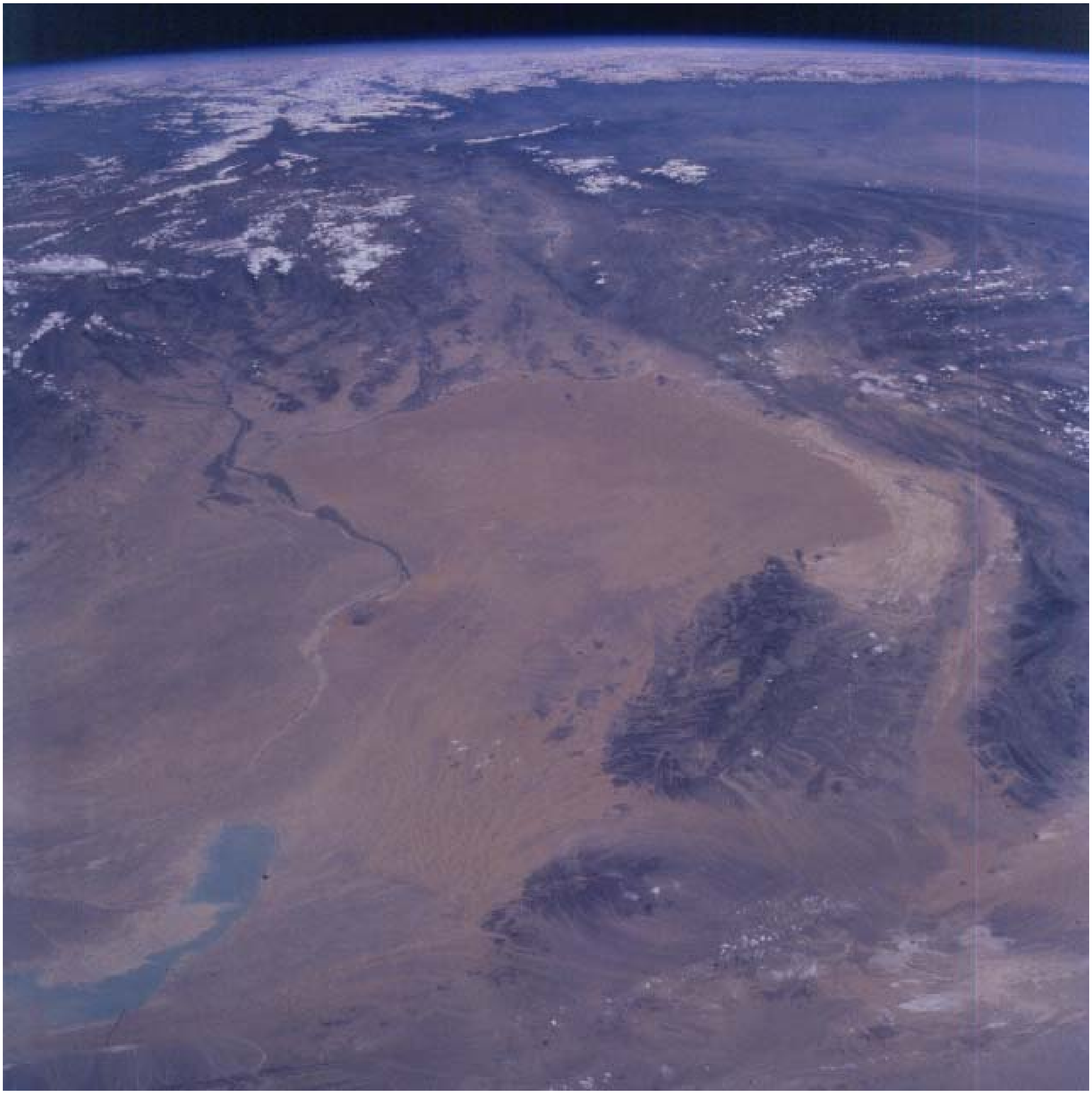

Figure 23. Photograph 84-701-047. The volcano line now lies along the right foreground. The Chaman fault extends for 300 miles along the base of the folded and faulted Suleiman Ranges. At the north (left) end of the Chaman fault lies Kabul, capital of Afghanistan.

