Chapter 72

The Monterey Submarine Canyon and Fan

Monterey Canyon, California, is probably the most studied submarine canyon in the world (Figure 72.1). Since it is typical of many others it is useful as an example to understand more about submarine canyons.

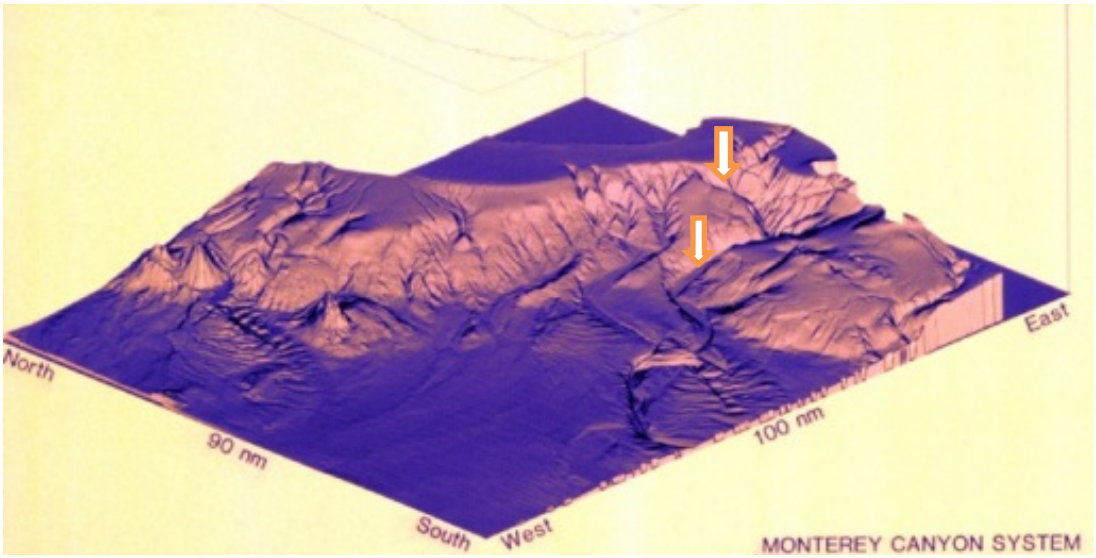

Figure 72.1. Monterey Canyon (arrows) and other smaller canyons off the central California coast (Wikipedia).

The Monterey Submarine Canyon

Monterey Submarine Canyon begins in Monterey Bay, which was designated the Monterey Bay National Marine Sanctuary in 1992 by Congress. As a result, there has been renewed impetus to study the canyon and bay. The purpose of the sanctuary is to preserve the environment of the bay. Eittreim and Noble expressed one of the reasons for the creation of this marine sanctuary:

> It must be admitted that a certain amount of interest in sanctuaries comes under the heading of moral or religious feelings about the sacredness of the earth's 'natural' systems and the importance of man's learning to live in harmony with these systems.[1]

The Length

Monterey Submarine Canyon is 60 miles (96 km) long. Like so many other canyons it continues out to a submarine fan (Figure 72.2). If the westward extending fan valley, entrenched on the Monterey submarine fan is included, the total length of the canyon is 295 miles (470 km).[2] Its maximum wall height is 5,575 feet (1,700 m), and its maximum rim-to-rim width is 7.5 miles (12 km). It is similar in depth and width to Grand Canyon (see Figure 70.5).

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[1] Eittreim, S.L. and M. Noble, 2002. Preface: seafloor geology and natural environment of the Monterey Bay National Marine Sanctuary. *Marine Geology* 181:2.

[2] Greene, H.G., N.M. Maher, and C.K. Paull, 2002. Physiography of the Monterey Bay National Marine Sanctuary and implications about continental margin development. *Marine Geology* 181:55-82.

