The Geologic History and Evolution of Italy:
Highlighting the Relationship Between Geology and Culture

A project submitted in partial fulfillment of the requirements for the degree of Master of Arts at George Mason University

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Summer Semester 2009
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DEDICATION

This is dedicated to my loving husband Harry who supported and encouraged me to indulge in my dream of becoming a geologist. Without his patience and love throughout this 10-year journey, this work would not have been possible. It is also dedicated to my two wonderful sons Michael and Stephen who inspire me to do my best as they do in pursuit of their musical careers. Finally, to Shatsee and Tiger who never failed to purr and snore throughout the late nights of work.

ACKNOWLEDGEMENTS

I wish to extend my heartfelt thanks to several individuals who have made this work possible. My husband Harry provided extraordinary loving support throughout the past ten years while I indulged my passion for geology. My two sons Michael and Stephen have encouraged, and inspired me to try my best through their own dedication to their music. Their technical assistance with computer issues has solved many a problem.

My graduate committee adviser Rosemary Jann has been of invaluable assistance in many ways. She taught me how to evolve from a scientific writer to a writer of the humanities and helped me to organize my ideas. Her suggestions on a model for the work were instrumental in establishing the general framework and enabled me to get my thoughts on paper. I am grateful for her steadfast pursuit of excellence on form and format. I appreciate all the time she dedicated to the review of the manuscript and to her many insightful comments.

Giuseppina Kysar Mattietti my friend and Italian trained geologist taught me Italy's geologic history gave me insights to Italian culture. Her gentle encouragement and Italian way of simplifying the complexities of Italy's geology complemented my way of reasoning and enabled me to understand this geologically challenging Mediterranean region. Rick Diecchio taught my first introductory geology class and several others at George Mason University. He encouraged me to do this work, and made many useful contributions to the manuscript.

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LIST OF ABBREVIATIONS

AD	Anno Domini (Year of the Lord)
BC	Before Christ
BP	Before the Present
Ca	Calcium
cm	centimeters
CO_2	Cardon dioxide
ft	feet
in	inches
hr	hour
Kbars	Kilobars
km	kilometers
lbs	pounds
m	meters
Ma	millions of years before the present
mi	miles
mm	millimeters
my	millions of years
oz	ounces

ABSTRACT

THE GEOLOGIC EVOLUTION OF ITALY: HIGHLIGHTING THE RELATIONSHIP BETWEEN GEOLOGY AND CULTURE

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This project describes the geologic history and evolution of Italy over the past 250 million years. The geologic evolution of Italy has been distilled from scientific literature and written in terms understandable for general audiences. The geology of Italy is closely intertwined with Italian culture. Throughout the project this connection is highlighted through a choice of interesting natural and cultural features. This project can be a useful tool as general introductory material to Italy's geologic history for geologists, teachers, students especially for those attending field camps in Italy, amateur geologists and the general public.

FOREWORD

This work is written as partial fulfillment of my Master's degree requirements at George Mason University. It is intended to provide the text for a geologic guide to Italy highlighting the connection between geology, and the cultural monuments of Italy. I have written it for general audiences after discovering that there is a void of simplified literature on Italian geology. The realization became apparent while researching for a similar work for myself as a basic introduction to Italian geology. I was a student preparing to visit Italy's volcanoes and I was looking for a synthesis of Italian geology to give me a general framework with which I could understand their origin.

There exists an immense body of scientific literature that addresses the various aspects of Italian geology. It spans from the micro scale of minerals that explain magma composition to the macro scale concerning the drainage patterns of the Apennine Mountains. The literature is technical, and it is directed at geologists and other professionals in the scientific arena. I could have spent years trying to get a general background to Italian geology by reading this literature. However, I had little time, and all I wanted was a work that distilled the scientific information into an easily understandable summary. The realization that a work like this was not available inspired me to write this.

My passion for geology expanded into a passion to educate the public not only on the field of geology but in particular to make known Italy's geologic history that is generally omitted from the general literature. I hope it is useful to novices, teachers, students, particularly those attending geologic field camps in Italy, amateur geologists, and anyone else who wants to expand their knowledge of the land where so much of geologic theory, and discovery began.

INTRODUCTION

Geology and Italian culture are as intricately woven as the stitches in this lace.

Fig. 1.1 "Lace From Burano Museum." Douglas Reay. 2004. Personal Web Page 4 Apr. 2008. <http://www.chiark.greenend.org.uk/~douglasr/venice/>.

This piece is made on the Italian Island of Burano located near Venice. One can appreciate the intricate pattern and how each stitch is connected to the one next to it. Close up the individual stitches do not reveal the creation, but if we stand back we can see the entire work laid out in all its beauty and intricacy. I observed women in Burano making similar pieces and was told it takes a very long time to create the finished product. I'd like to make the analogy that Italy's geologic features are like the individual stitches in the lace connected by Earth's processes, and their sum total is the beautiful landscape we know today as Italy. There is one major difference. Unlike the piece of lace, Italy is not finished evolving.

Earth is constantly changing though it is not perceptible to us. Just as each stitch changes the lace little by little, geologic processes have been ongoing for millions of years constantly changing and forming the physical landscape we see today. I am striving to take you on an Italian journey using a different perspective whether you are actually visiting the country or reading this from afar. The information provided here is not available in any other guide. This work is intended for those who have a natural curiosity and an interest in Italy beyond just usual sight-seeing at the frequently visited monuments. It is more than history and more than monuments. It is about how and why Italy came to be, and the connection between the land and the people. Let us now embark on a journey that will take us to the Italian land and will disclose how Earth's processes have shaped the Italian landscape over the millennia and how the Italian people have integrated geology into their everyday lives.

I discovered my passion for geology after an established career in a very different field. Returning to school I was faced with the challenge of studying science, an area that previously held little interest for me. I had studied business some years earlier and had been relieved that there was only a one year science requirement. But all that was to change drastically once I discovered my new passion for understanding the Earth through geology. Geologists love being out in the field, and I was no exception. As a geology student the greatest gift you could give me was to send me in the field with a real geologist who could explain the landforms I was observing. This desire took me on a series of field trips in the United States and eventually to Italy. In August of 2001 Mt. Etna on the Italian island of Sicily was erupting and was receiving a lot of media attention. I set out for Italy to climb the volcano on my first journey to Italy. Apart from the fact that I never made it to the volcano's summit because it was closed due to the danger, I discovered I had developed a passion for Italy, and the Italian people.

I did not know at the time that the Mediterranean region, and in particular Italy, have played a leading role in shaping and advancing geologic theory more than any other area in the world. It is the place where the earliest geologists developed theories based on observations and deductions, and where geologists continue to come back to test their models, and opinions. The Mediterranean is still at the forefront of geologic discovery in part due to its active geologic processes. While studying Italian geology I was often confronted with the discovery that the traditional plate tectonic model did not fit Italy. I found that Italian Geology is often unexpected which makes it more interesting and challenging.

Ideas regarding the observation of the natural world can be traced to the Greeks in the Ionian region around the sixth century BC who attributed the creation of the Earth to their own observations and conclusions rejecting ideas of gods (Fischer and Garrison 7). Italians were early contributors to the study of the Earth. Leonardo da Vinci made many observations of the rocks in Tuscany. He drew formations summarizing his thoughts on topics such how fossils are made, how sediment is carried by rivers, how strata correlate to one another, even how strata are created in deep water (Fischer and Garrison 12).

He was followed by a Danish scientist who arrived in Florence in 1638, Nicolaus Steno (Alvarez 75). Steno was a remarkable thinker. Studying the rocks of Tuscany he made a significant contribution to geology by discovering the law of superposition and formulated its principles. This law allows us to arrive at some order of the rock record, by realizing that the rocks on top of a formation are youngest while those below get older the farther down the order they occur. This was a remarkable conclusion that rocks have a relative age and they were not formed all at the same time. It was also a tuning point in understanding and deciphering Earth's history. For the first time Earth's history was viewed in terms of the rocks' relative order.

Ambrogio Soldani (1736-1808), an early Italian geologist, made another vital contribution that furthered the understanding of Earth's history. He spent many years studying and cataloging the microfossils in the rocks of Tuscany giving geologists a way to date rocks using tiny fossils called forams (Alvarez 86). In addition to these prominent figures there have been many other modern Italian geologists who have shaped geologic thought. I believe they have the advantage of living in a country that offers both a great

deal of landform diversity and active geologic processes. I am honored to have learned from the writings of many great scientists in Italian geologic exploration. Without any foresight, my first journey to Italy was well suited given my new passion for geology.

The geologic connection is tightly woven in Italian culture and goes back to the earliest inhabitants of the Italian land. It is the country's geology more than any other factor that has shaped Italian culture from the time of the Etruscans, who were the first people to settle in what is now Italy. There is another story to Italy's famous monuments that is untold unless one understands the intricate relationship between Italian geology and Italian culture. Traveling throughout Italy I formed many of these connections. I recognized that presenting some introductory geologic information combined with a general summary of Italy's geologic history could change the way one experiences Italian culture and cultural monuments. I am convinced that in telling Italy's geologic story, the reader will conceive new discoveries and acquire a better understanding of Italy's people, and their land. It is my hope that you too will experience the thrill of the discoveries I made. A primary goal of this project is that the reader will gain a distinct, more profound perspective and appreciation of Italy through understanding the country's geologic history.

This work can be read sequentially or in separate parts as it interests the reader. The first chapter provides a geologic primer. It will explain the basic concepts necessary to understand Earth's processes. Geologic concepts covered in the primer will not be explained in later chapters to reduce redundancy. I recommend that the primer be read first, and then it can be coupled with any chapter of interest. Chapter two will describe a

short summary of Italy's geologic history and evolution covering the last 250 million years to the present. This chapter will give you an overall big picture of how Italy came to be and can serve as a quick reference to the order of events.

The rest of the work is organized into Italy's geographic regions. In each subsequent chapter the format will be to introduce the geologic framework for that region, take you to areas that will exemplify both geologic and cultural features, and highlight their connections. I have spent considerable time to identify the most interesting examples of both. Chapter three covers central Italy the regions of Latzio and Abruzzo. In chapter four I cover north-central Italy, the regions of Tuscany, Umbria, and Marche. Chapter five covers northern Italy the regions of Lombardia, Trentino-Alto Adige, and Veneto, and the final chapter covers southern Italy the regions of Campania, and Apulia.

As I have studied geology and came to view the Earth through a geologist's eyes, I have been impressed many times with the way Earth's processes occur. Earth has an arrangement of systems and processes that operate in accordance with the laws of physics. Recently, global warming has made us aware of the interdependence between these systems. Consider for example the relationship between the atmosphere and the oceans. Increases in carbon dioxide CO_2 in the atmosphere directly impact Earth's temperature causing it to rise. A warmer atmosphere causes glaciers to melt. This in turn causes sea level rise, which in turn causes local climate changes, and many other phenomena.

Few people other than geologists understand Earth processes that have operated over the millennia to shape the planet. To imagine Earth as just a vast ocean of molten rock seems almost surreal. But this is our planet's earliest origins. Since 4.6 billion years ago it has changed form so dramatically that today it bears little resemblance to those early beginnings. When geologists look at mountains we do not just see the landforms, but we see their evolution over the many millions of years. It gives us a unique perspective of the Earth just to think that a mountain was once sediment at the bottom of an ocean, yet today that sediment might be thousands of meters high! The Earth is a dynamic planet in constant motion to be able to accomplish this.

Yet to most people it appears that Earth is static. In our human life span we will never see sediment become a mountain because humans live in terms of a human life span while the Earth operates in terms of a geologic time span. Understanding Earth's dynamics and long history allows us to understand that humans can affect change on the planet just in our short time on Earth. This is a startling realization, and one that should make us stop and take notice of our actions. It means human kind whose relative position in Earth's long history is but a millisecond as compared to geologic time can change the planet's dynamics. Another goal of this project is that the reader will discover Earth's processes, and develop an appreciation of how geology relates to the human experience. I hope it lead us to good stewardship of the Earth.

CHAPTER 1
A Geologic Primer

In this chapter, I will present a geologic primer. You will find basic terminology and an explanation of Earth processes that will facilitate understanding the rest of the chapters. The chapters have been written so that they can either be read in random or sequential order. However, it is recommended that this chapter be read first then it can be paired with any chapter if the reader has no background in geology.

What is Geology and How and Why do Geologists Study the Earth?

Formally the word geology comes from the Greek and has two parts γη (ge) "Earth" and λογος (logos) "speech." Thus geology means to speak about the Earth. The modern definition is the study of the earth, its physical materials of rocks and minerals, and the processes that operate both within it and on the surface. Geology is not a new science. It dates to Theophrastus, the Greek student of Aristotle 372-287 BC, who wrote Peri Lithon "About Stones." Some of the specialties of geology are paleontology (the study of fossils), mineralogy (the study of minerals), hydrology (the study of water resources), geomorphology, (the study of landforms) stratigraphy/sedimentology, (the study of layered rocks and sediments), and structural geology (the study of rock structures/tectonics).

A lot of the Earth consists of minerals and rocks which form landscapes, and by studying them, geologists unravel Earth's history. Geologists do this by "interpreting"

rocks meaning: determining the rocks' origins, deciphering the environment in which they were deposited, and reconstructing the history and Earth's processes that formed them. This knowledge allows us to learn about the Earth, and by extension about the environment we live in today, in order to improve our lives. The rocks of Italy will tell us the story of their creation. This is how we will understand how the Italian landscape came to look as it does today and appreciate how the Italian people have integrated geology into their lives.

For example, how did geologists determine that Leonardo da Vinci Airport in Rome is located on a volcanic plateau? I'm certain the answer did not come overnight but was the result of years of collaborative mapping and careful study of the region's geology. Certainly geologists mapped and analyzed the rocks in order to determine their properties and origin. Studying the tuff (a volcanic rock that consists of volcanic ash and glass) near the airport would have led geologists to expect its source (the volcano) to be located somewhere in the region. Sometimes the volcanoes are no longer there, having been destroyed by other processes, but in this case the volcanoes are in fact still near Rome.

The tuff would also give some strong clues as to the type of volcano from which it came and the type of eruption that occurred. There is technology to determine the absolute age of rocks. The age of the tuff would be when the eruption took place. The knowledge that it is a tuff gives additional clues as to what type of tectonic boundary existed to produce this kind of rock. This is because different tectonic boundaries produce very different rocks. In other words the identity of the rock gives

geologists some basic information about the region's past.

What I have described is a simple evaluation of one rock type found near the Leonardo da Vinci airport in Rome. Real geologic inquiry requires a long time of area investigation and systematic study, mapping of the region's rocks, and laboratory analysis of rock samples to draw conclusions about an area's evolution. At the end of these investigations geologists may be able to tell the story or at least pieces of the region's evolution. Like pieces of a large puzzle, scientific inquiry by others sometimes years later comes together to tell the entire story.

Geology and Earth processes affect everyone around the globe. Earthquakes, volcanic eruptions, floods, landslides, tsunamis, tidal waves are all earth processes in action. Society depends on oil as the fuel that powers virtually everything, but did you know that the formation of crude oil is also the result of geologic processes? Crude oil is called a fossil fuel because it is derived from the remains of ancient fossils like zooplankton and algae that settled at the bottom of a body of water. Geologic processes then buried, heated it, and over many millions of years the organic matter changed into oil. Next time you drive your car or fly in an airplane you can thank the ancient animals and the geologic processes that made the fuel for our use. You might be wondering why oil is found in places where there's no longer a body of water, for example in Saudi Arabia. Again, the answer lies in the geologic processes that have changed that region from a vast ocean to a desert. The Earth also supplies us with many raw materials necessary to our everyday lives. Quartz, the most abundant mineral on Earth, has many

uses including in computer components, as an ingredient in toothpaste, and even in clocks. These are but a few examples of how geology is relevant to our everyday lives.

Geologic Time – How Change in Earth's History is Measured.

Geologic time is a key concept to understanding Earth's history, and it is unique to the study of the Earth. As geology students we were required to memorize it because it puts everything we learned into context. I mentioned that Earth has been evolving over millions of years since its beginning 4.6 billion years ago. This means Earth is evolving in terms of geologic time which is measured in terms of millions of years (my). This is a difficult concept to understand because most people understand the world in terms of human time: years, days, hours etc. The geologic time scale in figure 1.1 has been developed over the last two hundred years. This was achieved by piecing together information from numerous rock exposures and constructing a sequence of time based on changes in the Earth's biota (plants and animals) through time (Monroe and Wicander 16).

Notice that the units in the geologic time scale have a name and two numbers by each unit. For example next to the Pliocene it says 5.3 – 1.8 mya. This means that the period of time from 5.3 million to 1.8 million years ago is called the Pliocene Epoch. Having a name for the unit of time makes it easier for geologists to communicate about Earth's history like days of the week or months of a year. You might also notice a couple of other things about the geologic time scale. First, that the Holocene covers the most recent time from 10,000 years ago to the present, and that the oldest time in the past is 4.5 billion years ago (though some put it at 4.6 billion years ago). It is by most accounts the

Phanerozoic Eon (543 mya to present)	Cenozoic Era (65 mya to today)	Quaternary (1.8 mya to today) Holocene (10,000 years to today) Pleistocene (1.8 mya to 10,000 yrs) Tertiary (65 to 1.8 mya) Pliocene (5.3 to 1.8 mya) Miocene (23.8 to 5.3 mya) Oligocene (33.7 to 23.8 mya) Eocene (54.8 to 33.7 mya) Paleocene (65 to 54.8 mya)
	Mesozoic Era (248 to 65 mya)	Cretaceous (144 to 65 mya) Jurassic (206 to 144 mya) Triassic (248 to 206 mya)
	Paleozoic Era (543 to 248 mya)	Permian (290 to 248 mya) Carboniferous (354 to 290 mya) Pennsylvanian (323 to 290 mya) Mississippian (354 to 323 mya) Devonian (417 to 354 mya) Silurian (443 to 417 mya) Ordovician (490 to 443 mya) Cambrian (543 to 490 mya) Tommotian (530 to 527 mya)
Precambrian Time (4,500 to 543 mya)	Proterozoic Era (2500 to 543 mya)	Neoproterozoic (900 to 543 mya) Vendian (650 to 543 mya) Mesoproterozoic (1600 to 900 mya) Paleoproterozoic (2500 to 1600 mya)
	Archaean (3800 to 2500 mya)	
	Hadean (4500 to 3800 mya)	

Fig. 1.1. "Geologic Time Scale." Palmer, A.R. and J. Geissman. Geological Society of America. 1999. University of California Museum of Paleontology. 7 Mar. 2009. <http://www.ucmp.berkeley.edu/help/timeform.html>.

genesis of the Earth.