The Helmand River flows into the desert from the mountains beyond (Qandahar is at the desert edge of the mountains), past the lake (Gowd-e-Zereh) and turns north to empty into another lake on the Iran-Afghanistan border (just off left side of the picture). The Hindu Kush and Pamir Mountains lie along the horizon on the left and the Himalaya Mountains on the right.

A detailed trip along the Arabian Plate boundary structures can be found at the following URL: http://eol.jsc.nasa.gov/handbooks/arabianpages/mainframe.htm.

Kashmir-Tibet-Tarim Basin

Figure 24. Photograph 79-789-072. View east past Mir, to the Pamir Mountains and beyond to the Tibetan Plateau. Curving around the right side of the high, desert valleys (all over 12,000 ft) is the Wakhan Valley (center of frame), one of the main Silk Road routes across this high region. Marco Polo traveled up that valley.

The snow-capped range on the left is the Pamir; on the right, the mass of mountain ranges are the Hindu Kush. Beyond lies a crescent-shaped valley (bluish) in which the Indus and Gilgit Rivers flow. They outline the Kohistan Arc, an island arc accreted to Asia before the Indian Plate collided. The Indian Plate underlies the low, hazy country on the far right as well as the Himalaya Mountains to its left. The Valley of Kashmir is the large elongate cloud-covered valley in the lower part of the Himalaya.

The lowest pass across this region to the Tarim Depression (Takla Makan Desert, the dust-covered region on the left skyline) is in the valley near the left edge (elevations reaching barely 11,000 ft), the Kyzyl River valley. The Talas-Fergana fault, a major strike-slip fault, extends off the frame to the left just where the Kyzyl valley enters the Tarim basin. The south flank of the Kyzyl valley marks the northernmost thrust of the oncoming Pamir-Hindu Kush block. The far edge of this block is marked by the Karakoram fault, a major right-handed strike-slip fault, which extends as a straight valley to the upper right from the bend at the right edge of the Tarim Basin, The bend is occupied by the Kunlun Mountains and the boundary with the Tarim Basin and the Kunlun Mountains and Tibetan Plateau is marked by the left-handed strike-slip fault that continues for several hundred more miles beyond the horizon.

Figure 25. Photograph 66-95-083. West along the central segment of the 500-mile-long Altyn Tagh fault. It is the structural boundary between the Tarim Basin (right side) and the Tibetan Plateau (far left) and Qaidam Basin (near left). In near left the south branch of the Altyn Tagh fault turns to the left (southwest) to become the thrust front of the Tanghe Nan Shan (highest peak- 18,540 ft). The north branch continues off the near edge of the photo for another 100+ miles. The lakes in the Qaidam Basin are about 10,000 ft above sea level; the distant lakes on the Tibetan Plateau are near 13,000 and 14,000 ft (farthest one) in elevation. The highest peaks along the Altyn Tagh fault exceed 19,000 ft in elevation.

The long, arcuate range to the right of the linear Altyn Tagh fault is bounded by thrusts as a result of being along a transpressional bend.

The Tarim Basin has its lowest elevation at Lop Nor, the dry lake basin with abandoned shorelines in the shape of an ear (at the right, near end of the sand desert).

Himalaya Mountains

Figure 26. Photograph 17-120-023. West along the Himalaya Mountains, with the plains of India on the left and the Tibetan Plateau on the right. Overview of the landmarks that lead from the distance to Mt. Everest in the near foreground. The Tibetan Plateau averages about 15,000 ft above sea level, with the Himalaya Mountains rising above that level by as much as 14,000 ft. The mountains are being driven up and over the plains of India (left). Because the rain clouds (and monsoon) come from the Indian side, erosion and uplift are nearly balanced.