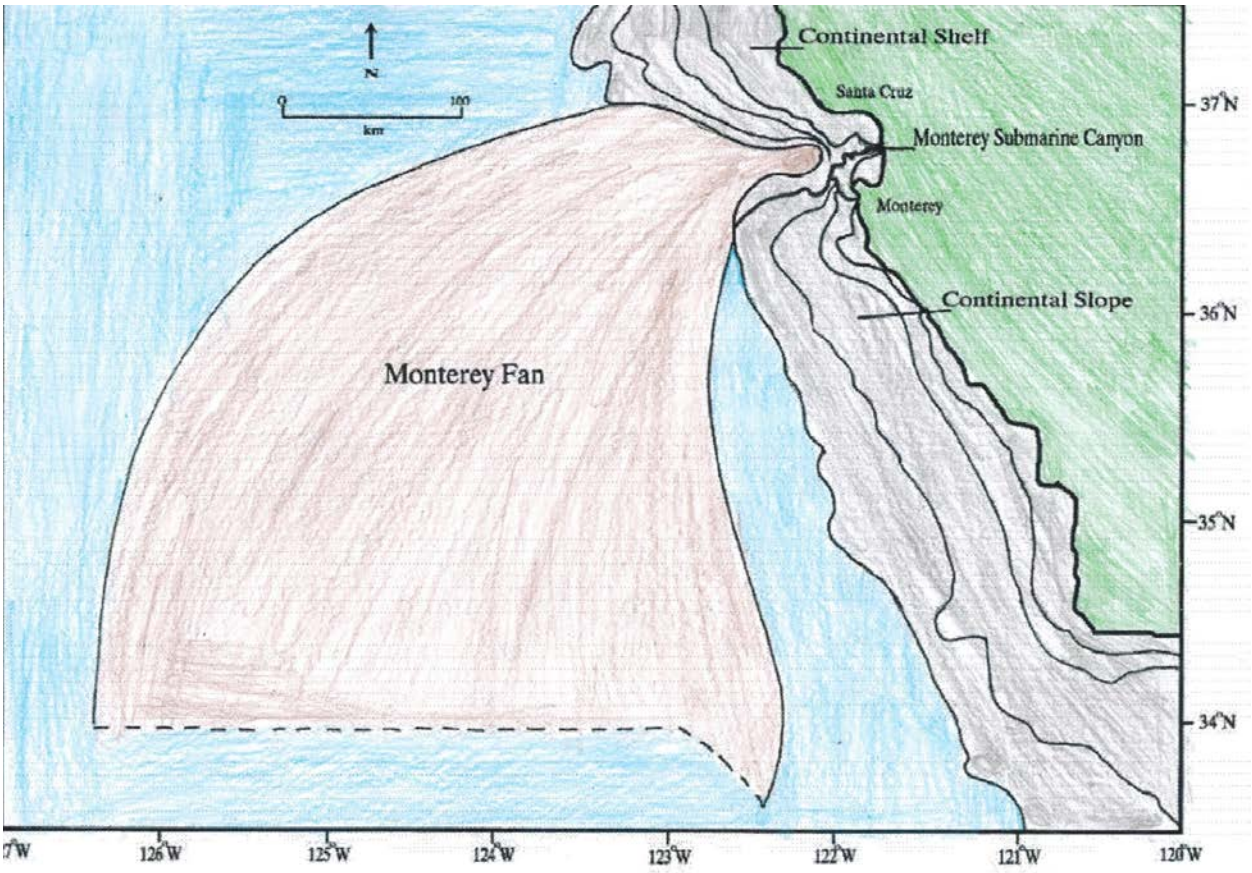

Figure 72.2. The Monterey Submarine Fan offshore from Monterey Canyon (drawn by Mrs. Melanie Richard).

Carved through a Planation Surface

Monterey Canyon is cut into a widespread planation surface. The planation surface shears the continental shelf granite.[3,4] It is unusual for a continental shelf to have a planation surface. Usually, it is composed of massive sediment deposition (see Chapter 30). This planation surface is generally smooth with little relief, regardless of whether it is adjacent to the rugged coastal mountains or the lowlands of Monterey Bay.[2] Gravels top the outer shelf planation surface.[3,5] The gravel is probably a remnant from planning, similar to planation surfaces on the continents. The inner shelf has some outcrops of granite over a thin cover of unconsolidated sediment.[5] The outcrops can be considered inselbergs, left over after sheet erosion formed the planation surface (see Part XI).