The middle column subdivides the first column on the right into larger sections of time and the last column on the left subdivides those into even larger sections of time. I will be referring to the time periods of the Mesozoic through the Quaternary frequently

throughout the discussions in this work. In a human life span it is not possible to observe most Earth processes such as formation of continents, the opening or closing of an ocean, or building mountain belts because these take millions of years. We may, however, see some rapidly-occurring processes such as a volcanic eruption or experience earthquakes.

An analogy to help put geologic time in perspective is to think of Earth's entire history as one calendar year. The time of Earth's formation (4.6 billion years ago) corresponds to January 1, 12:00 a.m. March 13 the oldest fossils appear. The first land plants appear around November 27, and dinosaurs appear around December 11. Humans come into the scene December 31, just a few hours before the end of the year. In other words humans are very recent to Earth's history, but we've made a large impact. Here are a few other facts to put geologic time in perspective: Italy is about 60 million years old; Mt. Vesuvius is approximately 400,000 years old; The Atlantic Ocean is 200 million years old, and humans have walked the Earth for about 200,000 – 300,000 years (Monroe & Wicander 705).

Determining the Age of Rocks.

If we could not tell the age of a rock we would have no context of the order of events to relate it to Earth's history. Early on in the field of geology the theory of superposition was formulated. It states that if a rock is on top it is younger that the rocks beneath it unless some other process has intervened such as compression to overturn it. This was key to unraveling Earth's history, but without some other marker how could we understand the order of events? Geologists then discovered that by using fossils, a correlation of sediments could be made. This is possible because certain fossils only

existed during certain periods in Earth's history, and they do not appear in some sediments but they do in others. But armed with only this, it would only be possible to put events into order nothing more. The final key that allowed geologists to unravel Earth's chronology was the law of faunal and floral succession. According to this principle fossil types succeed each other through time in a predictable and recurring manner. The law is based on three key points: (1) life forms have differed over time, (2) fossils are different from one another, and (3) it is possible to determine the relative age of fossils (Wicander & Monroe 436). This law made it possible to pull events of Earth's history together in terms of a chronological or relative time order. There are several other ways to get what is called the absolute age of rocks including using argon gas and carbon.

The Founding Principle of Geology - Uniformitarianism.

This long word has a rather simple meaning, but it is a powerful tool and essential to understanding how the Earth works. Uniformitarianism is based on the assumption that Earth's processes are operating today in the same way they have operated in the past. Therefore, we can get clues to how Earth's features were formed by studying Earth processes operating today in modern day analogs. This means we must first understand present day processes and their results, and then we can understand and interpret the rock record (Monroe & Wicander 16). James Hutton, an eighteenth century naturalist and a geologist, is credited with the principle of uniformitarianism. He drew his conclusions after many observations of the surrounding countryside near his farm in Edinburgh, Scotland. Grasping this cornerstone principle is a first step to understanding geology.

What is Inside the Earth? Can we Drill to the Center of the Earth?

To understand how Earth functions we must understand how it is constructed. What lies immediately beneath our feet is not the same material that lies 500 m (1640 ft)

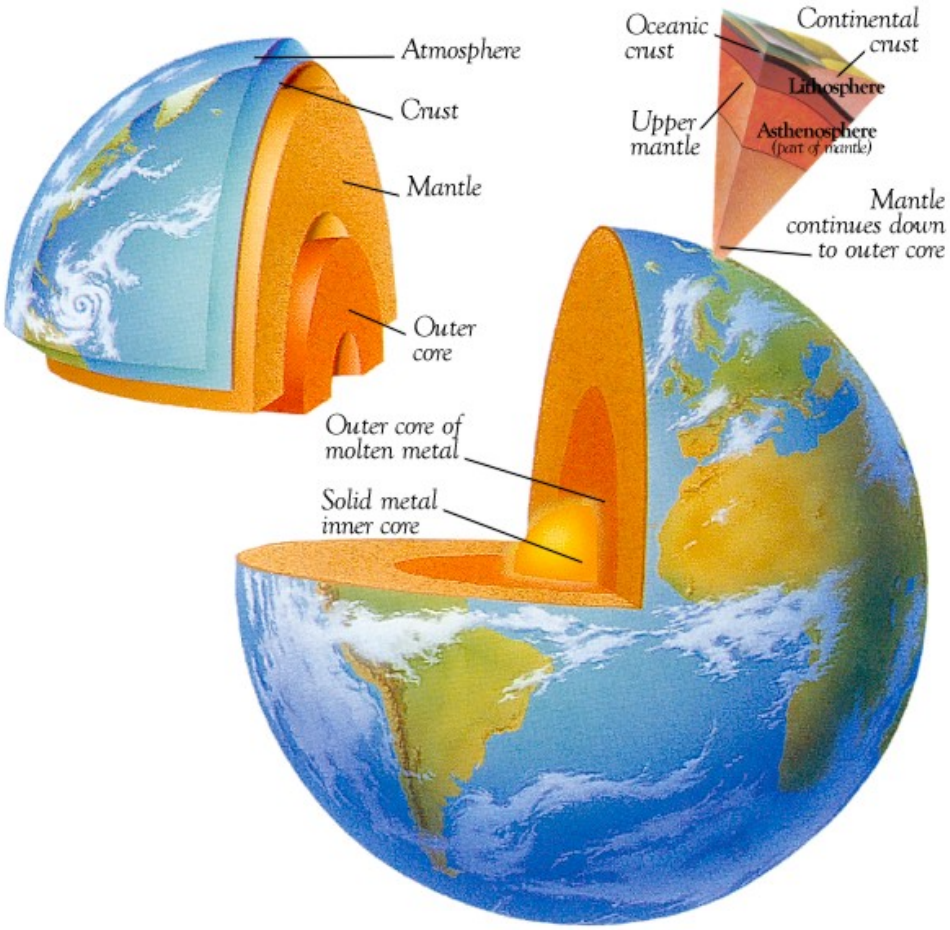


Fig. 1.2. "Earth Cutaway." Rose, Collin & Dorling Kindersley. 2000. ThinkQuest. 17 Mar. 2009. <http://mediatheek.thinkquest.nl/~ll125/en/volcano.htm>.

below or even 1000 km (621 mi)down. Earth is made of three concentric layers of material, the core, the mantle, and the crust (fig. 1.2). Each of these subdivisions is because the layers have different densities, as a function of variations in

composition, temperature, and pressure (Monroe and Wicander 7). You can think of Earth's layers like a hard boiled egg. The outer most layer is the crust. It is composed of both continental and oceanic crust, and in our egg analogy it would be the shell. Earth's middle layer is called the mantle and would be the egg white, and the inner most layer is called the core which would be the yolk of the egg. You can see from the diagram that the crust is the smallest part of the Earth, almost superficial compared to the size of the mantle, and core. This size analogy between Earth and crust also holds true for the egg and egg shell in that it is the smallest part of the egg.

Humans live on the crust. The crust is attached to the upper mantle, and together they make up the lithosphere from the Greek words lithos (rocky) and sphera (sphere). The lithosphere is broken into a number of pieces called tectonic plates. Some tectonic plates contain continental crust; some are made of oceanic crust. Continental crust consists of a variety of sedimentary, igneous, and metamorphic rocks. Oceanic crust is comprised mainly of basalt covered with sediment. Continuing the hard boiled egg example, if we cracked the shell but left it intact around the egg, it would be similar to the way Earth's plates fit next to each other (like puzzle pieces) around the Earth. The plates move, interacting with each other in a process we call plate tectonics. Italy is located on a tectonic plate of continental crust that travelled northward and collided with Europe, which is located on another continental plate.

The mantle is the largest constituent of Earth's layers comprising approximately 83% of Earth's total volume. The mantle has three parts. The upper and lower mantle is solid and surrounds the asthenosphere from the Greek asthenos (without strength).

Composed of the same material as the upper and lower mantle it is neither solid nor liquid. Its semi solid state (think of silly putty) is a key characteristic because it allows the tectonic lithospheric plates to easily slide over it. The innermost part of the Earth holds the core and that has two parts. The outer core is liquid while the inner core is solid. The solid core is very dense, comprised of iron alloys, nickel, silicon and sulfur. It is very dense and solid due to the fact that located at the center of the Earth it is under the influence of all Earth's weight and accompanying pressures.

Earth's radius, that is the distance from a point on the surface to its center, is approximately 6.4 million km (almost 4 million mi). The deepest we have been able to drill is only 12 km (7.5 mi) by the Russian Kola Superdeep Corehole Project, which was a Russian project that attempted to drill as deep as possible into the earth's crust. In other words we've only scratched the surface. This is due to the extreme temperatures and pressures found inside the Earth the deeper we go. Historically, people thought of hell as a place inside the Earth where it was very hot. Although we'll leave speculation about hell's location for others, a portion of this idea is actually true. We know that Earth harnesses a great deal of heat. The deeper we drill the higher the temperatures and pressures we will encounter. Earth's interior is an inhospitable place where humans cannot survive. Miners who work only 3.5 km (about 2 mi) below the surface suffer from temperatures reaching 53˚ C (127˚ F). Consider that the core at the center of the earth may reach temperatures exceeding 6,500˚ C, close to the estimated temperature of the Sun's surface, and the pressure is equivalent to about 3.5 million times normal atmospheric pressure (Monroe and Wicander 178-181).

What is known about the Earth's interior is not a result of direct access. Scientists realized that earthquakes produce seismic waves that travel through the Earth. They measured the time it takes seismic waves to travel from one point to another, and it was apparent that something was causing the waves to slow down or speed up in certain regions. This led to the conclusion that the density and compressibility of material within the Earth must change to cause the waves' different travel times. There must be material of different composition causing the varying travel times. This is how Earth's three layers were identified.

Continental Drift Hypothesis.

The idea that Earth's geography was different in the past is not new. Almost four hundred years ago, Leonardo da Vinci noticed that Earth's geography was different in the past. He noted that "above the plains of Italy where flocks of birds are flying today fishes were once moving in large schools" (quoted in Wicander and Monroe 209). Following Leonardo, others made observations that the coastlines between continents on opposite sides of the Atlantic seemed to fit together. Still others noted the trends of mountain ranges such as the Appalachian Mountains of North America that seemed to end at the coastline of one continent and continue on another across the Atlantic Ocean. If you look a globe can you see what they observed? Like four giant puzzle pieces the North and South American continents, look like they fit right next to the European and African continent if we did away with the Atlantic Ocean. Others studied both plant and animal fossils appearing on all five continents which would not otherwise be plausible unless the continents had at one time been joined. They concluded that by some mechanism the

continents had somehow been united into one supercontinent called Pangaea from the Greek word meaning “all land.” But if all the continents had been joined at one time how did they move thousands of miles to where they are today? They had to move or drift, thus the continental drift hypothesis.

Plate Tectonic Theory - The Unifying Theory.

Although Earth appears to be static to us, in fact it is a very dynamic planet that is constantly changing. It has changed dramatically from its formation 4.6 billion years ago. At that time it did not have any land masses, oceans, and continents like today. Scientists believe it was one vast sea of lava which was constantly bombarded by thousands of meteors from space. The reason the Earth received so many meteors is mainly due to the material traveling in space trying to coalesce into planets during the early formation of the solar system and to the lack of a protective atmosphere around the Earth. Scientists believe that slowly tectonic processes such as divergence and convergence began as Earth began to differentiate into the different layers of varying density I described earlier. It is not clear what steps occurred in Earth’s early history to create plate interactions, but at some point tectonic plates did form and began interacting. Figure 1.3 indicates Earth’s major plates as they exist today and their relative movement. The discovery that Earth’s plates are not static is probably the most important discovery to the study of geology. Scientists today know that the tectonic plates are either moving toward each other, away from each other, or sliding past each other, all driven by convection cells (heat) in the mantle. The semi-solid asthenosphere allows the plates to slide. Initially it was not known what drove plate movement.

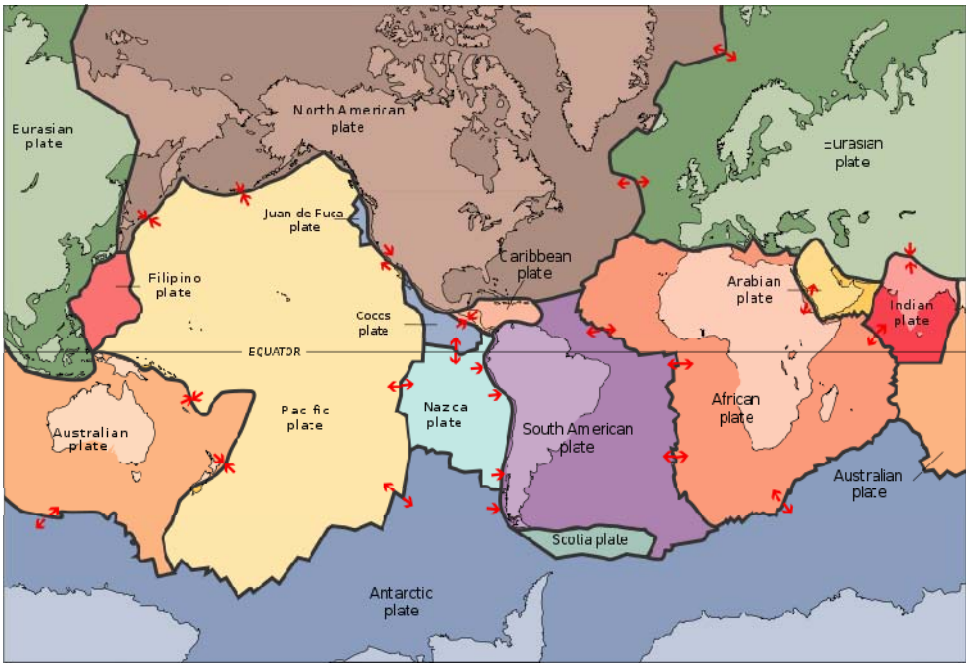


Fig. 1.3. "Plate Tectonics." Wikipedia, The Free Encyclopedia. 13 Mar. 2009, 14:47. Wikimedia Foundation, Inc. 14 Mar. 2004. <http://en.wikipedia.org/wiki/Plate_tectonics>.

By the early 1960's another great theory emerged that resolved how continents move. It is called the sea-floor spreading theory. When magma cools the magnetic iron-bearing minerals align themselves with the Earth's magnetic field. In other words the rocks record the orientation of Earth's north magnetic pole (Wicander and Monroe 217). After scientists studied remnant magnetism in lava flows at the Mid-Atlantic Ridge it became apparent that Earth's magnetic field reverses over time. The reasons for this are not well understood. Dating the rocks indicated that the youngest rocks are directly at the oceanic ridge where upwelling (new magma rising from the mantle reaches the ocean floor) creates new crust while the oldest material would be located the farthest away from

the oceanic ridge. The rocks farthest from the oceanic ridge located at the eastern and western margins of the Atlantic Ocean are indeed oldest (about 200 million years old). This is a bit like two conveyor belts of freshly made donuts each moving away from the donut maker. The freshest (youngest ones) are those dropped on the conveyor first, and as they move away they become older.

This discovery in the early 1960's was labeled the sea-floor spreading theory. Data derived from the sea floor indicated that continents and even sections of oceanic crust move as single units away from the Mid-Atlantic Ridge and all oceanic ridges. This provided the mechanism to explain how continents could have travelled thousands of miles from where they are today. Plate tectonics is accepted by geologists today as the unifying theory that adds to the knowledge about the locations of continents, oceans, mountains, and other geologic features. Both the sea floor spreading theory and plate tectonics were revolutionary to the study of geology.

Major Earth Processes: Divergence and Convergence their Interactions and the Resultant Features.

The discussion of plate tectonic theory leads us now to discuss the type of land features formed by tectonic plate interactions. Plate interactions determine where landforms. There are three main types of plate boundaries, those that are converging, those that are diverging, and those that are sliding past each other. Figure 1.4 summarizes all three boundaries. You can see by the black arrows plates are moving towards each other or away from each other. Plates that are converging close up oceans through a process called subduction, and they form mountains, while plates that are

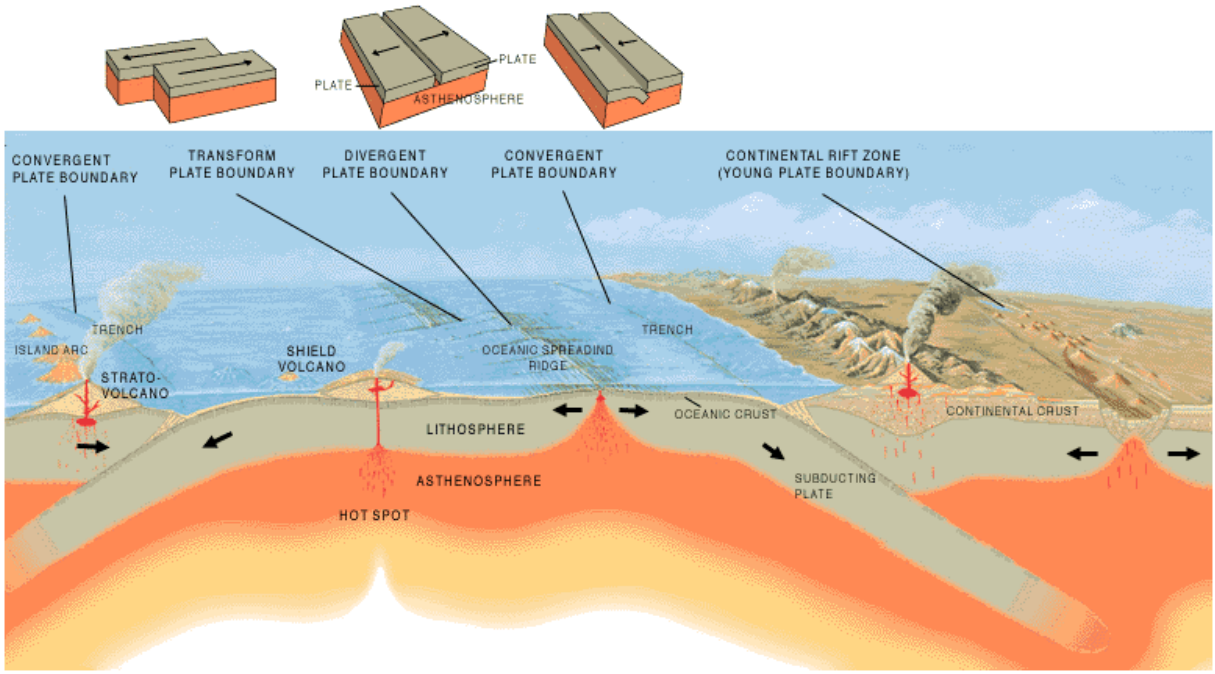


Fig. 1.4. "Plate Tectonics." Wikipedia, The Free Encyclopedia. 13 Mar. 2009, 14:47. Wikimedia Foundation, Inc. 14 Mar. 2004. <http://en.wikipedia.org/wiki/Plate_tectonics>.

diverging form oceans. In divergence zones new ocean crust is formed while in convergent zones ocean crust is destroyed. Through these processes the quantity of Earth's crust remains constant.