Because the Shuttle always flies east (towards us in this view), either from upper left to lower right, or from upper right to lower left, the landmarks that help to locate Mt. Everest will be described on successive slides from the distant lakes and faults to the near landmarks that specifically pin down the location of Mt. Everest (The family pronunciation for their name is "Eve-rest"!!).

An interactive internet tutorial "How to find Mt. Everest from space" can be found at http://eol.jsc.nasa.gov/education/Everest/.

From below the tip of the tail, the Karakoram fault extends toward the lower left to where it meets the valley of the Brahmaputra River, which runs parallel to the mountain front, but on the Tibetan Plateau. The river lies in the suture between the Indian Plate (left) and the Asian Plate (right). Extending from the tail tip to the right is the Altyn Tagh fault that marks the boundary between the Tibetan Plateau (near) and the Tarim Basin (far). These are strike-slip faults which cause the Tibetan Plateau to be pushed to the east (toward the lower right).

The next slide covers the region near the junction of the Karakoram fault and the Brahmaputra River. As the details are described in the next series of slides, this overview picture will be useful to return to and integrate the features identified.

Figure 27. Photograph 33-72-078. Northwest along the right-lateral strike-slip Karakoram fault. In the center lie 'Pear' and 'Champagne' Lakes (real names: La'nga Co and Mapam Yumco, both 15,510 ft above sealevel, both closed basins). Extending the stem of the 'glass' across the valley to the snow-capped peak is Mt. Kailas, 21,770 ft, where Buddha is said to have risen to heaven from its peak.

The Indus River starts beyond the lakes and flows away from the viewer along the valley of the Karakoram fault to where it cuts through the mountains to the left. The Gilgit River starts near the lakes and takes the left valley to flow away from the lakes. The Brahmaputra heads to the right of the lakes and continues east for the length of the Himalaya in the valley formed by the suture zone.