The upper reaches of Monterey Canyon generally were cut into granite.[6,7] The lower reaches of the canyon were mainly carved in the sedimentary rocks of the Franciscan Formation which

[3] Chin, J.L., H.E. Clifton, and H.T. Mullins, 1988. Seismic stratigraphy and Late Quaternary shelf history, south-central Monterey Bay, California. *Marine Geology* 81:137-157.
[4] Anima, R.J., S.L. Eittreim, B.D. Edwards, and A.J. Stevenson, 2002. Nearshore morphology and late Quaternary geologic framework of the northern Monterey Bay Marine Sanctuary, California. *Marine Geology* 181:35-54.
[5] Eittreim, S.L. and M. Noble, 2002. Preface: seafloor geology and natural environment of the Monterey Bay National Marine Sanctuary. *Marine Geology* 181:1-2.
[6] McHugh, C.M.G., W.B.F. Ryan, S. Eittreim, and D. Reed, 1998. The influence of the San Gregorio fault on the morphology of Monterey Canyon. *Marine Geology* 146:63-91.
[7] Green *et al.*, Ref. 2, p. 63,

outcrops widely in the coastal areas of central and northern California.[8]

Tributary Canyons

There are numerous small tributary canyons and an extensive gully (small canyon) network leading into the upper Monterey Canyon, as well as into the larger Soquel Canyon that forms the northern head of the canyon.[6] Side canyons enter the lower reaches as *hanging valleys*, including the Ascension Canyon system to the north[9] and the straight, fault-controlled Carmel Canyon that enters Monterey Canyon from the south.[2] This indicates Monterey Canyon is the dominant erosional channel.

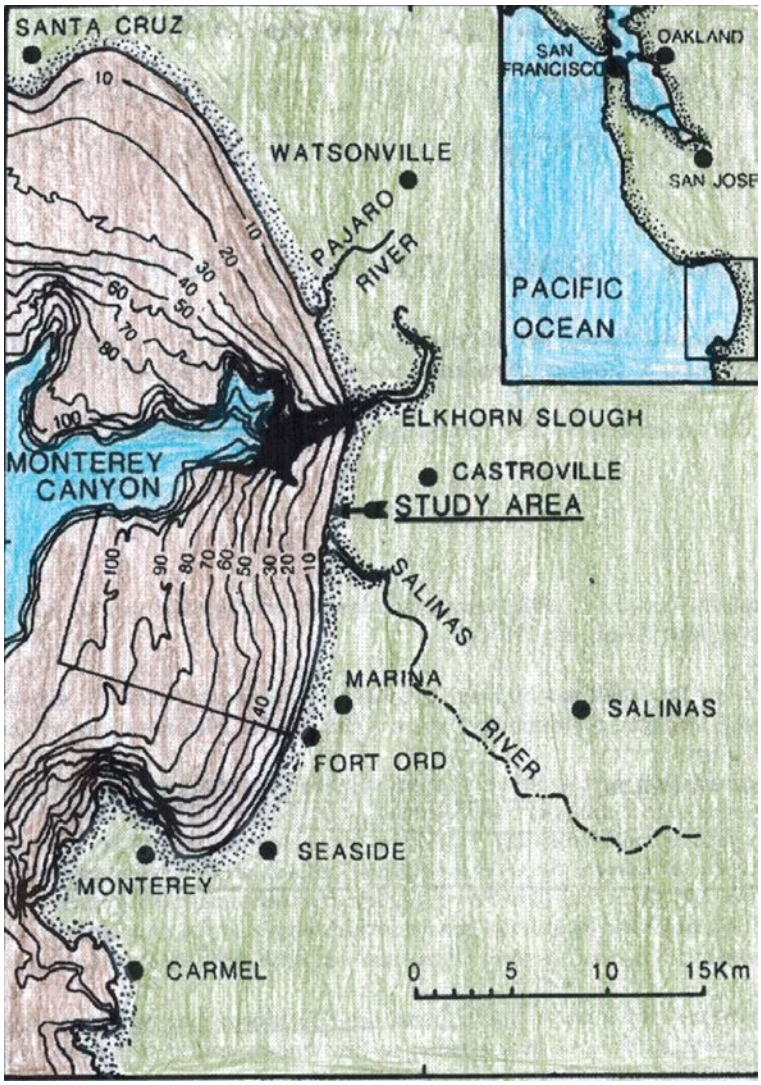

Figure 72.3. The coast of Monterey Bay showing that Monterey Canyon is an extension of Elkhorn Slough and not the Salinas River to the south (from Chin et al., 1988, p. 138).