To visualize divergence and subduction you might think of a conveyor belt at your local grocer as representing oceanic crust. The divergent zone is the area of the belt that comes up from beneath the belt and moves away from you bringing the groceries to the cashier. The belt itself is like the new crust forming at the oceanic ridge. The subduction zone is where the belt meets the counter top close to the cashier. This is analogous to the oceanic crust colliding with another crust. The subduction zone is the area where the conveyor belt goes below and disappears. This is analogous to a

subducting oceanic crust beneath continental crust.

The third possibility of plate movement is laterally past each other. This is called a transform boundary. This is occurring in the western United States with the Pacific plate and the North American plates. The result of this is many earthquakes along the San Andreas Fault in California. For purposes of this discussion I will focus on the first two plate interactions: divergent and convergent margins.

Converging plates. This process is currently on-going in several areas on the globe including the Alps involving the European and the African plates. There are three types of plate combinations at converging plate margins. Two pieces of continental crust coming together is called continental-continental convergence, two pieces of oceanic crust coming together is called oceanic-oceanic convergence, and when an oceanic and a continental plate are converging it is called oceanic-continental convergence.

Continental-continental convergence. What happens when two continental crusts come together, and what are the resultant land forms? When two pieces of continental crust come together usually neither will subduct (go beneath the other) because they are of similar density. This compression results in the blocks of continental crust being deformed, and over millions of years they rise to form mountains (fig. 1.5). This in fact is how the Alps were formed. The continental crust of Africa was moving towards the European continental crust of Europe since about 100 million years ago. This movement continued until the two plates collided having consumed the oceanic crust that separated them. As compression continued neither plate would go under the other. The only place

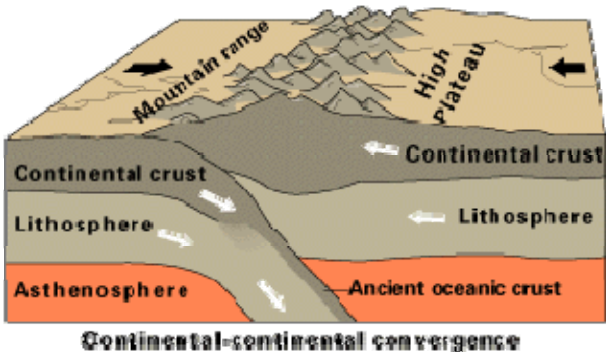


Fig. 1.5. "Continental-Continental Convergence." USGS. 1999. 11 Mar. 2009. <http://pubs.usgs.gov/gip/dynamic/understanding.html>.

for the continents to go was upward. This resulted in folding and deforming huge rock masses and began the mountain belt known as the Alps. Even today compression between the two landmasses is continuing. You would be correct to draw the conclusion that the Alps are still getting higher.

Oceanic-oceanic convergence. In cases when two tectonic plates of oceanic crust are converging together it is called oceanic-oceanic convergence (fig. 1.6). In this case one of the plates subducts under the other. The subducting plate bends downward, moves to depth, melts, and the rising magma forms submarine volcanoes. Then over millions of years the submarine volcano may grow above the ocean to form what is known as a volcanic island. After several islands are formed they are collectively known as volcanic island arcs. An example of a convergent plate boundary where two oceanic plates are moving toward each other is the east side of the Philippine Oceanic Plate converging with the west side of the Pacific Plate. The Pacific Oceanic Plate is subducting beneath the Philippine Plate. The resultant landforms are many islands like the Philippines.

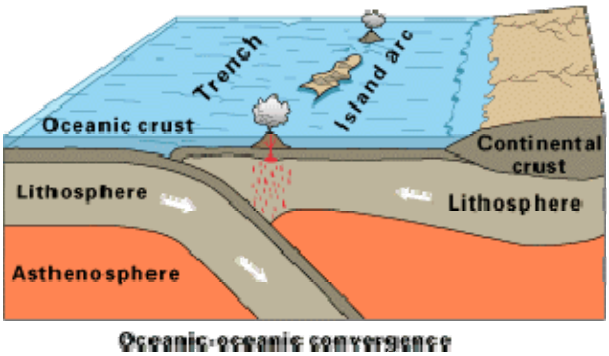


Fig. 1.6. "Oceanic-Oceanic Plate Convergence." USGS. 1999.11 Mar. 2009. <http://pubs.usgs.gov/gip/dynamic/understanding.html>.

Oceanic-continental convergence. The last case of convergence is when an oceanic and a continental plate converge (fig. 1.7). In this scenario the oceanic crust is denser than the continental crust so it subducts under the continental plate. The wet oceanic crust is assisted in its downward motion using water as a lubricant. Once again the subducting plate melts forming volcanoes. A classic example of this is in the western U.S. The Cascades Range of volcanoes including Mt. St. Helen's are the result of the Pacific oceanic Plate moving eastward towards the North American Plate and subducting beneath it.

Diverging plates. Diverging plate boundaries are doing the opposite motion of convergence, they move away from each other. This process creates oceans, a very different kind of feature than the ones I just described. Figure eight shows four steps to the progression of an oceanic opening. The process starts with rifting due to swelling of the ocean basin because of heat rising from the mantle and continues with the production of magma due to the decompression of the upper mantle figure 1.8 (step one). This

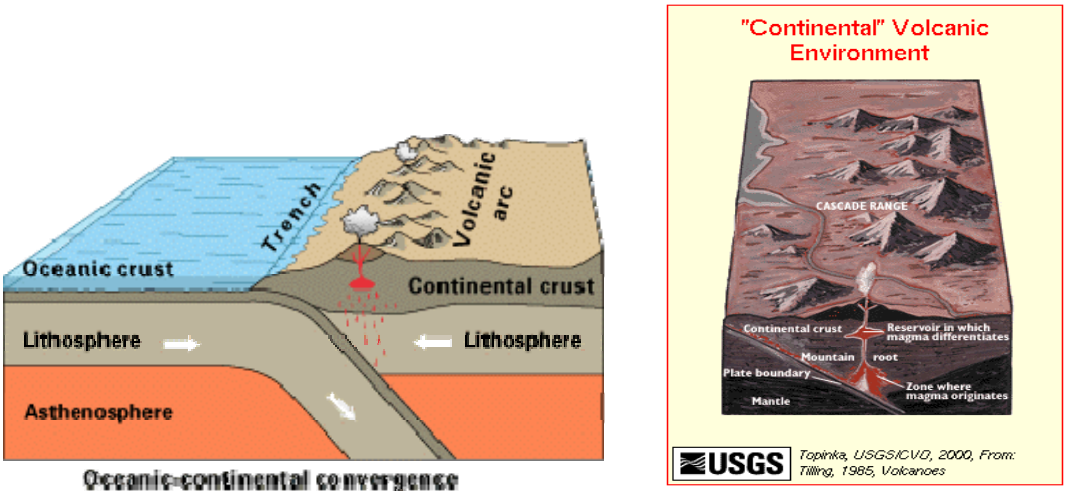
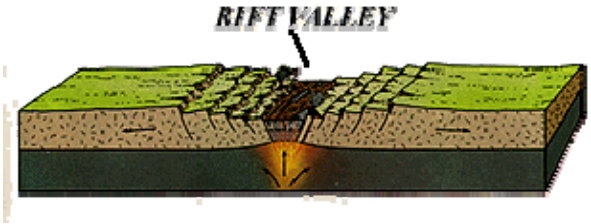


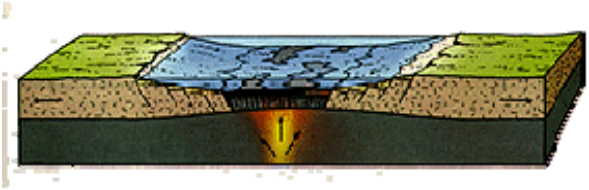
Fig. 1.7. "Oceanic-Continental Plate Convergence." USGS. 1999. 11 Mar. 2009. <http://pubs.usgs.gov/gip/dynamic/understanding.html>.

process forms volcanoes and rift eruptions at the mid-ocean ridge. There are continuous volcanoes on the ocean floor bisecting the Atlantic, Pacific and other Oceans around the globe. These features are all below the sea except in one case. Iceland is a portion of the mid Atlantic ridge that is exposed allowing scientists to study what is actually going on in the submerged portions of the ridge (fig. 1.9). Figure 1.8, step 2 in the rifting process creates normal faults and rift valleys. The crust moves away from the volcano. As it moves away from the heat source it cools. In turn, more magma reaches the surface and solidifies to fill in the gap and form new oceanic crust and the process continues figure 1.8, step 3. Eventually a deep rift valley is formed in an ocean figure 1.8, step 4. The rock produced at spreading centers is called basalt. Figure 1.10 is a side view of this process.

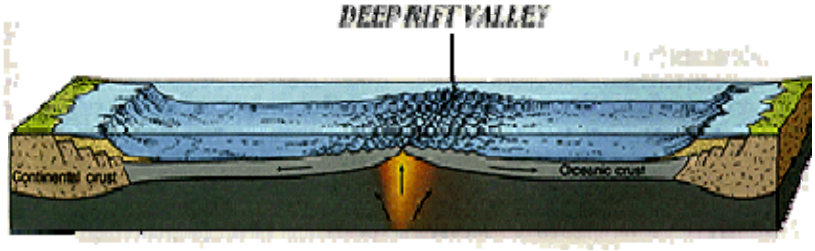
STEP 1



STEP 2



STEP 3



STEP 4

Fig. 1.8. "Divergent Plate Boundary Sequence." Moorland School. 15 Mar. 2009. <http://www.moorlandschool.co.uk/earth/tectonic.htm>.

Over millions of years these processes, also known as sea floor spreading, continue forming an ocean. Sea floor spreading is how the Atlantic and Pacific Oceans were formed. It takes roughly 200 million years to form an ocean like the Atlantic. It is hard to imagine the Atlantic Ocean at its early stage as a small inlet separating the

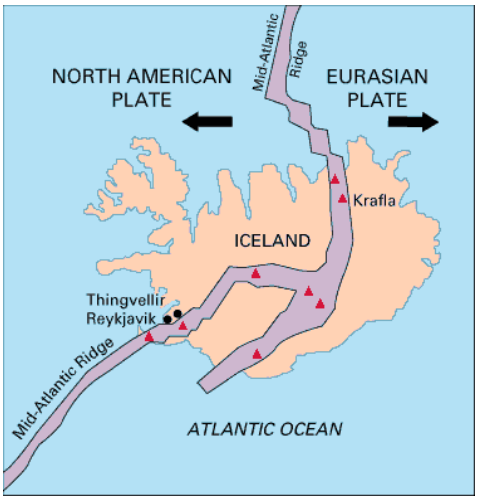


Fig. 1.9. "Mid-Atlantic Ridge." Wikipedia, The Free Encyclopedia. 26 May 2009, 22:37. Wikimedia Foundation, Inc. 3 June 2009. < http://en.wikipedia.org/wiki/Mid-Atlantic_Ridge>.

continents of Europe, Africa, and the Americas. The rates of plate motion average between 2.5 cm/yr to more than 15 cm/yr. Just thinking about how long it would take to form an ocean at 15 cm/yr (6 in/yr) gives us a sense of the vast period of time Earth processes have been ongoing!

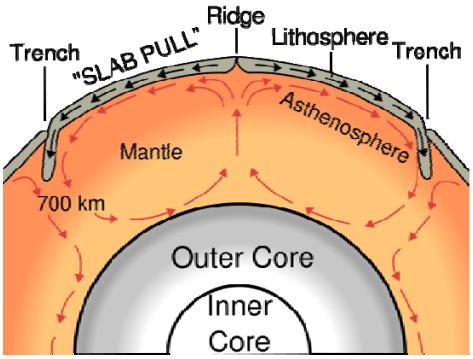


Fig. 1.10. "Mid-Ocean Ridge." Wikipedia, The Free Encyclopedia. 15 Mar. 2009, 16:31. Wikipedia, Foundation Inc. 15 Mar. 2009. <http://en.wikipedia.org/wiki/Mid-ocean_ridge>.

Faults and Earthquakes.

Faults and Earthquakes go together because at plate boundaries there are many earthquakes due to plate motions. Faults are fractures of Earth's crust along which movement has occurred. An earthquake is the result of movement along a fault.

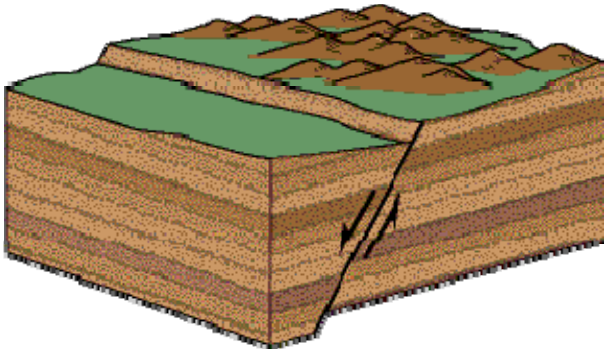


Fig. 1.11. "Normal Fault." USGS Western Region East Surface Process Team. 2004. 15 Mar. 2009. < http://geomaps.wr.usgs.gov/parks/deform/gfaults.html>.

Faults are classified in terms of the direction of movement along the rock blocks. There are three types of faults, normal, reverse, and strike-slip. Let's begin with normal faults (fig. 1.11). These occur in areas where crustal extension is taking place. I just mentioned there are normal faults at rift zones. You can see in figure twelve that the left side has moved down relative to the right. The block on the right is called the footwall while the block on the left is the hanging wall. The name normal comes from the fact that if we held the foot wall stationary gravity would cause the hanging wall to move downwards. It moves in a manner you would *normally* expect.

Reverse faults behave just the opposite of normal faults (fig. 1.12). In this case the left side or hanging wall of the block has moved up relative to the right side. Reverse faults occur where the crust is shortened (pushed together) at convergent plate

boundaries. A special type of reverse fault is a thrust fault where the angle of the fault plane dips less than 45º. We have many of these in the Apennine Mountains of Italy.

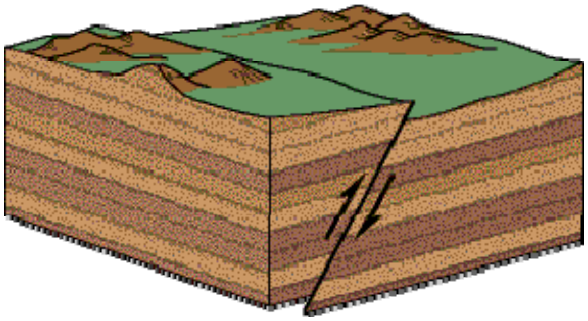


Fig. 1.12. "Reverse Fault." USGS Western Region East Surface Process Team. 2004. 15 Mar. 2009. <http://geomaps.wr.usgs.gov/parks/deform/gfaults.html>.

Finally, there are the strike-slip faults where the movement is different than either the normal or the reverse faults (fig. 1.13). In this case, there is no sliding up or down but there is a horizontal movement along the blocks. A prime example of this is

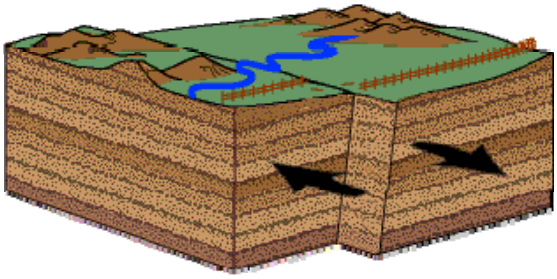


Fig. 1.13. "Strike-Slip Fault." USGS Western Region East Surface Process Team. 2004. 15 Mar. 2009. <http://geomaps.wr.usgs.gov/parks/deform/gfaults.html>.

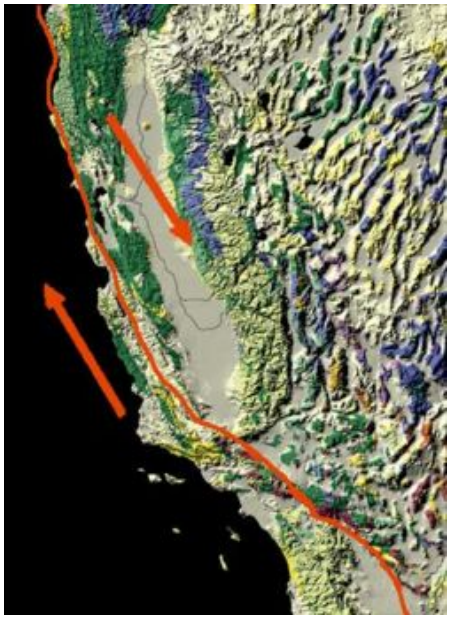


Fig. 1.14. "San Andreas Fault." Wikipedia, The Free Encyclopedia.14 Mar. 2009, 20:57. Wikimedia Foundation, Inc. 15 Mar. 2009. <http://en.wikipedia.org/wiki/San_Andreas_Fault>.

the San Andreas fault in California. There, the North American plate is moving laterally (grinding) past the Pacific Plate (fig. 1.14). The plate motions and faults are described in a simple way; however in real life movement between plates may go on for many miles and may not be so well defined. For example, there can be two large plates and a microplate (a fragment of a plate) caught up in the deformation zone interacting in a normal and strike-slip direction at various parts of the boundary. In the Mediterranean region involving convergence of the African and Eurasian plates and Italy, there are several microplates that play a role in the region's evolution. Complex areas of the world like these tend to exemplify complicated plate relationships, and this is reflected in the geologic features and earthquake patterns.