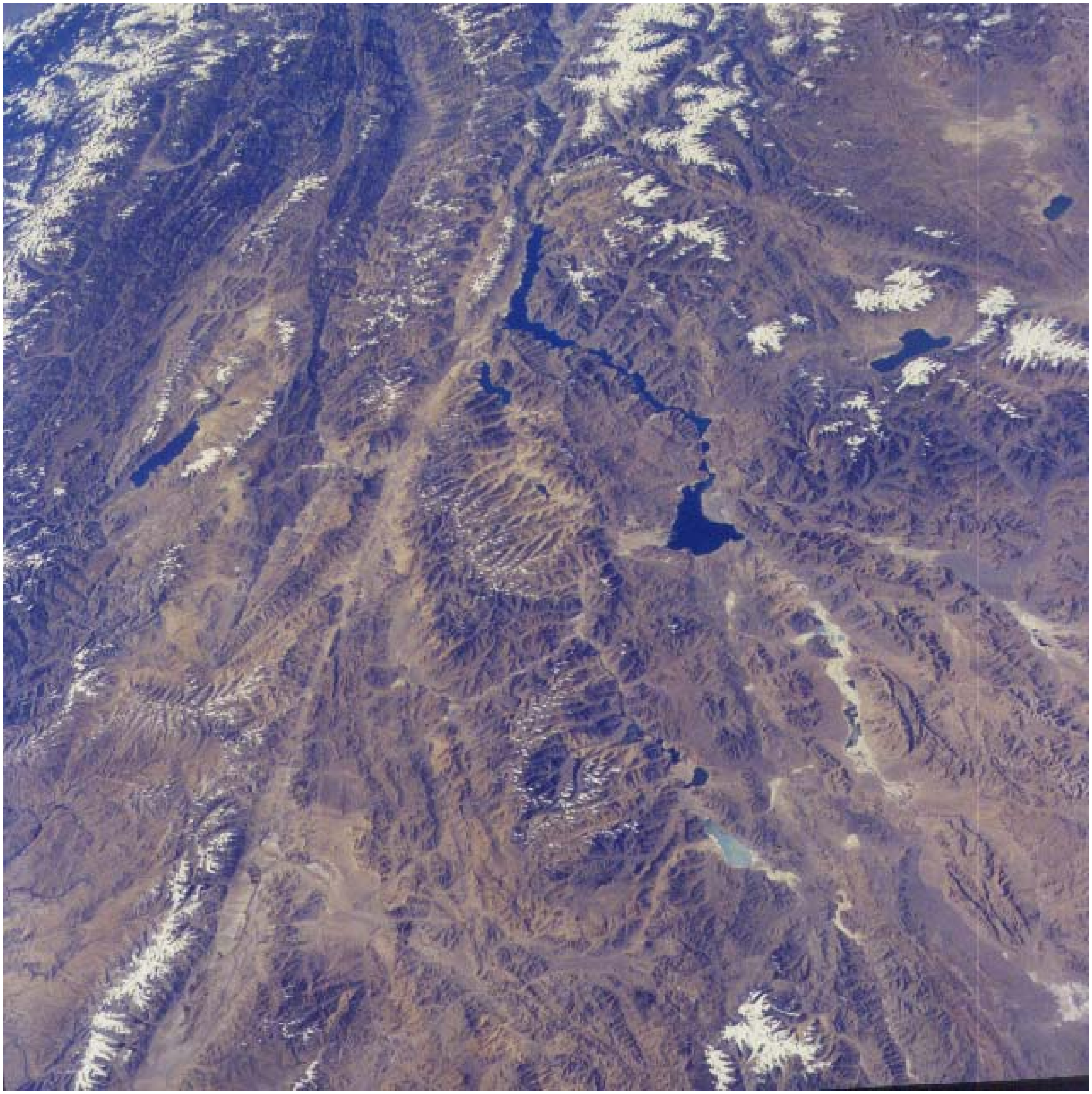

Figure 28. Photograph 17-31-046. View northwest along the central part of the Karakoram fault, which extends from bottom left to top center of the picture, a distance of about 200 miles. Lake Bangong has its short leg (30 miles long) along the fault and its long leg parallel to the suture between two of the terranes that constitute the Tibetan Plateau.

Figure 29. Photograph 17-31-052. West along the Indus suture to its intersection with the Karakoram fault near Lakes ‘Pear’ and ‘Champagne’. Two hundred miles to the east, in the lower left is the Koli-Thakkola graben, a normal fault-bounded valley that cuts across the thrusts of the Himalaya.