[8] McHugh, C.M.G. and W.B.F. Ryan, 2000. Sedimentary features associated with channel overbank flow: examples from the Monterey Fan. *Marine Geology* 163:205.

[9] Nagel, D.K., H.T. Mullins, and H.G. Greene, 1986. Ascension Submarine Canyon, California—evolution of a multi-head canyon system along a strike-slip continental margin. *Marine Geology* 73:285-310.

How Is Monterey Canyon Related to Coastal Features?

At first glance it looks as though Monterey Canyon is an extension of the Salinas River. However, it is actually an extension of the Elkhorn Slough (a swampy, slow-moving stream or river) that flows into Monterey Bay about 4.5 miles (7 km) north of the river (Figure 72.3).[10] There is *no* buried channel connecting the head of Monterey Canyon with the Salinas River.[11] So, Monterey Canyon is not simply an extension of this river, but an extension of the slough. This presents a problem for the "present being the key to the past" since there is no indication of enough water and sediment to form Monterey Submarine Canyon.

It is possible that the Elkhorn Slough may be a diminutive remnant left over from a greater flow through the area. Monterey Canyon has what appears to be a subsurface extension inland, in the form of a buried canyon to the east.[12] The canyon is cut in granite and has been subsequently filled in with sediments. It is now sedimentary rock. It is not clear if this inland canyon is related to the development of Monterey Canyon or not, but it seems logical that it is. Curiously, recent investigators seem uninterested in it.

A Meandering Canyon

Monterey Canyon has several meanders, beginning in its upper reaches.[2] Some investigators think fault movement caused the meanders, but there is little evidence to support their hypothesis. The meanders cut into the steep continental slope proving meanders do not necessarily need a nearly flat surface to develop.

Monterey Canyon Indicates Little Movement of the western San Andreas Fault Zone

The San Andreas Fault system separates the North American and Pacific plates. The width of the fault zone stretches from around Monterey Canyon northeast into Nevada. Monterey Canyon is in the western part of the fault zone and is split by the San Gregorio fault, the western fault of the San Andreas fault system, that passes through the lower Monterey Canyon at the depth of about 5,900 feet (1,800 m).[6] Dickenson recently reanalyzed the fault movement and based on geology, fault movement was claimed to be 98 miles (156 km) since it first developed in the late Miocene.[13] But, Monterey Canyon seems to indicate there has been very little movement along the fault line (see Appendix 22).

The Giant Monterey Submarine Fan

The Monterey Submarine Fan is a huge deposit that starts at the downslope end of the canyon and fans out westward (Figure 72.2).[14,15] It is an especially sand rich fan, implying substantial bottom currents spread the sand far and wide. It is 9,800 to 15,400 feet (3,000 to 4,700 m) below

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[10] Chin *et al.*, Ref. 3, p. 138.
[11] Chin *et al.*, Ref. 3, p. 154.
[12] Starke, G.W. and A.D. Howard, 1968. Polygenetic origin of Monterey Submarine Canyon. *GSA Bulletin* 79:813-826.
[13] Dickinson, W.R., Net dextral slip, Neogene San Gregorio—Hosgri fault zone, coastal California: geologic evidence and tectonic implications, *GSA Special Paper 391*, Geological Society of America, Boulder, Colorado, 2005.
[14] McHugh, C.M.G. and W.B.F. Ryan, 2000. Sedimentary features associated with channel overbank flow: examples from the Monterey Fan. *Marine Geology* 163:199-215.
[15] Normark, W.R. and C.E. Gutmacher, 1989. Major submarine fans of the California continental rise. In, Winterer, E.L., D.M. Hussong, and R.W. Decker (editors), *The Geology of North America, Volume N, The Eastern Pacific Ocean and Hawaii*, Geological Society of America, Boulder, CO, pp. 373-382,

sea level and extends more than 220 miles (350 km) from the mouth of Monterey Canyon covering an area of 39,000 mi^2 (100,000 km^2). The fan has an average thickness of a little less than one mile (1.6 km). Newer figures suggest it extends a little farther, about 250 miles (400 km) from the canyon mouth.[16] The volume, therefore, would be more than 39,000 mi^3 (150,000 km^3).