Most earthquakes correspond with plate boundaries where stresses accumulate as plates interact. Plate motions cause stresses and strains to build up between the blocks. At particular points the material cannot take any more stress and therefore it strains by

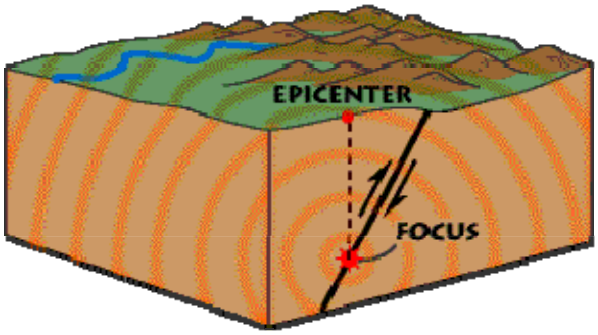


Fig. 1.15. "Earthquake Along a Reverse Fault." USGS Western Region East Surface Process Team. 2004. 15 Mar. 2009. <http://geomaps.wr.usgs.gov/parks/deform/gfaults.html>.

suddenly releasing the energy resulting in earthquakes. Figure 1.15 is of an earthquake along a reverse fault. The circles emanating from the quake are known as "P" and "S" waves. They propagate from the earthquake through the Earth. The epicenter of an earthquake is the point on Earth's surface right above the focus of the earthquake. It is where most of the energy is released and which experiences the most damage. Most people are aware that earthquakes can be devastating depending on their magnitude (the total energy released). Italy suffers from many earthquakes due to the tectonic boundary interactions in the Mediterranean region.

What on Earth is Earth Made of and What is a Rock?

Now that you have a general framework of Earth's basic processes it's time to discuss the stuff Earth is made of, rocks. Earth is made of rocks and minerals and geologists love them. They are the key to geologic exploration because they hold secrets about the Earth's past. I'm sure everyone who reads this has picked up a rock at one point or time in their lives. But did you know that a rock is comprised of one or more minerals? Granite is a very common rock on Earth's surface. It is composed of four main minerals of potassium feldspar, lesser amounts of plagioclase feldspar, quartz, and muscovite mica. Quartz is a very common mineral on Earth's crust. Most beach sand is made entirely of quartz. Chances are if you pick up a rock it will probably have quartz in it. The three main categories of rocks are igneous, sedimentary, and metamorphic. I will present each of these separately. The Italian landscape is dominated by sedimentary rocks, but there are also igneous and metamorphic rocks in Italy.

Igneous rocks. Rocks are organized based on their origin. Igneous rocks are formed when magma (molten rock), cools. When cooling takes place below the surface they are called intrusive plutonic rocks, and when it takes place on the surface they are called extrusive volcanic rocks. All magma is not of the same mineral composition. Therefore, the type of rocks formed from a particular magma depends on several factors including mineral composition of the magma, its texture or crystal size. The latter depends on how fast the magma cools. This is just like making a chocolate cake depends on using chocolate powder while making a vanilla cake depends on using vanilla. An example of igneous extrusive rock found in Italy is tuff in figure 1.16. The word tuff

Fig. 1.16. "Welded Tuff." David Schumaker. 2001. Geology News. 15 Mar. 2009. <http://geology.rockbandit.net/tag/photos/page/2>.

comes from the Italian word tufo. The rock is comprised of volcanic ash and glass; it is also called an ignimbrite. It is the product of volcanic explosive activity. In fact, when you look at it you can easily imagine it as consolidated ash and crystals because the crystals are visible to the naked eye.

Tuff mounds are a result of volcanoes spewing into the atmosphere tons of loose material including ash and lapilli (pea size particles) that settle on Earth's surface and solidify. With the passing of time and subsequent eruptions the volcanic tuff layers built up. Over the centuries, Italian civilizations have built their towns on them and many buildings all around Italy are made from ignimbrite. Tuff is found in Northern Italy, in Tuscany, around Rome and in Southern Italy. Tuff is also used extensively as building material because although it is rather soft it is also very strong. Some of the most scenic and charming towns in Italy are perched on tuff deposits.

Fig. 1.17. “Basalt.” Alden, Andrew. 2006. About.com. 22 Mar. 2009. <http://geology.about.com/od/rocks/ig/igrockindex/rocpicbasalt.htm>.

Another igneous rock is basalt. Unlike the tuff above, it is extruded as a flow from volcanoes mostly at spreading centers but in crustal regions as well. Basalt is a hard igneous grayish-black volcanic rock produced typically when the crust stretches initiating the opening of an ocean (fig. 1.17).

Sedimentary Rocks. Another category of rocks is called sedimentary rocks. These rocks originate not from volcanoes but as their name implies from sediments. Sediment is weathered material that comes from preexisting rocks. What is weathering, and how does it happen? All rocks on Earth’s surface undergo a process called

weathering. They break down into their mineral constituents or they are chemically changed with the passing of time, and the effects of water, and/or exposure to the elements. It's as though we could break down our previous cake example into its constituents of flour, eggs, water, etc. Of course we can't do it with a cake, but with rocks through weathering processes it's possible. Sometimes rivers will carry sediment far from their source such as at the delta of a river. There they might be deposited layer upon layer. Over the millennia a set of processes facilitated by the weight of the sediments themselves and the presence of trapped water and other fluid material will form sedimentary rocks.

Some sediments are formed by plants or animals. An example of such a sedimentary rock in Italy which is found in great abundance is limestone (fig. 1.18). Limestone is formed from the chemical alteration of the skeletal remains of tiny organisms that swam in warm shallow seas millions of years ago. These organisms in the sea secrete skeletal shells that fall to the bottom of the ocean floor when the organisms die. The main constituent of limestone is a mineral called calcite. Limestone is called calcium carbonate. Sounds close to calcium right? That's because it's actually calcium and salt combined. These are both crucial constituents to the development of most living organisms, particularly for humans. Our bones are made of calcium phosphate. Limestone has many uses: for example, it is a major component in making of cement, as building stone, and it is also chalk used in classrooms. Who could ever imagine that your grade school teacher was able to write on the chalkboard because of the existence of these tiny organisms on the sea floor millions of years before humans ever inhabited the

Fig. 1.18. "Limestone." Wikipedia, The Free Encyclopedia. 1 Mar. 2008, 4:08. Wikimedia Foundation, Inc. 16 Mar. 2009. <http://en.wikipedia.org/wiki/Limestone.>

Earth?

The Apennine Mountains of Italy are dominated by limestone. When geologists see these rocks in the field they can be sure that the paleoenvironment was one of a warm shallow sea, similar to the type of seas in today's Bahamas. How do we know these things? We revisit James's Hutton's theory of uniformatarianism. This law allows us to find examples where limestone is forming today, and reason that the limestone we find today in the Apennines must have come from a similar environment, and presumably by similar processes. Hutton's principle is very powerful in helping us piece together clues about Earth's history so that we can understand Earth processes ongoing today. Another question is why is the limestone, remnants of warm shallow seas, found on top of a mountain today? This is a result of plate interactions discussed earlier such as subduction

and compression that are responsible for both burying rocks and raising them to great heights, although there can be other contributing processes. A discussion about how the Apennines were raised will follow in later sections.

A special type of limestone very abundant in Italy is called travertine (fig. 1.19). Travertine is a rock that is made through a chemical process and is used extensively in Italy as building material. The story of travertine begins with the fact that Italy has an

Fig. 1.19. "Travertine in 400 Year Old Building in Rome." Wikipedia, The Free Encyclopedia. 3 Mar. 2009, 6:51. Wikimedia Foundation, Inc. 22 Mar. 2009. <http://en.wikipedia.org/wiki/Travertine>.

abundance of limestone from ancient basins that closed millions if years ago. When groundwater makes contact with limestone, a chemical reaction takes place that causes the limestone to dissolve releasing the carbon dioxide (CO_2) as gas into the atmosphere much like opening a bottle of soda releases gas. The calcium then recrystallizes forming the travertine. Living biotic organisms such as moss, algae and cyanobacteria can become incorporated into the travertine as it continues to form and increase in size. It is a porous material as can be seen in the picture above making it relatively light in weight as compared to other rocks.

Metamorphic Rocks. The last category of rocks is called metamorphic. This is from the Greek word meta = change and morphosis = form. It means to transform the character, function, condition or appearance of something. In a biologic sense when a tadpole becomes a frog we call that process metamorphosis. In a geologic context certain types of rocks such as sedimentary can change form and become metamorphic rocks. How do rocks change form? Rocks are often subjected to burial deep into the Earth's crust as a result of tectonic plate interactions. This could occur at a subduction plate boundary as the subducting plate moves to greater depths. Often when rocks are buried they are subjected to tremendous pressures and temperatures. Sometimes the result is that rocks will melt, becoming magma and mixing in with the mantle material. Other times the rocks may be subjected to just enough heat and pressure to undergo a transformation. During metamorphism the minerals in the rock deform and recrystallize in response to pressure and temperature to form other minerals. The resulting rock takes another form becoming a different rock altogether.

An example of rock metamorphosis is what can happen to limestone. When it is subjected to burial accompanied by the right pressures and temperatures it becomes something you're probably familiar with: marble. There is an abundance of marble in Italy, and it is used frequently as building material. Some of the most beautiful marble in the world is Italian. Many statues are made of marble and the interior of buildings are often decorated with marble in Italy. If we stop and reflect for a moment we realize there is a strong connection between geology and culture in what I've just said. Even Michael Angelo's famous marble statute of David owes its very existence to the skeletal remains

of tiny organisms and the plate tectonic processes that transformed them into marble. Moreover, did the marble as a material with specific hardness and fracture tendency lend itself to the sculpting processes that resulted in such a life like figure? I'll leave this question for pondering, but it is an alternative way to contemplate Italian statues. I believe there may also be a connection between the type of building material and the art forms of a culture.

The fact that there are an abundance of marble works in Italy is reflective of the fact that the material is readily available and plentiful. We see a similar connection between building material and culture in other parts of the world besides Italy. One of the simplest ways to see this is to look at the type of building material used for houses in different countries. For example, if you see stone dwellings chances are that's the readily available material. Similarly, if you see brick dwellings, chances are there's plentiful clay in the region. People generally use the material available to them.

All About Volcanoes.

Let's turn our attention now to volcanoes and learn how they fit into Earth's processes. I mentioned volcanoes already in the plate tectonics section. In this section I'll define the main types of volcanoes, why and where they exist. Volcanoes are an important component to this work about Italy because Italy has many. This is not a well known fact. Figure 1.20 is a map of the major volcanoes in Italy. There are several more that are not active, therefore they are not noted on the map.

Some mountains are made of deformed rock layers and have nothing to do with volcanoes. They are a product of folding and thrusting of Earth's crust causing it to buckle, fold and deform as compressional forces are exerted upon it. Other mountains are volcanoes because they are formed as a result of volcanic material that comes from conduits or channels within the Earth where it is extruded onto the surface. In general when observing a mountain it's more likely to be a volcano if it's more of an isolated feature as opposed to a chain of aligned mountain ranges though there are some exceptions to this rule.

It is appropriate to note that the word "volcano" is of Italian origin and comes from the word Vulcan the Roman god of fire. There are three main types of volcanoes: shield volcanoes, composite volcanoes, and cinder cones. They are categorized based on their eruptive pattern and general form. In a prior section I covered the interactions between Earth's plates and the types of tectonic boundaries. Volcanoes are formed at tectonic plate boundaries whether plates are converging or rifting. The melting crust magma is lighter than the material surrounding it, therefore it begins to rise through the Earth, forming conduits called vents and fissures that lead onto Earth's surface. The contents of an eruption are called magma while inside the volcano, but once the magma erupts onto the surface it is referred to as lava.

Some volcanoes are characterized by a crater at their summit. Calderas are much larger than craters. A collapsed caldera forms after a volcanic eruption due to the fact that the eruption blows out a large volume of material leaving behind a void that has no

Fig. 1.20. " Map of Major Volcanoes in Italy." USGS. 2000. 2 June 2009. <http://vulcan.wr.usgs.gov/Volcanoes/Italy/description_italy_volcanics.html>. From Tom Simkin and Lee Siebert. Volcanoes of the World. Geoscience: Tucson, 1994.

support and it collapses. In figure 1.21 the steps of a volcanic caldera's evolution are numbered. If you've ever boiled oats or cream of wheat you've watched a similar process take place as each bubble rises beneath the oats, bursts, and collapses, forming a concave depression. In time calderas can become lakes like several located near Rome.

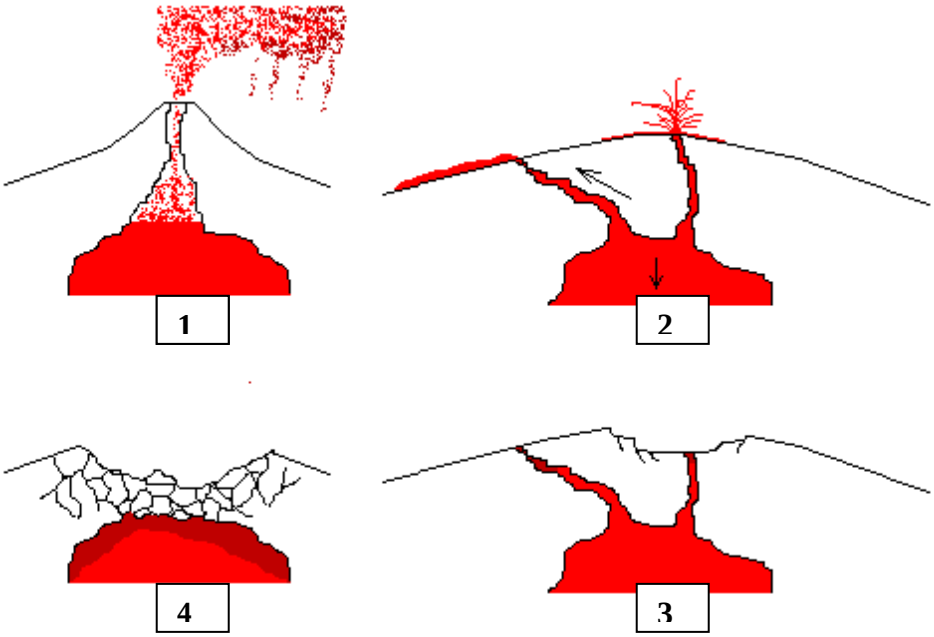


Fig. 1.21. "How Calderas Form." Steven Dutch. University of Wisconsin-Green Bay. 2007. 22 Mar. 2009. <http://www.uwgb.edu/DutchS/EarthSC202Notes/igneous.htm>.

Shield volcanoes. As their name implies these volcanoes are shaped like a warrior's shield (the curved side up) or the shape of a turtle's shell (fig. 1.22). Hawaiian volcanoes are shield type as is Italy's Mt. Etna in Sicily. Shield volcanoes have effusive mafic type lava. Mafic lava has a composition that allows it to flow slowly with little explosive activity, forming a layer over the expanse of the volcano. Think of maple syrup flowing over a stack of pancakes. An effusive type eruption is an outpouring of lava onto the surface as opposed to violent explosive eruption. One reason for the low explosive nature of these volcanoes is because the lava is fluid, allowing gasses to escape

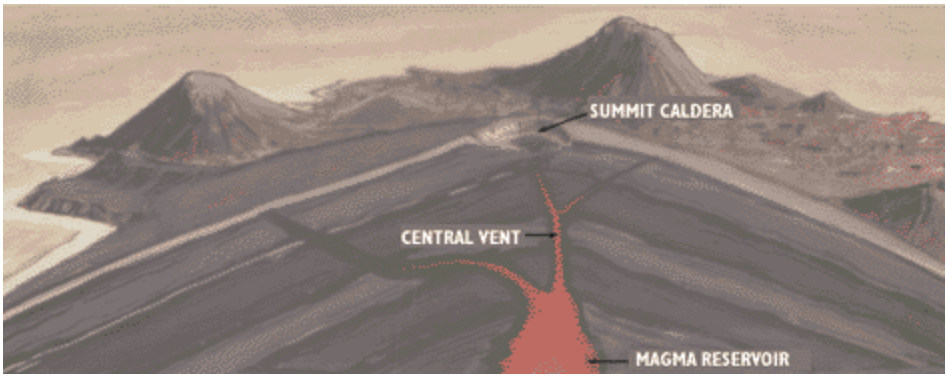


Fig. 1.22. "Shield Volcano." USGS. 1997. 17 Mar. 2009. <http://pubs.usgs.gov/gip/volc/nature.html>.

slowly. Due to the slow nature of these eruptions they are not usually a hazard to humans since they often allow plenty of time for humans to clear the area. We don't hear of people dying in Hawaii due of volcanic eruptions even though Kilauea has been erupting continuously since 1983.

Composite volcanoes. On the opposite spectrum we have composite volcanoes. They are shaped very differently than shield volcanoes. They are shaped like a cone with steep sides (fig. 1.23). Composite volcanoes erupt two types of material: pyroclastic flows (explosive ejecta) and lava flows. The different types of flows create alternating layers along the flanks of the volcano. Think of Mount St. Helen's or its Italian counterpart Mt. Vesuvius. The eruption of Mount St. Helen's in 1980 was a pyroclastic one. Similarly, the eruption of Mt. Vesuvius in Italy in 79 AD was also a pyroclastic flow. Pyroclastic eruptions of composite volcanoes are violent, explosive, and happen

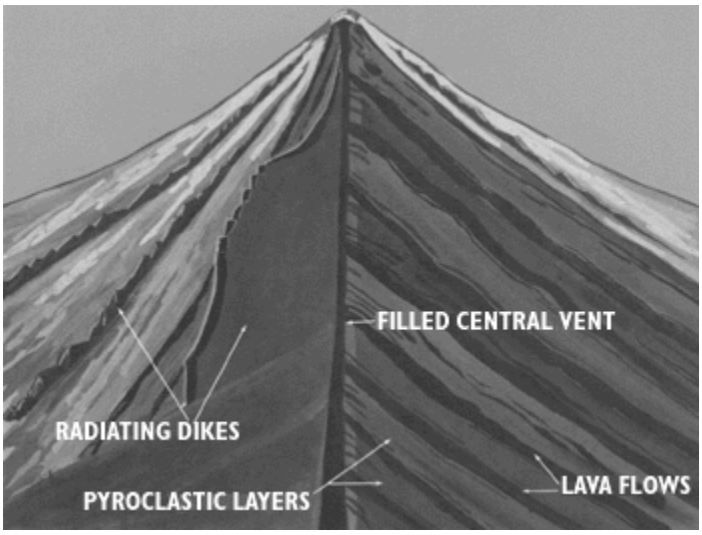


Fig. 1.23. "Composite Volcano." USGS. 1997. 17 Mar. 2009. <http://pubs.usgs.gov/gip/volc/nature.html>.

quickly, posing a great danger to humans. It is similar to what happens when you open a bottle of soda that has been shaken. Both of these volcanoes have also had a history of erupting quieter lava flows.