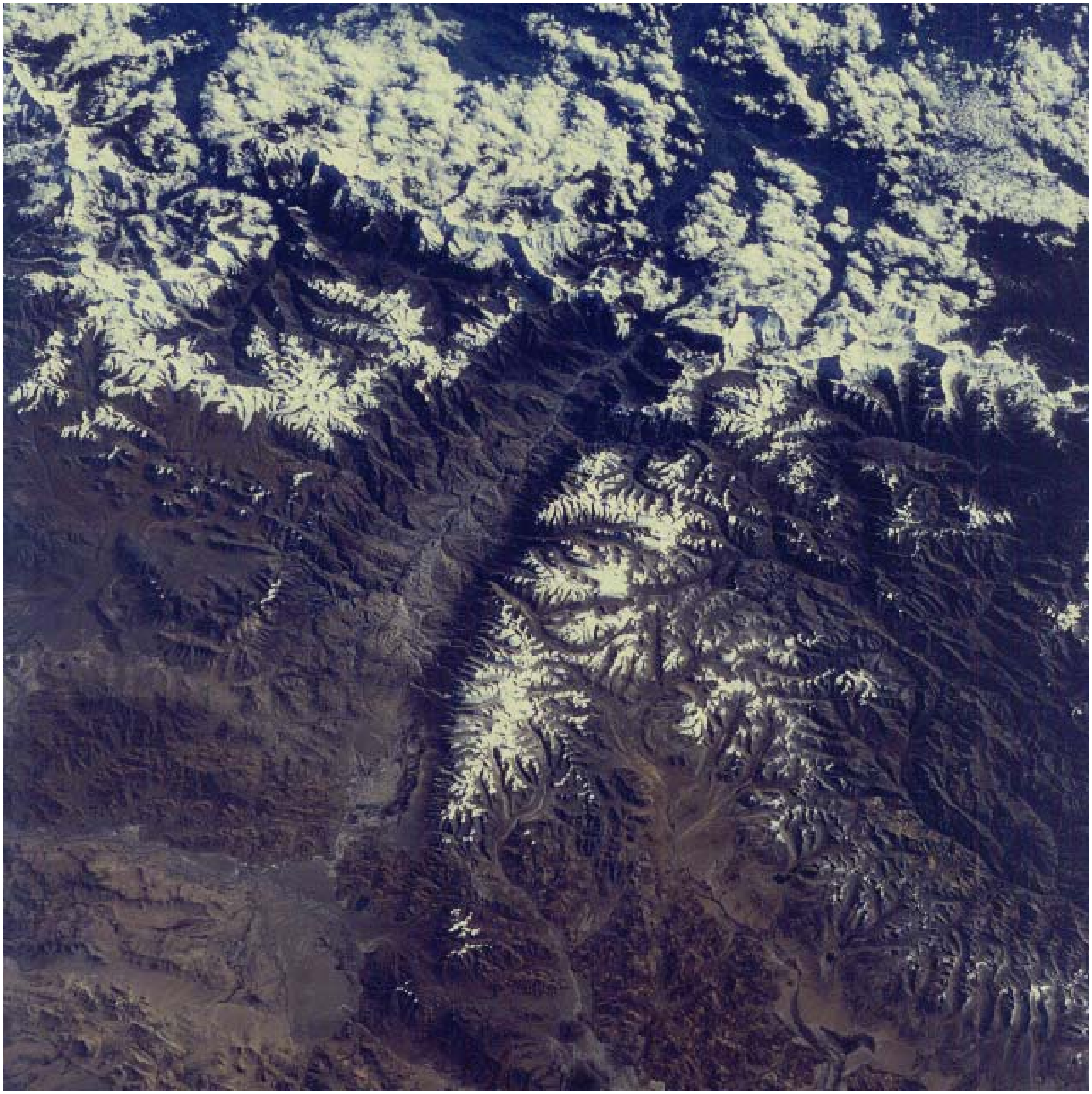

Figure 30. Photograph 17-31-047. South down the Koli-Thakkola graben. It demonstrates that the Himalaya Mountains are extending parallel to its length. North-trending graben are found across the southern Tibetan Plateau showing that it too is extending east-west as India moves north under the Asian Plate. At the southern (far) end of the graben is a major fault at right angles to the graben. Along the far side on the left is Annapurna; to the right is Dhaulagiri, both over 26,000 ft.

Figure 31. Photograph 65-96-042. Another 100 miles to the east is Lake Peiku ('Bowtie Lake'), 15,510 ft above sea level. This is the key landmark for the final steps to Mt. Everest. View north.

Figure 32. Photograph 55-95-004. View north across the Himalaya Mountains to 'Bowtie' Lake (left) and Mt. Everest (right edge). North-trending graben filled with light-colored glacial outwash extend away from the viewer in the center of the frame. At right center is an inverted "V" formed by two valleys. Trace the right (longer) one up the valley toward you. At the end of the valley is the sheer face of Mt. Everest, 29,026 ft.

Figure 33. Photograph 58-101-022. West to Mt. Everest. The ‘V’ of valleys is in the center of the frame. Follow the near arm (left) to its end and the triangular snow-covered mass of Mt. Everest should be easy to pick out.