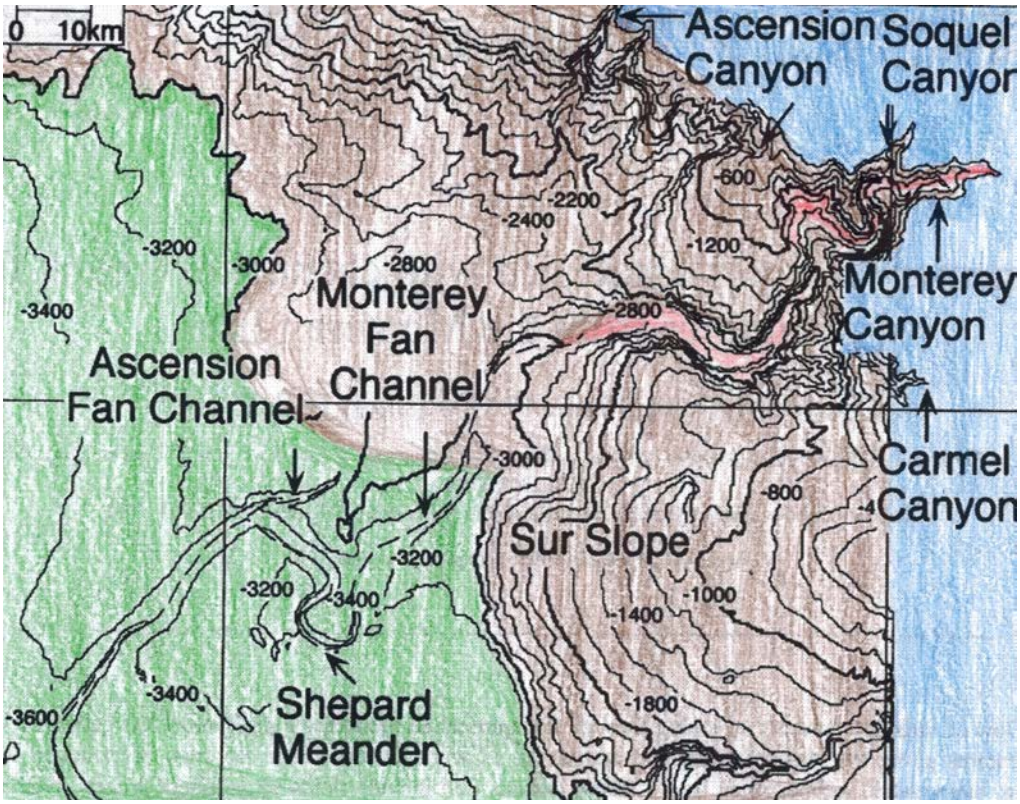

Figure 72.4. Shepard Meander of the Monterey Fan Cannel on Monterey Fan (from McHugh and Ryan, 2000, p. 2001).

The top of the fan is cut by a channel that is a continuation of Monterey Canyon. The fan valley is 1,000 to 1,640 feet (300 to 500 m) deep and 2.2 miles (3.5 km) wide in its upper portion. The fan channel can be traced almost the entire length of the fan and decreases to a depth of 165 feet (50 m) on the outer part of the fan.[17] There are levees, sediment mounds, piled up on the outside of the walls of the fan valley. They are probably from the spillover of sediments from thick mass flows that moved down the canyon and fan channel. Appendix 23 briefly discusses the types of submarine mass flows.

The fan channel also has a *horseshoe-shaped entrenched meander* called the Shepard Meander (Figure 72.4).[6,14] This suggests entrenched meanders can form deep underwater (see Chapter 61). In fact, submarine fans possess the largest meanders in the world.[18]

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[16] Fildani, A. and N. Normark, 2004. Late Quaternary evolution of cannel and lobe complexes of Monterey Fan. *Marine Geology* 206:199-223.

[17] Klaucke, I., D.G. Masson, N.H. Kenyon, and J.V. Gardner, 2004. Sedimentary processes of the lower Monterey Fan channel and channel-mouth lobe. *Marine Geology* 206:181-198.

[18] Imran, J., G. Parker, and C. Pirmez, 1999. A nonlinear model of flow in meandering submarine and subaerial channels. *Journal of Fluid Mechanics* 400:295–331.