Cinder Cones. Lastly, there are volcanoes known as cinder cones. These are very steep conical shape volcanoes composed of cinders (fig. 1.24). They often have a bowl-shaped crater at the summit. The cinders are ejected into the atmosphere and fall back onto the volcano's flanks together with explosive pyroclastic material. Cinder cones can appear as part of other volcanoes like the ones on the flanks of Mt. Etna (a shield volcano) in Sicily, or they can stand alone.

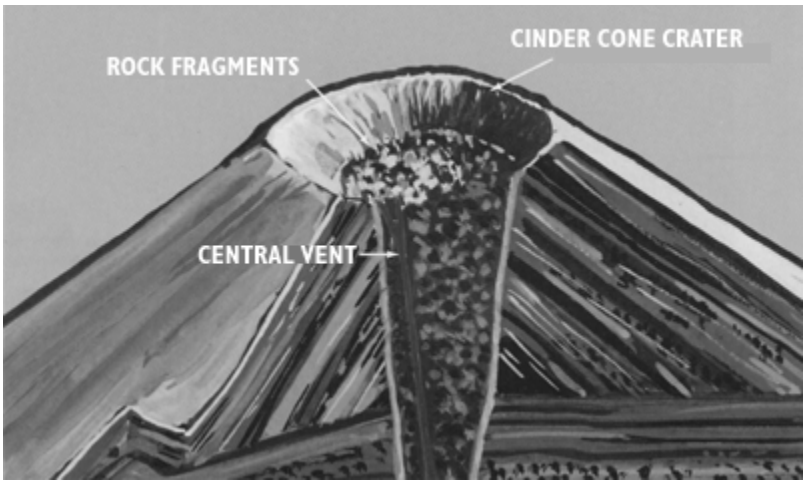


Fig. 1.24. "Cinder Cone Volcano." USGS. 1997. 17 Mar. 2009. <http://pubs.usgs.gov/gip/volc/nature.html>.

Conclusion.

In this chapter, I have tried to prepare the reader to understand better the chapters that follow by providing a very basic geologic lesson. This is a work that merges Italy's geologic history and cultural highlights showing how they are closely interconnected, therefore it's imperative to have a fundamental grasp of how Earth works. The geologic time scale unique to geology defines geologic time in millions of years, terms unfamiliar to most people. Acquiring an appreciation of the vast time Earth has been operating from its origins 4.6 billion years ago is a key concept to grasping Earth's processes and evolution of landforms. The principle of uniformatarianism is key to understanding earth's processes because we assume that the same processes that operated in the past are still operating today.

Continental drift theory led scientists to plate tectonic theory that explains how continents drift unifying thought about Earth's processes. The action is at plate boundaries. Divergence, and convergence Earth's two great processes are responsible for most landforms. Volcanoes are key agents in these processes because they produce and destroy crust thereby maintaining a balance of Earth's total crust. If it were not so, Earth's continents would grow larger over time.

The rock cycle is the ultimate example of how Earth's mechanisms work in unison with each other (fig. 1.25). It shows the interrelationships between Earth's internal and external processes. It bears mentioning here to raise awareness of the purposeful and harmonious relationship of Earth's mechanisms. The three rock groups are related to each other; to processes ongoing on the surface of the Earth, such as weathering (the physical breakdown of rocks at Earth's surface); to processes inside the Earth such as crust melting to form magma, and metamorphism; to plate tectonics that keep driving the entire mechanism. The rock cycle means that when you pick up a rock most likely its mineral constituents had a previous form. They might have been in the form of magma that was deposited onto the surface by a volcano, only to have broken down by weathering processes, only to reach the ocean to be buried, and lithified (become rock) only to be consumed at a plate boundary, buried, and become magma again.

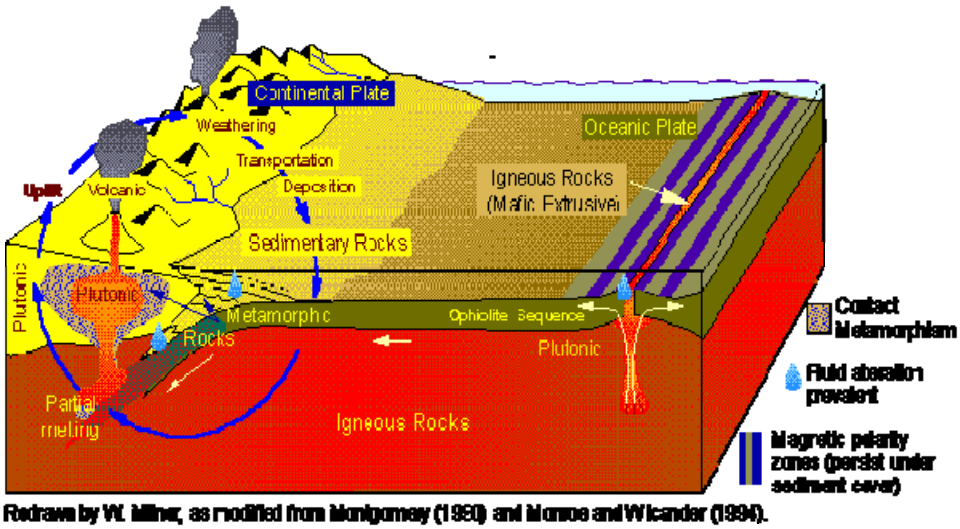


Fig. 1.25. "Rock Cycle." 2005. In Cornish, Jim. Elementary Themes.19 Mar. 2009. <http://www.cdli.ca/CITE/rocks_general.htm>. From Monroe, James S. and Reed Wicander. The Changing Earth: Exploring Geology and Evolution. St. Paul: West Publishing Co. 1994.

Rocks are the critical geologic tool of a geologist to uncovering Earth's past because they record Earth's history. Analysis of their origin reveals the paleo-environment and the processes that formed them. The study of geology gives us a better understanding of the Earth that can help improve all our lives.

CHAPTER 2
A Summary of Italy's Geologic Evolution

How Did Italy Become Italy?

In this chapter, I will present a concise summary of Italy's geologic evolution. I will tell the story of how the Italian peninsula evolved to look like it does today. It may surprise some that Earth's continents have changed dramatically in the past 200 million years, and Italy has been a part of that. Plate tectonic processes form and destroy continents, and continents travel thousands of miles. You can be sure these processes ongoing around the globe have been also ongoing in the Mediterranean region. Italy did not always look as it does today both in form and geographic location. In fact, its beginnings were sediments formed on the sea floor. Much has transpired in time and Earth processes to "make" Italy look as it does today. I will approach Italy's evolution in terms of a geologic time line using the time markers of 200 my, 85 my, 50-35 my, 24-15 my, 6 my, and 1 my as time "windows" to Italy's development. I have chosen these times because they represent key events during Italy's past. It is analogous to introducing a person by highlighting their date of birth, their teenage years, their early twenties, and so on.

To view Italy's past we will have to pretend we can go back in time using an

imaginary time machine. We have to unravel the past in order to understand step by step the geologic history. Once we get to the particular time period, we will "fly-over" the Mediterranean region to get a bird's eye view and see what Italy looked like during that particular period of time. I have presented a series of paleogeographic reconstructions for each period we will be visiting. They are like snapshots of time showing the position of Earth's continents and Italy's position during those times.

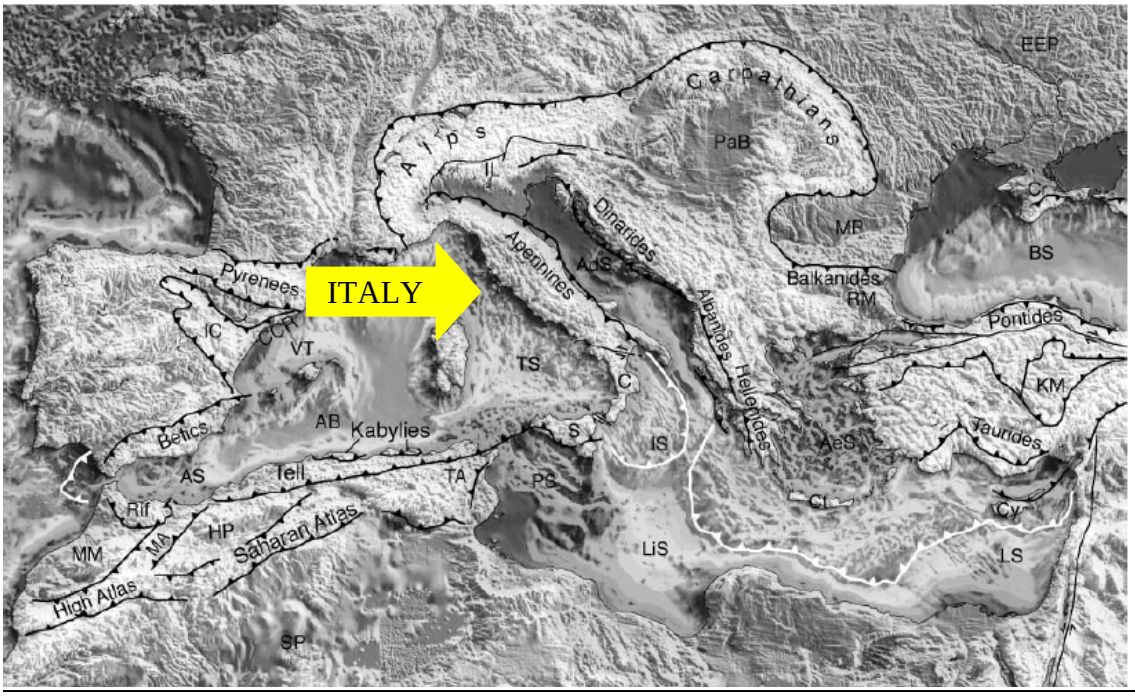


Fig. 2.1. "Digital Elevation Terrain Model of Mediterranean." Modified from Cavazza, William and Forese Carlo Wezel. "The Mediterranean Region-A Geologic Primer." Episodes 26 (2003): 161.

Figure 2.1 is a special map of the Mediterranean. It is a modern day digital terrain model of the Mediterranean region indicating the relative height or depth of the

geological structures (landforms) that are represented by various shades of gray. The water in the Mediterranean is not shown in this map. You might recognize Italy in the center with the Apennines represented by light gray lines. The term "structures" refers to the arrangement and relative position of major rock units. Using a map with regional perspective of geologic structures gives geologists valuable information about the relative motions of tectonic plates, it marks the boundaries between them, and points out the resultant features. In other words it indicates what processes produced the major landforms present today namely the basins and mountain chains.

Notice the dark black lines that look like they have teeth. These represent plate boundaries. The teeth indicate the tectonic plate that is on top overriding the tectonic plate beneath. Right away you realize the Apennine Mountains are a structural front (a linear mountain range), and Italy's boundary with the Adriatic Sea is a subduction zone. Notice also the large arcuate (curved like a bow) front representing the Alps and Carpathian Mountain chain along the top of the map. This is another deformation zone of mountains whose boundary marks the collision between the European and African Plates. The white line with teeth along the bottom of the map represents the subducted Ionian plate front beneath the Mediterranean Sea. It is possible to have mountain fronts formed below sea level as well as on the surface.

<u>200 Million Years Ago – The Opening of the Great Tethys Ocean.</u>

If we flew over the Mediterranean two hundred million years ago we would see a

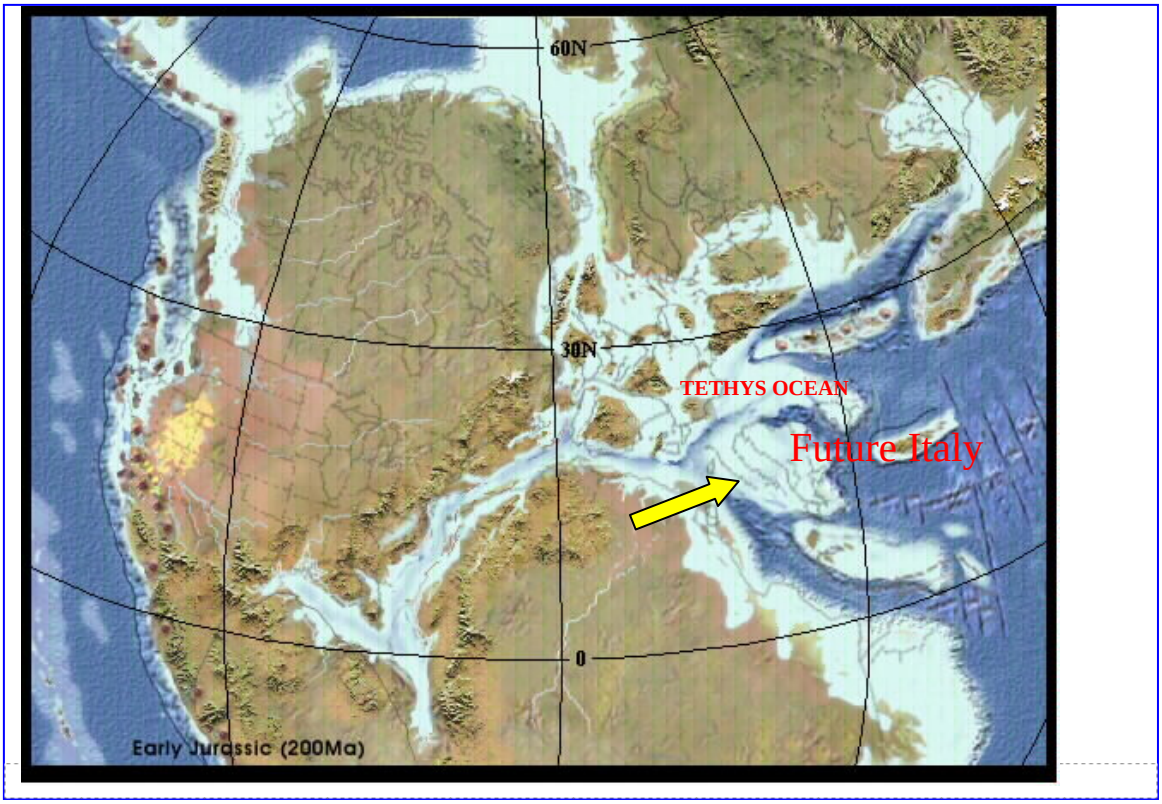


Fig. 2.2. "Paleogeography of the Mediterranean Late Triassic 200 MY." Modified from Scotese, C.R. 1998. PALEOMAP Project. 19 Mar. 2009. <http://jan.ucc.nau.edu/~rcb7/latetrimed.jpg>.

very different landscape. We would see the continents situated roughly as in the paleogeographic reconstruction in figure 2.2. There would be no Mediterranean Sea, no Italy, no Sardinia or Sicily, nothing at all but a great sea known as the Tethys beginning to open, breaking apart the supercontinent known as Pangaea. We will not recognize any continents. This is the time of the Jurassic so from our vantage point we may see large dinosaurs walking or flying by. The Tethys Ocean (light blue areas) is shown at the very beginning stages of separating Pangaea the supercontinent (shown in brown) into two

large northern and southern continents. As the supercontinent begin rifting, small basins and warm shallow seas form (shown in light blue). This tells us that there is active limestone formation beneath the warm waters similar to the Bahama Banks today. This process happens slowly over millions of years as the seas and basins accumulate sediments of carbonate muds. The sediments will eventually become limestones. Some will travel long distances and great heights to become the Apennines Mountains of Italy.

Not long after Pangaea broke apart, another process begins. The Tethys Ocean starts to close causing the European and African plates to converge. Where is Italy at this time? It is shown forming as a pale outline indicated by the yellow arrow in figure 2.2. Notice that it is close to the equator, but through the millions of years that follow it will eventually reach the position it is now of 54° latitude and 29° longitude.