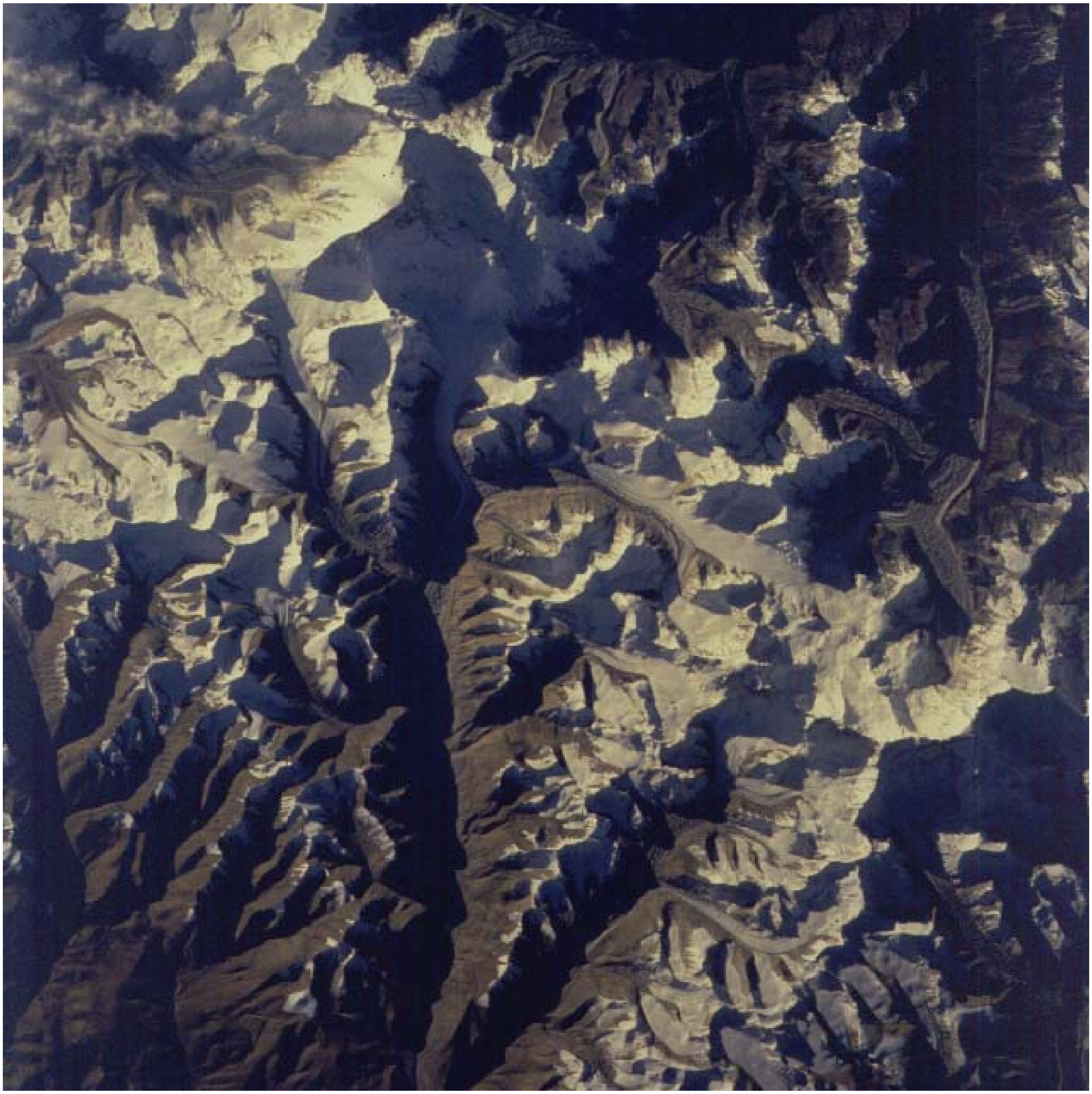

Figure 34. Photograph 58-101-014. Near vertical view on Mt. Everest. Taken a few moments before the last frame. The “V” forks at the bottom of the frame. Mt. Everest is at top end of left side of “V” (near top of frame).