85 Million Years Ago – Closure of Tethys & Apennine Orogeny (Mountain-Building).

About one hundred million years have passed, and this time as we fly over the Mediterranean, we would begin to notice a few familiar land features. They would look like island terrains (indicated between the red brackets) in figure 2.3. As the African and Eurasian continental plates continue to converge they are closing the Tethys Ocean and the smaller basins within the region. The limestone landmasses (shown between the red brackets in figure 2.3) are now folding into what geologists call nappes. Nappes are sheets of rock that have been moved more than 2 km (1.2 mi). The nappe forms from the

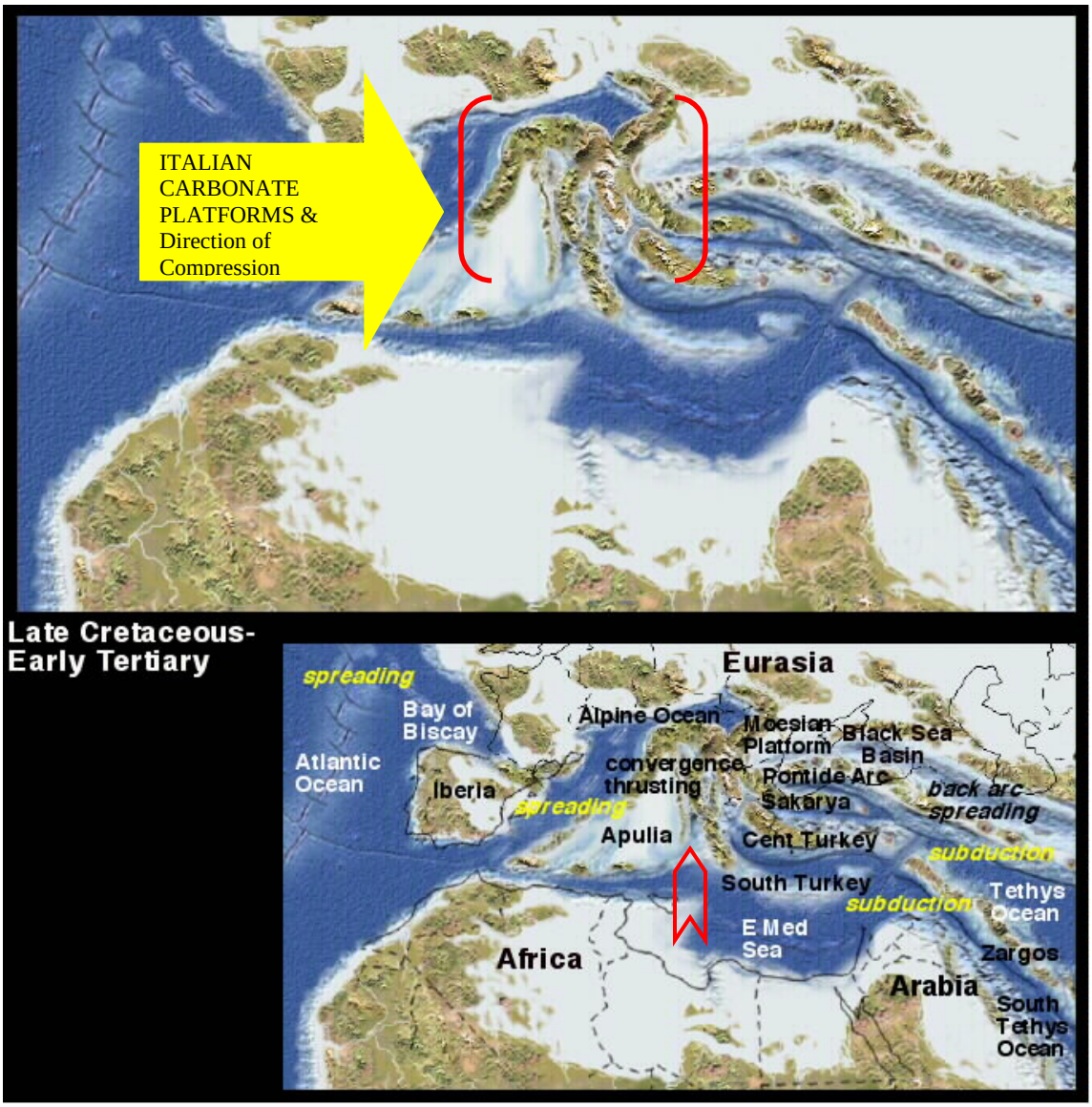


Fig. 2.3. "Paleogeography of the Mediterranean Late Cretaceous to Early Tertiary 100 - 56 MY." Modified from Scotese, C.R. 1998. PALEOMAP Project. 19 Mar. 2009. <http://jan.ucc.nau.edu/~rcb7/latetrimed.jpg>.

compression of the tectonic plates and causes the folded rock to fold back, and over itself.

To visualize the limestones stacking into nappes you might imagine a stack of books

standing on a bookshelf and then being pushed so they fall one over the other. Notice in figure 2.3 that compression causing the convergence and thrusting of the "Italian" nappes is coming from the west or the left side of the image.

The red arrow in figure 2.3 indicates the converging front that will become the Apennine Mountains. Notice that they are shaped like long narrow ribbons sort of parallel to each other. It may give us a clue as to why Italy came to be shaped like a long narrow peninsula. The two continents of Africa and Europe continue to converge eventually colliding in another 20 million years into the future when the Tethys Ocean closes.

50 - 35 Million Years Ago. Closure of Tethys, Alpine Orogeny, Opening of the Mediterranean and Tyrrhenian Seas and Adriatic Subduction.

There is a lot of tectonic activity on going during this fly over. The first thing we notice is that the Tethys Ocean is no longer there, it has closed. This means the European Plate and the African plate have converged (come together). Recall that when two continental plates converge an orogeny (mountain building) occurs. This is called the Alpine orogeny or the formation of the Alps. Meanwhile the nappes (shown between the red brackets in figure 2.4) are continuing to stack against each other in the same west over east direction. As the terrains come together, they are beginning to take the shape of Italy, and they are rising higher. What used to be low-lying limestones on our last fly over is now folded, stacked, and is rising because of continued compression, limited

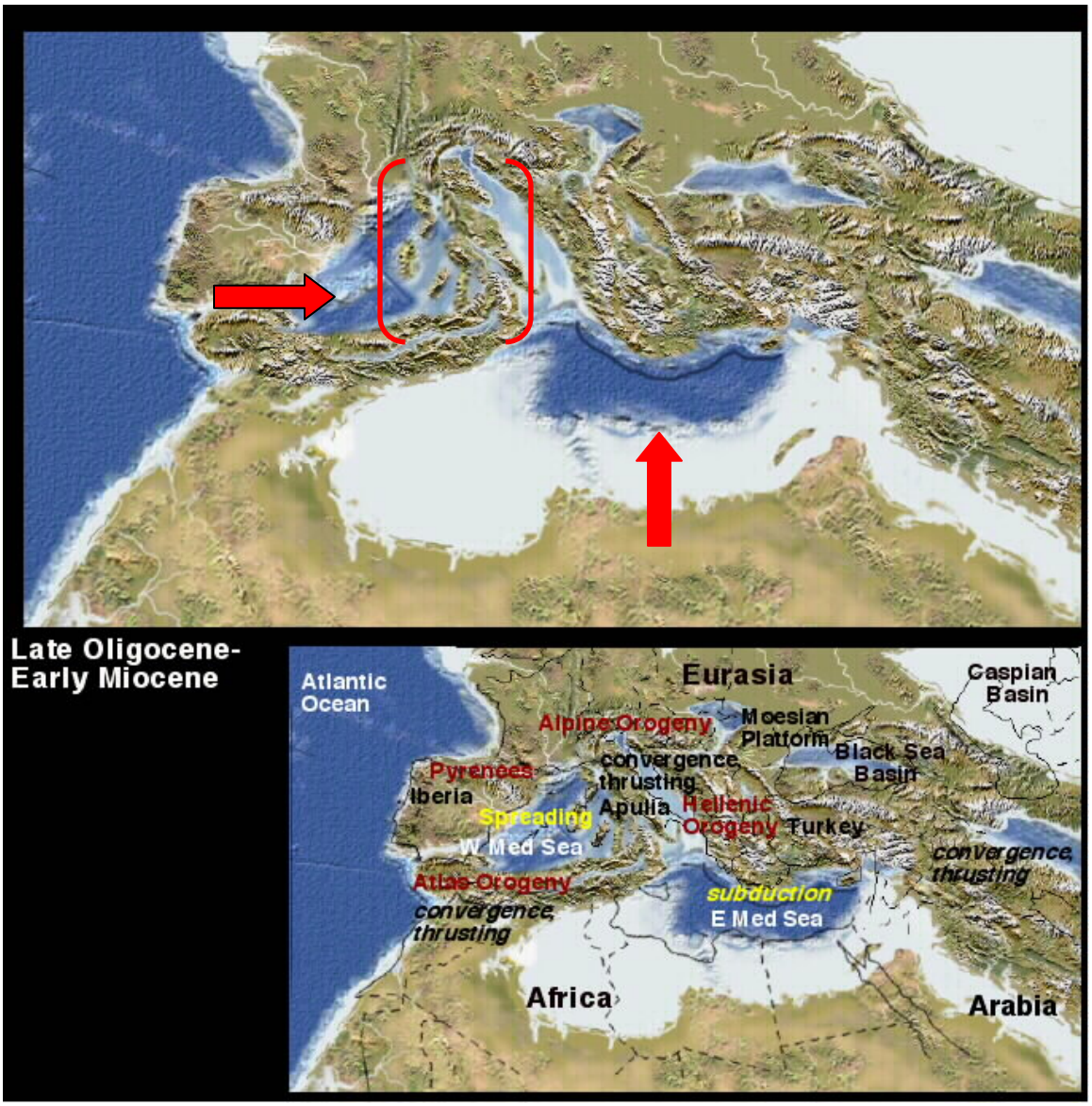


Fig. 2.4. "Paleogeography of the Mediterranean Late Oligocene to Early Miocene 24 - 15 MY." Modified from Scotese, C.R.1998. PALEOMAP Project. 19 Mar. 2009. <http://jan.ucc.nau.edu/~rcb7/latetrimed.jpg>.

space, and nowhere for the landmasses to go but up. This is how mountains form. At this point most of the terrains are probably low-lying hills, and then with the passing of

several more million of years into the future they take the shape of Italy and rise to be the Apennine Mountains that form the "backbone" of Italy today. In chapter three I will discuss a little more about the central Apennines in the discussion of the Gran Sasso's evolution, and in chapter four I will discuss the northern Apennines, and Tuscan hills, all part of this great Apennine Mountain chain.

Another significant feature we notice (shown between the two red arrows in figure 2.4 is the two sectors of the Mediterranean Sea that are opening during this time. The dark blue lines in each section of the Mediterranean Sea represent the two spreading oceanic ridges. Another event during the end of this fly over (about 33 million years ago) is the opening of the Tyrrhenian Sea on the west cost of Italy (represented by the small yellow parallel lines inside the red brackets). Coincidentally with the Tyrrhenian Sea opening, subduction of the Adriatic sea floor (on the east side of Italy) begins sliding under the Italian peninsula. It seems to the casual observer that there have been many changes in the region in a relatively short period of geologic time.

6 Million Years Ago. The Mediterranean Gets Larger.

We step into our imaginary time machine set the time to 6 million years ago and head for the Mediterranean. This time we recognize the Apennine Mountains, and Italy looks a lot like it does today. We also notice Corsica and Sardinia having separated from the European mainland. They are indicated as two white circles to the left of the yellow parallel lines in figure 2.5. Opening of the Tyrrhenian Sea is continuing and we notice it

is now larger.

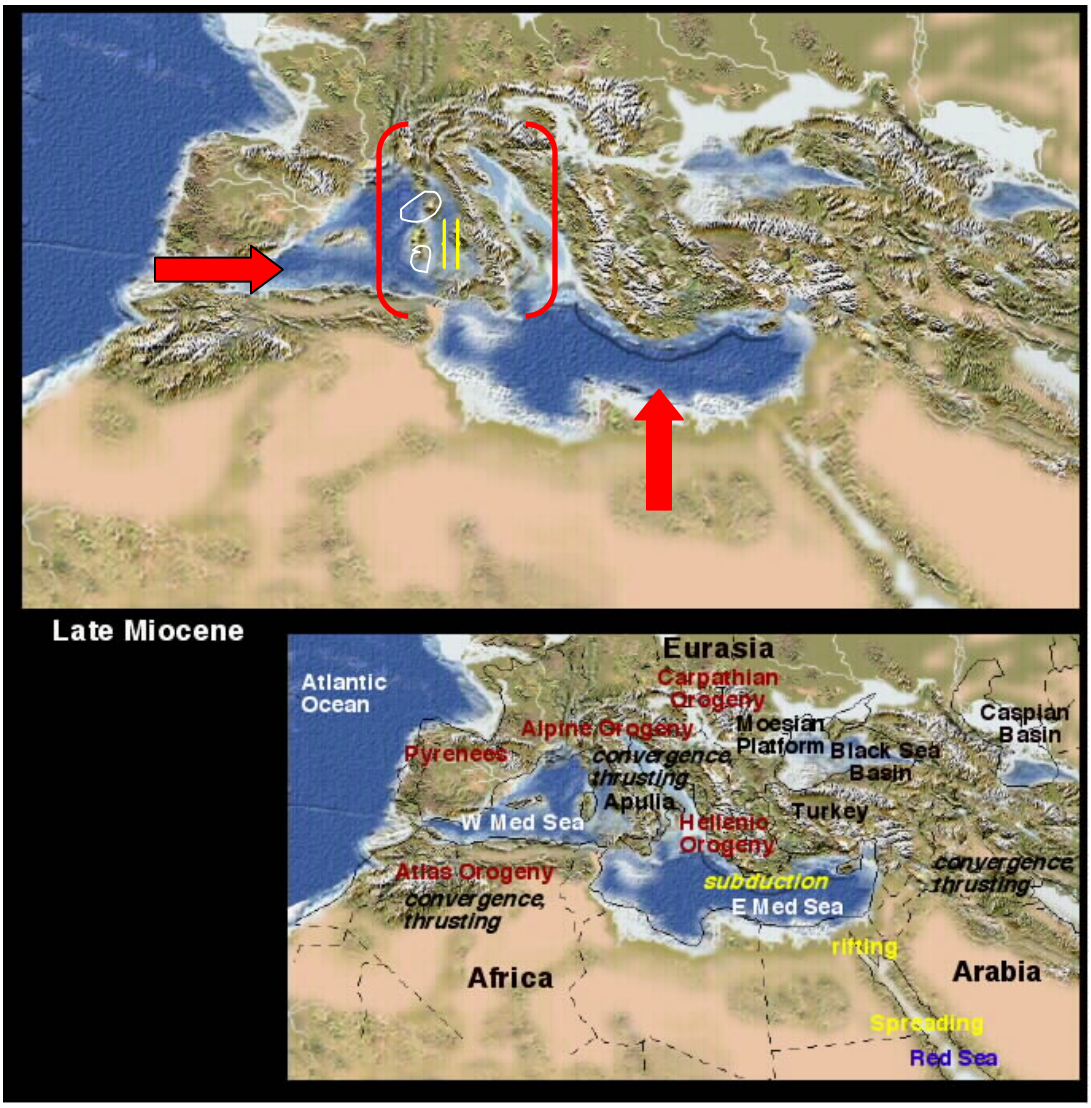


Fig. 2.5. "Paleogeography of the Mediterranean Late Miocene 6 MY." Modified from Scotese, C.R. 1998. PALEOMAP Project. 19 Mar. 2009. <http://jan.ucc.nau.edu/~rcb7/latetrimed.jpg>.

1 Million Years Ago. Volcanoes Appear Near Rome.

We are now flying over the Mediterranean about one million years ago. It is like yesterday in geologic time. Italy looks much like it does today. There is also something else we notice. Volcanoes are beginning to form on the western part of Italy from Tuscany all the way to Naples. Near Rome they are called the Sabatini and the Alban Hills volcanic fields. The Alban Hills volcanic flows eventually make the famous seven hills or Rome. If we could take an x-ray and see what was (and is still) going on beneath the crust of western Italy to produce the volcanoes, we might see that rifting of the oceanic crust (from the opening of the Tyrrhenian Sea) is probably pushing the western margin of Italy's crust eastward. The approaching oceanic crust is causing thinning, stretching, and melting of the Italian crust which is why the Roman volcanoes are there. This is one of the explanations currently available to explain the complex geology of this area.

Conclusion.

We have seen dramatic changes in the evolution of Italy during the fly-overs covering a span of about 200 million years. The paleogeographic reconstructions have helped us visualize the region's evolution. The dominant processes are opening and closing of oceans and mountain building. They are the recurring theme. We saw the large Tethys Ocean open then break apart what was the supercontinent Pangaea. This was followed by the Tethys Ocean's closing which caused the African and European

continents to collide and started the formation of the Alps. In the meantime, compression from the west closed several oceanic basins and elevated the Apennine Mountains. We also saw Sardinia and Corsica break off from the European mainland. In the last stages of the Mediterranean region's evolution we noticed volcanoes near Rome. Ancient and modern civilization would eventually build settlements on those.

While other factors have played a role in shaping Italy like sea level rise and drop, ice ages and erosional processes, the information I covered will provide the reader with a general background to make sense of the remaining discussions. I am covering the most important events of Italy's geologic story. I have done so to give you a succinct story without bringing in many other complications in this geologically challenging region.

CHAPTER 3 – A SLICE OF CENTRAL ITALY
From Rome to Gran Sasso D'Italia
The Seven Hills of Rome, The Tiber River, The Forum and Colosseum, The Trevi Fountain, The Appian Way and The Gran Sasso D'Italia
The Regions of Lazio and Abruzzo

Fig. 3.1. "Lazio and Abruzzo Regions of Italy." Modified from Wikipedia, The Free Encyclopedia. 4 June 2009, 14:35. Wikimedia Foundation, Inc. 5 June 2009. <http://en.wikipedia.org/wiki/Italy>. Latzio is blue, Abruzzo is green, route is red.

In this chapter, I will concentrate on a west-east slice of Italy from Rome on the west coast to the Gran Sasso D'Italia Mountain close to Italy's east coast. The geologic history of each region will be presented followed by examples of the cultural connection

to geology. In Rome I will focus on the volcanoes including the volcanic deposits that constitute the Seven Hills of Rome. It is on these deposits that the Roman civilization began. I will discuss the Tiber River (Tivere) flowing through the heart of Rome. It has played a key role in making the area a desirable place for settlement and in shaping the regional landscape.

The close relationship of geology to Roman culture will be illustrated through visiting important structures like the Pantheon, the Colosseum, the Trevi Fountain and the Appian Way. This most ancient of roads called the Appian Way was built two thousand years ago with material from the local region. It owes its existence in great part to the volcanic material that was used to makes its surface.

Leaving the Latium region of Rome we will travel due east to the Abruzzo region, climbing the Apennine Mountains until we reach the crown jewel and Italy's tallest mountain known as the Gran Sasso D'Italia (large stone of Italy). The mountain is located in one of Italy's national parks, the Parco Nazionale del Gran Sasso e Monti della Laga, which translates as "national park of the large stone and mountains of the lake." I will answer the question why is the Gran Sasso Mountain there? A more interesting question is how have the rocks of an ancient sea been raised to 2912 m (9554 ft) above sea level to become this mountain? Perhaps after you read the story you might want to pay homage to Italy's tallest peak as I did. Besides its geologic story the Gran Sasso is a beautiful and peaceful place to visit. It is what I call the "other Italy."