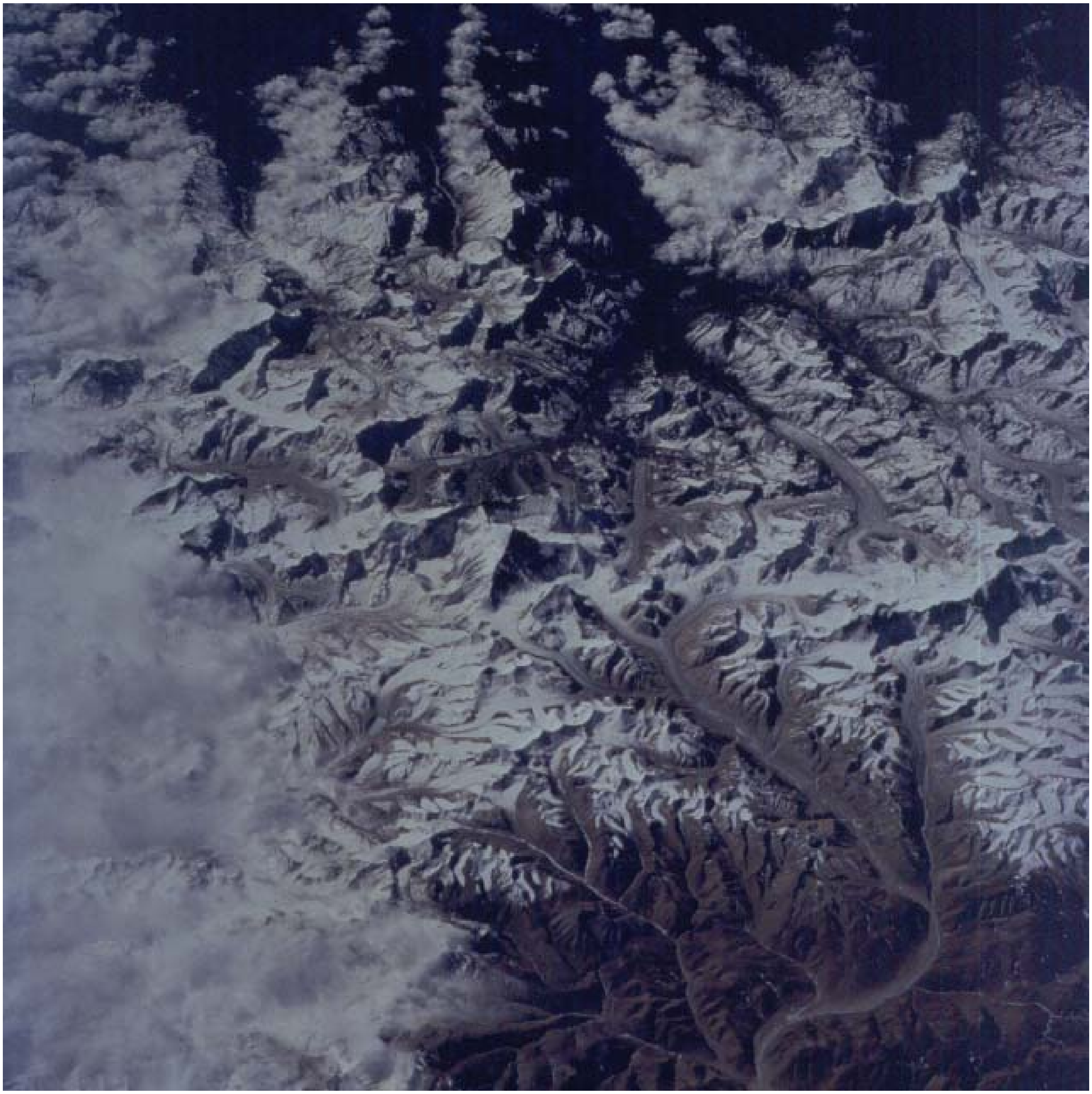

Figure 35. Photograph 99-735-046. South to Mt. Everest. This view shows how high above the surrounding region it stands: nearly 14,000 ft above the plateau! It is the surviving remnant of a larger region that once stood high.

Sunset

Figure 36. Photograph 46-105-033. Sunset near Hawaii, 7 August 1992. Because they loop the world every 90 minutes, the astronauts see 16 sunrises, sunsets, moon rises, and moonsets each day.