<u>The Seven Hills of Rome & Rome's Foundation.</u>

What is the story of the Rome's geologic foundation, and what are the so-called Seven Hills of Rome? The Seven Hills of Rome are called the Capitoline, the Quirinal,

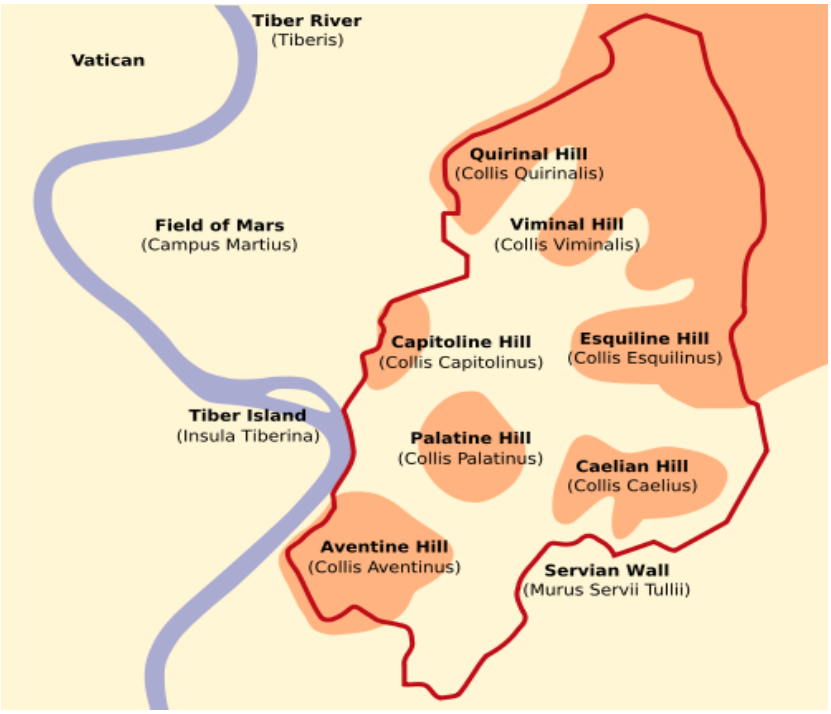


Fig. 3.2. "The Seven Hills of Rome." Wikipedia, The Free Encyclopedia. 27 Mar. 2009, 6:25. Wikimedia Foundation, Inc. 28 Mar. 2009. <http://en.wikipedia.org/wiki/Seven_hills_of_Rome>.

the Viminal, the Esquiline, the Caelian, the Aventine, and the Palatine. They are the physiographic hills upon which Rome was built. Figure 3.2 shows the Seven Hills of Rome within the outline of the walls of the ancient city. Rome is said to have been founded by Romulus on the Palatine Hill. In Victorian times, English children used this clever mnemonic memorizing the first letter from each word to learn them: Can Queen Victoria Eat Cold Apple Pie? Although Rome is well known for its rich history, its

famous monuments and museums, even its notorious traffic jams, it is not known for its neighboring volcanoes. The Roman volcanoes are not actually inside the city, but nearby. Yet volcanoes are a big part of the geologic heritage in the region surrounding Rome.

Few people other than geologists realize that the Seven Hills of Rome are volcanic deposits forming plateaus that date to volcanic activity during the last 1.64 my. I am of the opinion that the site Rome was built on was strongly influenced by the region's geology and the location of the Tiber River. The geologic setting was perfect for defense because it was easier to see the enemy from the hills. The Tiber River was used for transportation of materials and commerce and the regional rocks in the Apennines stored plenty of drinking water.

To get a better picture of the rock sequences in an area geologists sometimes use diagrams like figure 3.3 called stratigraphic columns. In figure 3.3 we can see the rocks as they are arranged beneath Rome. The left column represents the rocks from the Sabatini volcanic field and the right column shows the rocks from the Alban Hills volcanic field. We get a sense of both the order and the deposit's size. The top of the column indicates the rocks beneath our feet. The deposits just below that are the next layer getting deeper and so on. Recall from the geologic primer that rocks on top of a sequence are youngest unless they have been upturned. Notice marine sediments (pre-volcanic sedimentary rocks) are at the bottom being the oldest. Because this stratigraphic column focuses on the volcanic rocks, it does not include much about the sedimentary rocks. To make this column a little more complete I would include that there are deposits

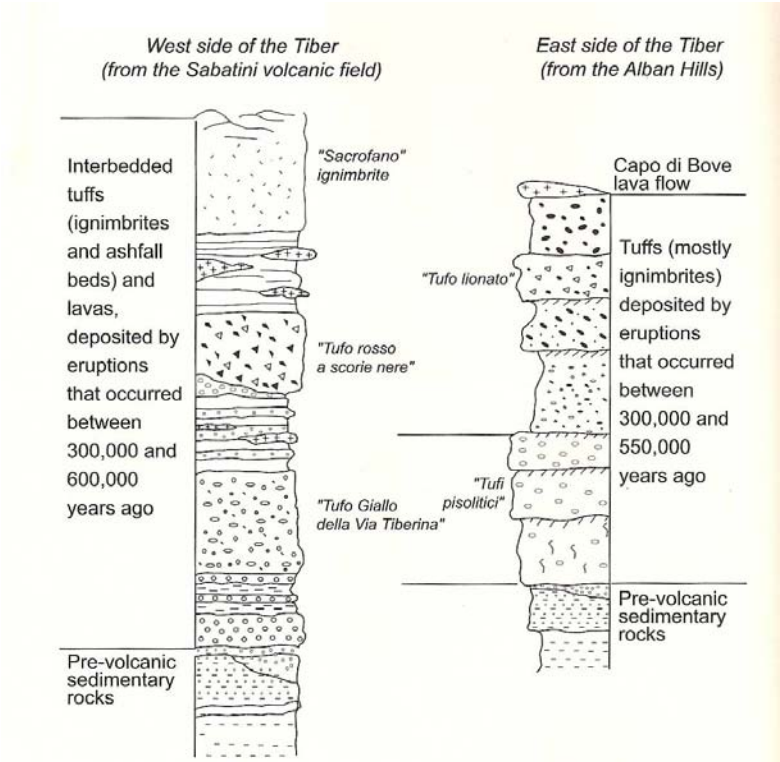


Fig. 3.3. "Volcanic Rocks of Sabatini and Alban Hills, Rome." Heiken, Funiciello and De Rita 48.

by the Paleo-Tiber and the present Tiber that intersect the volcanics along the river's floodplain. Another layer that is missing is not a geologic layer rather an archaeologic one. Present day Rome is built on human debris. This is the building material and other debris left behind by prior (more than two thousand years) of civilizations, and it exists at varying depths. It is often the practice of ancient civilizations to build their homes on top of prior civilizations. If you have any doubt you can go to the Roman Forum, and notice how much lower all the structures are relative to present-day Rome.

Let us discuss now in a little more depth the different rock layers beneath Rome starting with the oldest sediments. The deposits at the bottom of the Roman stratigraphic columns are marine sediments. They were deposited about three and half million years ago when a sea covered the region (Donatella and Giampaolo 185). The sea deposited thick sequences, some 800 m (2625 ft) of fossil-bearing sandstones and mudstones (claystones). Comparatively this represents a thick sequence of deposits. The particular fossils in the rocks tell us that they are of marine and not terrestrial origin. Therefore, in a sense the rocks themselves tell us their original depositional setting. The rocks are what we call shore-to-shallow-water sedimentary rocks. By this I mean they are sequences of rocks associated with two environments: sandstones from a beach (shore) and mudstones from a (near the shore) environment. In this region they would have been deposited along what was then the west coast of Italy's beaches just offshore from the Tyrrhenian Sea's eastern margin. Figure 3.4 shows different depositional environments and the rocks associated with them.

About 0.88 Ma (88,000) years ago after these rocks were deposited, tectonic processes associated with uplift of the Apennines ended the submerged cycle in the region (Donatella and Giampaolo 185). On top of the marine rocks the area's volcanoes deposited volcanic rocks that eventually built up the volcanic plateaus (relatively flat raised areas) where the Romans built their civilization. They are comprised of tuffs, ignimbrites, and basalt. The basalt's presence is unexpected but interesting as we will see shortly. The volcanic deposits in many areas of Rome overlap with the Tiber's gravel and sand deposits brought down from the Apennines.

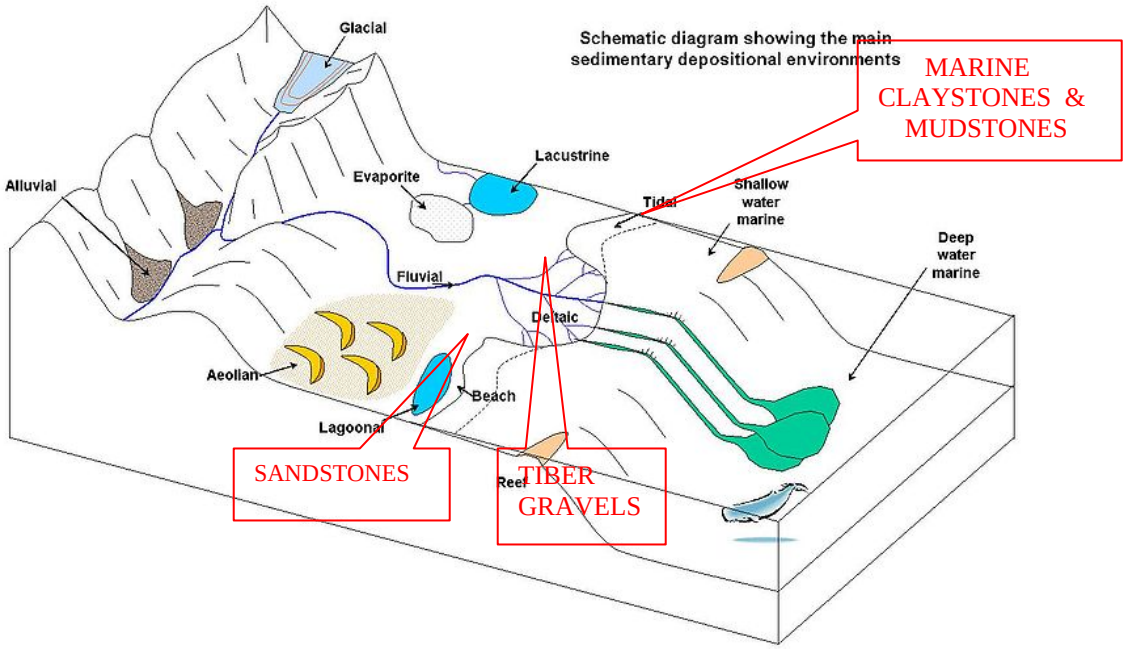


Fig. 3.4. "Sedimentary Environment." Modified from Wikipedia, The Free Encyclopedia. 8 Nov. 2008. Wikimedia Foundation, Inc. 28 Mar. 2009. <http://en.wikipedia.org/wiki/File:SedimentaryEnvironment.jpg>.

Where are the volcanoes of Rome? Rome is surrounded by two major volcanic fields: the Alban Hills to the southeast and the Sabatini Volcanic Fields to the northwest (fig. 3.5). Alban Hills and Sabatini Volcanic Fields are actually part of an even larger magmatic province in the region that includes Vulsini, Vico, Ernici, and the Roccamonfina volcanoes. Geologists call it a magmatic province because the rocks were formed (the volcanoes were active) during the same period of time. The volcanoes span

in age from roughly 1.8 my to 3500 years ago the last time the Alban Hills volcanic field was active. For a more detailed refresher on the processes that generated the Roman

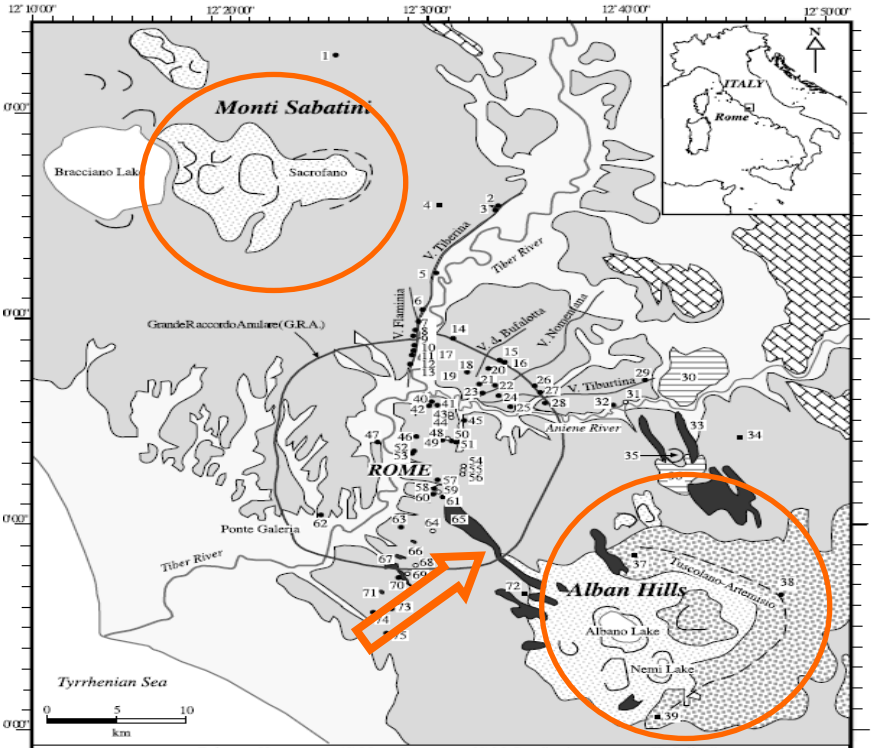


Fig. 3.5. "Simplified Geologic and Location Map Showing Sampling Locations." Modified from Karner, Marra, and Renne 187. Ovals indicate Monti Sabatini and Alban Hills volcanic fields, arrow indicates Capo Di Bove volcanic flow referred to on page 28.

volcanoes see chapter two.

Recall that on the last fly-over (about 1 my) tectonic processes caused the lithosphere beneath Italy to stretch (rift) and thin to the point of melting. This was a consequence of the Tyrrhenian Sea's opening. The evidence for this is the basalt because we know it comes from rifting episodes. There were actually several processes operating concurrently to generate the Roman volcanoes. The rifting episode did not advance to

the opening of an ocean, and there is no back arc to explain the volcanoes' presence. However, we do know that during this period of time the Apennines were (and are still) undergoing extension (the crust stretching beneath them). One way the origin of the Roman volcanoes is presently understood is that Italy's crust was concurrently pushed eastward, stretched by regional tectonic processes related to the Tyrrhenian Sea's opening, and affected by the regional extension of the Apennines.

The Roman volcanoes are characterized by explosive pyroclastic flows in part due to hydromagmatic (magma mixing with groundwater) activity. The volcanoes produced the massive tuff and ignimbrite deposits in the stratigraphic column of figure 3.3. Volcanoes from the Albani and Sabatini volcanic fields had cycles of eruptions followed by cycles of quiescence. The satellite image in figure 3.6 shows the Roman volcanoes as a series of depressions. They are a series of collapsed calderas, and today some are lakes. Notice that the volcanoes are more or less aligned parallel to the Tyrrhenian coast. This makes sense geologically because the ongoing geologic processes are operating along this Italian coast. Thus we would expect to find the volcanoes lined up along the west coast of Italy. In the satellite image of figure 3.6 Rome is in the center represented by the large orange circle. Some of the lakes are very scenic such as Lake Bracciano only 32 km (about 20 mi) from Rome. It is also an important tourist attraction (fig. 3.7).

The Seven Hills of Rome have been carved from a massive volcanic plateau into hills by erosional processes over the past 88,000 years (Donatella and Giampaolo 185). The Tiber, having been blocked by prior volcanic eruptions, established its current

Fig. 3.6. "LANDSAT -7 Image of Rome and Environs." Modified From Short, Nicholas M. 2001. RST Web Page. 22 Mar. 2009. <http://www.fas.org/irp/imint/docs/rst/Sect6/Sect6_12.html>.

Fig. 3.7. "Lake Bracciano." Wikipedia, The Free Encyclopedia. 21 Mar. 2009, 18:59. Wikimedia Foundation, Inc. 22 Mar. 2009. <http://en.wikipedia.org/wiki/Lake_Bracciano>.

course. Together with its tributaries it began eroding (cutting down) the easily erodible tuff sediments as it flowed through the region to form the seven hills. In addition to

water the Seven Hills of Rome were shaped by sea level rise and fall due to glacial episodes. Rivers are powerful agents in changing the landscape. If you have any doubt just look at the Grand Canyon to see how much the Colorado River has cut down into the bedrock. It is thought that at one point the Colorado River was flowing along what is now the top of the Grand Canyon.

If you are wondering if the volcanoes are still active, and what kind of risk there is living in the region of Rome, you are not alone. Geologists are not sure when or if they will erupt again. They are fairly certain it will not happen in the near future. One indicator of a volcano's activity is earthquakes. Certainly central Italy near Rome, in fact most of Italy is plagued by earthquakes. Is this an indicator of activity in the Roman volcanoes? The answer is probably not. The region's earthquakes come primarily from three sources but the most devastating are not associated with the Roman volcanoes. Within 15-km (9 mi) from the city center the earthquakes are very mild, shallow, and rarely detected except by highly sensitive seismometers (Heiken, Funiciello, and De Rita 103). The source of the strongest earthquakes is actually 60-130 km (37-81 mi) farther east in the region of the central Apennines. Ongoing extension in the Apennines is the reason for these earthquakes. Remember that extension means normal faults, and earthquakes are associated with faults.

The Tiber River.

The Tiber River flows through the heart of Rome. It has played a very important part in Rome's history. I mentioned how it shaped the city's topography into hills before humans ever settled in the region. It starts 406 km (252 mi) away on Mt. Fumaiolo high

in the Apennines and follows a narrow valley formed by faults that developed recently in geologic time (Heiken, Funiciello, and De Rita x). These faults are associated with regional extension of the Pliocene age (about 5 my), and the opening of the Tyrrhenian Sea.

The Tiber's course was altered approximately half a million years ago when volcanoes from the Sabatini district erupted and dammed the Paleotiber (Alvarez 62). Eventually the lake that built up behind the dam spilled over and formed a new path for the Tiber that it still follows today. Figure 3.8 shows the Tiber on its way to the Tyrrhenian Sea. The physiographic region of the Tiber's drainage area consists of tall mountains next to the sea. This set up allows conditions to create weather patterns of

Fig. 3.8. "The Tiber Near Rome." 2007. Vroma Web Page. 30 Mar. 2009. <http://www.vroma.org/~araia/tiber.html>.

Fig. 3.9. "Tiber River." Wikipedia, The Free Encyclopedia. 8 Apr. 2009, 07:00. Wikimedia Foundation, Inc. 4 Mar. 2009. <http://en.wikipedia.org/wiki/Tiber>.

intense rainfall that occurs over a concentrated region often causing the Tiber to flood.

Let us examine this phenomenon a little further. As can be seen from figure 3.9 the Tiber runs more or less parallel to the Apennines crossing the regions of Tuscany, Umbria, and Lazio. The river's drainage area is a vast area of the Apennine Mountains, $17{,}156^2$ km (6623^2 mi) roughly the size of New Hampshire (fig. 3.10). Forty-two tributaries drain into the Tiber (Heiken, Funiciello, and De Rita 65). If we think about the geometric relationship of the river with respect to the Apennines it is easy to see why there is often flooding.

An analogy of the Apennines and the Tiber's relationship is similar to the function between the roof of a house and the gutters. Think of the Apennines as the roof and the Tiber River as the gutter. Now imagine a torrential rain over a short period of time and the gutters will overflow because they cannot contain the amount of water they

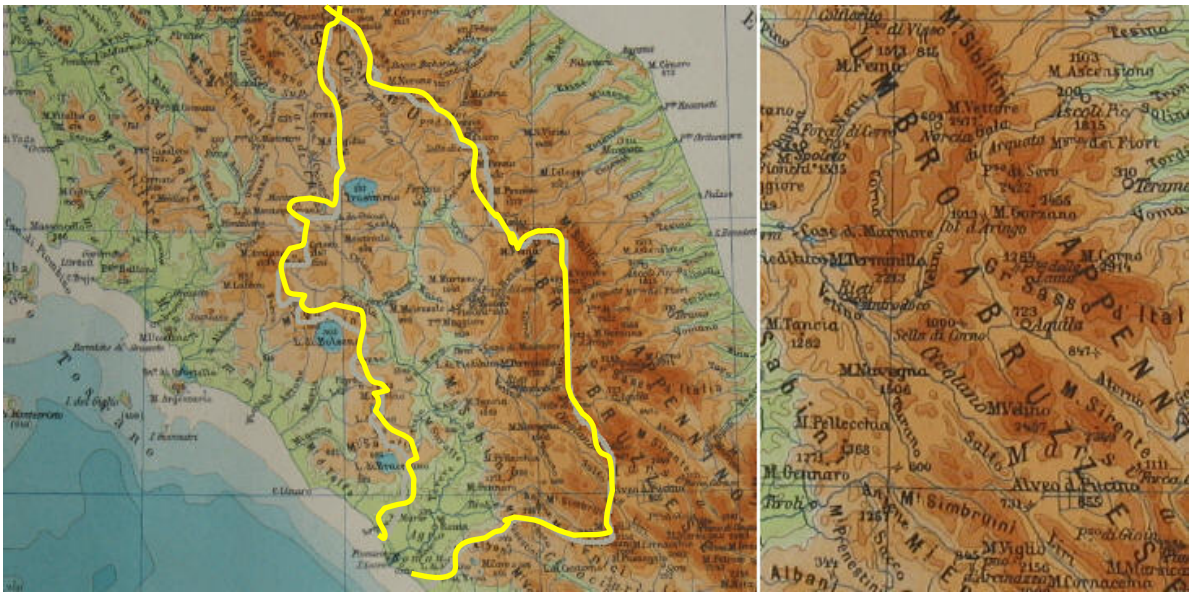


Fig. 3.10. “Drainage Area of Tiber.” Modified from Roberto Piperno. 2005. Personal Web Page. 30 Mar. 2009. <http://www.romeartlover.it/Tevere.html>. Tiber drainage area outlined in yellow.

receive. This is exactly what often happens to the Tiber. Another factor contributing to flooding is deforestation along the river’s course.

During ancient times the building structures along the Tiber’s floodplain in Rome consisted mainly of sports arenas and theaters. Residential areas were built on higher ground. This was a good land use practice by wise city planners. The city was not adversely affected by floods for this reason. However, as population grew during the medieval period there was extensive building along the Tiber’s flood plain including residential and other important structures. Predictably this made them susceptible to flooding episodes.

If you are in Rome and would like to see a place where devastating floods are

Fig. 3.11. "Santa Maria Sopra Minerva." Wikipedia, The Free Encyclopedia. 5 Dec. 2008, 15:33. Wikimedia Foundation, Inc. 26 Mar. 2009. <http://en.wikipedia.org/wiki/Piazza_della_Minerva>.

chronicled you might go to the church called Santa Maria Sopra Minerva (St. Maria Over Minerva). It is located near the Pantheon. The church has plaques on its façade that mark the high water mark of some early floods (fig. 3.11). According to historians one of the worst floods occurred on December 14, 1598 when the river rose 3.9 m (13 ft) above its normal level. In more recent times Rome has endured twenty-eight floods in the last two hundred years. The most recent devastating flood occurred in 1948 when the river crested at 18.3 m (60 ft) (Heiken, Funiciello, and De Rita 64). Today the Tiber River is bound by floodwalls to prevent flooding but as you can see from figures 3.12 and 3.13 taken December 14, 2008 certain parts of Rome are still vulnerable to flooding.

Fig. 3.12. “Fire Department Rescues in Rome Dec. 14, 2008.” Times On Line. 14 Dec. 2008. Times Newspapers Ltd. 2 Apr. 2009. <http://www.timesonline.co.uk/tol/news/world/europe/article5330066.ece>.

Fig. 3.13. “Flooded Banks of Tiber in Rome – Dec. 2008.” Mail On Line. 2008. The Mail on Sunday. 2 Apr. 2009. <http://www.dailymail.co.uk/news/worldnews/article-1094251/First-Venice-Rome-River-Tiber-bursts-banks-storms-strike-Italian-capital-like-earthquake.html>.

In ancient times, the Tiber had several tributaries that are no longer in existence. Volcanic flows from the Alban Hills cut off the river’s tributaries south of Rome. The

tributaries in Rome have been filled in or diverted (Heiken, Funiciello, and De Rita 65). I contemplate what the river would look like without human intervention. Certainly it would have changed course shifting east or west as it has done during other times in its history (Heiken, Funiciello, and De Rita 110).

All rivers carry sediment. Some of it is very fine and suspended in the water while other is coarser and rolls along the riverbed. Sediment over the millennia has been deposited in the floodplain of the Tiber as well as along its delta. In Rome the Tiber has formed an island from that sediment known as Tiber Island which is shaped like a boat. The island is located at a meander (bend) in the river. The sediment dynamics in a bend of a river are such as there is sediment deposition and over time it has accumulated enough to form the island. It is thought that the island is located where there were perhaps several tributaries emptying into the Tiber in earlier times (Heiken, Funiciello, and De Rita 72).

Like most rivers, the Tiber has a wider valley downstream from Rome as it flows toward the Tyrrhenian Sea. There the floodplain widens extensively and the terrain becomes flatter. The river reaches its delta in the Tyrrhenian Sea at the ancient port of Ostia. Ostia was a former port but due to the Tiber's heavy sedimentation it was filled in and abandoned. Another port was built in Fiumicino during the first century AD. It too was abandoned due to heavy silting. During the early days of Rome the river was navigable as far inland as 100 km (62 mi) and was extremely important historically as a trade route, and strategically important to the defense of Rome. Today because of heavy

sedimentation and despite dredging efforts over the last 300 years, the Tiber is only navigable a few kilometers inland.

Drinking Water.

Favorable geologic conditions make water plentiful for present day Rome as well as during ancient settlements. However, it is not the Tiber that brings drinking water to the city except during wars when the aqueducts were destroyed. Something one notices in Rome, in fact all over Italy, is the plentiful water flowing from fountains. In the vast majority of instances it is clean and meant for consumption (fig. 3.14).

Fig. 3.14. "Author Drinking From a Fountain at the Vatican." Photograph by Harry Katrivanos. 17 Sept. 2008.

This is an astounding realization to most people visiting Italian cities. The primary source of water in Rome is the vast aquifers in the Apennine Mountains (Heiken, Funiciello, and De Rita 133). In central Italy within the regions of Latzio and Abruzzo the Apennines have formed a lot of karst terrain. Karst is formed when limestone makes

contact with acid rain dissolving the carbonate in the limestone and forming caves. This process in turn forms springs and rivers in the underground (fig. 3.15). Notice the bumpy

Fig. 3.15. "Karst Terrain in Gran Sasso D'Italia." Personal photograph by author. 20 July 2006.

like surface to the terrain around the water in figure 3.15. This is characteristic of karst areas. Grant Heiken reports that groundwater outflow for the central Apennine area of about 8000^2 km (3100^2 mi) is 220,000 liters per second (3.5 million gallons per minute). Small wonder the Romans decided to settle in Rome. There was plenty of drinking water.

The Romans built elaborate aqueducts that brought water to the city from the Apennines. Many of the ancient aqueducts remain standing. Scholars marvel at the engineering involved to design aqueducts systems that relied entirely on gravity bringing water from hundreds of kilometers away. Imagine the task of building concrete lined

structures at a constant slope for great distances through terrains like mountains and valleys. Today Rome's aqueduct system is essentially the same as the one built during ancient times.

A second important water source for Rome is the highlands of the Alban Hills and Sabatini volcanoes. The naturally porous volcanic material allows rainfall to soak in filling important aquifers underground. Heiken, Funiciello, and De Rita report that these areas provide a cumulative flow from groundwater of 45,000 liters per second (700,000 gallons per minute). We have seen how the favorable geologic setting of the Apennines close to the sea makes for plentiful rainfall allowing the aquifers to be replenished. In addition, the limestone rocks in the Apennines and the volcanic rocks surrounding the city make it possible to hold vast amounts of fresh water. This was undoubtedly a key factor to settlement in this region.

Landslides.

Is there such thing as a bad geologic setting? In some cases yes particularly if humans ignore treacherous locations to build homes. Landslides associated with heavy rains are a large problem within the Tiber's drainage area and have killed many people. Often the local geology plays a key role with respect to landslides. There is a history of many landslides in this region (Guzzetti et al. 109). In a recent study Guzzetti and others found that landslides are strongly correlated to the local geology. They found that slope failures are most common where there are weak rocks, where the rocks are chaotic or disorganized and compromised by weathering and erosion. Unfortunately, homes have been built in regions of loose volcanic rocks or other sediments that make for unstable

ground and directly in the path of landslides. In this instance, we have an example where culture and geology have not been working together. A reason for this may be that there was not geologic knowledge about land stability until recent times.

The Building Material of Rome and Cultural Connections to Geology.

Let us turn our attention now to the actual Roman rocks to see how they have influenced the region through their use as building materials. The most prevalent volcanic rocks generated by the Roman volcanoes are tuffs or ignimbrites (welded tuffs), and basalt. The tuffs constitute the largest component in the foundation rocks of Rome. They are plentiful, easily cut, and were quarried in several nearby quarries located close to the Tiber. This made it easy to transport them by barge to the city (Heiken, Funiciello, and De Rita 44). There are many examples of tuff use in the city. Let us examine some.

The Roman Forum and The Colosseum. One of the most important places in Rome to see tuff is in the Roman Forum. According to Heiken, Funiciello and De Rita, you can actually see volcanic bedding (layering) in the tuffs of the columns of the Temple of Antoneus and Faustina because the outer layers have been worn off (figures 3.16 and 3.17). Just a short distance from the Roman Forum is the Colosseum symbolizing Rome's glory. At its structural base, we find another volcanic rock, this one called sperone or welded scoria (a type of basalt). Sperone is a rock with strong mechanical properties. The Roman engineers used excellent skills and chose from several welded tuffs in the region the strongest one to place as the foundation of the Colosseum! The

Fig. 3.16. “Temple of Antonius and Faustina, Forum.” Personal photograph by author. 19 Jan. 2008.

Fig. 3.17. “Close up of Temple of Antonius and Faustina Column.” Personal photograph by author. 19 Jan. 2008.

statement warrants an exclamation mark because there are several varieties of tuffs and welded tuffs in the area yet the Romans figured out sperone was the strongest without sophisticated instruments with which to measure the rocks’ physical and mechanical

Fig. 3.18. “Travertine on Outer Wall of Colosseum, Rome.” Personal photograph by author. 19 Jan. 2008.

properties like we have today. It is a testament to their talents as builders and engineers.

The exterior walls of the Colosseum are made with travertine making the Colosseum the largest building in the world constructed of travertine (fig. 3.18). Only 30 km (18 mi) from Rome there are extensive travertine deposits in the town of Tivoli, making transporting the travertine very convenient. The Romans called travertine lapis tiburtinus because the name of Tivoli was Tibur. Travertine is used extensively as a building material for decorative applications in Italy. It can be found in many settings including as steps to cathedrals, columns, statues, fountains, even the walls of the Roman Colosseum. Reflecting for a moment on the formation process of travertine I realize that it is symbolic of the region’s geologic history and close bond to the Roman culture. During formation travertine precipitates and bonds together also.

The Roman Colosseum serves as a great example of the importance the geologic setting plays in the stability of a structure, something we will see again, when we are in Tuscany discussing the Leaning Tower of Pisa as well as in Venice. The ancient Romans did not understand geologic concepts as we do today, and they did not realize that there were unstable rocks at the site where they laid the Colosseum's foundation. They built the Colosseum over a geologic boundary made of two very different materials: one of tuff and the other of poorly consolidated stream sediment (fig. 3.19). A geologic boundary refers to a physical boundary between different rocks possibly of differing ages. I have placed a dashed line in figure 3.19 just to illustrate how the geologic boundary coincides with the damage of the structure though of course geologic boundaries in the subsurface are not as clearly outlined. The left side is underlain by the tuff deposits, while the right side of the image is underlain by the loose unconsolidated river material.

It turns out that half of the Colosseum straddles solid rock while the other half straddles loose unconsolidated deposits, pebbles, gravel, muds and other loose sediment brought there by the Tiber. This unfortunate setting made the Colosseum unstable and particularly vulnerable to the many earthquakes in the region. Earthquakes during the past 1900 years have caused damage to the outer wall of the Colosseum making it asymmetrical (Heiken, Funiciello, and De Rita 97). The part underlain by the tuff has remained stable while the other half has sustained considerable damage, losing at least one or two floors (Heiken, Funiciello, and De Rita 97). This damage was due to the fact that when the earthquakes occur, the unconsolidated material shakes more because of its

loose nature. The other half of the boundary containing the homogenous solid tuff withstood the earthquake shocks better and kept part of the Colosseum from sustaining

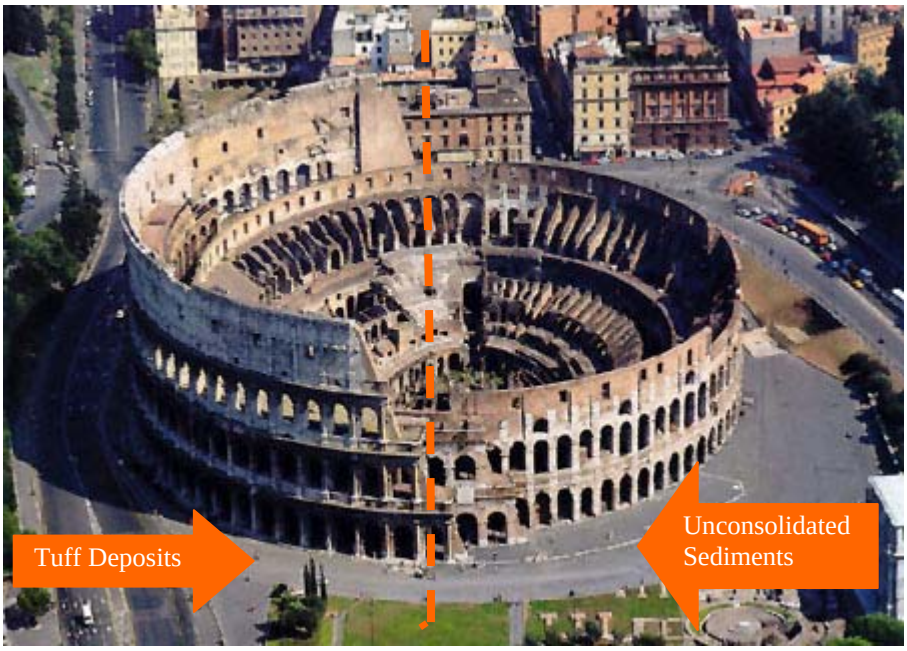


Fig. 3.19. "Roman Colosseum." 2002. Modified from ef-Stop Photography. 2 Apr. 2009. <http://portfolio.neotenicdesign.net/efstop/architecture.htm>. Dashed line indicates hypothetical geologic boundary.

much damage (Heiken, Funiciello and De Rita 97).

The Trevi Fountain. One of the most beautiful and prominent features in many towns in Italy are the fountains. Fountains were not built for aesthetic purposes in Italy but rather for the utilitarian function of serving as an outlet for water. Since water was brought into the city from afar by aqueducts the fountains served as a place for the public to obtain water. Local citizens gathered at the fountains, and usually for a fee could buy

water. The ancient Romans had a custom of building beautiful fountains at the terminus of an aqueduct. In Rome the Trevi Fountain (Fontana De Trevi) is located at the

Fig. 3.20. "Trevi Fountain." Wikipedia, The Free Encyclopedia. 26 Apr. 2008, 12:27. Wikimedia Foundation, Inc. 30 Mar. 2009. <http://commons.wikimedia.org/wiki/File:Trevi_Fountain,_Rome,_Italy_2_-May_2007.jpg>.

terminus for the Aqua Virgo (Aqua Vergine) and is the most famous fountain in Italy (fig. 3.20). The Trevi Fountain is located at the intersection of three roads (tre vie) hence its name.

You can take Rome's underground train called Metro (Metropolitana) Line A (Barberini) that stops at the fountain. It is a magnificent example of Baroque architecture. The building stones at the base of the fountain are made of travertine. The

figures are carved of Carrara marble, the finest marble in Italy known and used for centuries because of its uniform grain size and its ivory color. Carrara marble does not come from the Roman region. It is quarried near the city of Carrara in northwestern Italy near the gulf of Genoa. It was brought to Rome on barges and was used in many other parts of Rome. Important sculptors like Michelangelo (1475-1564) and Gian Lorenzo Bernini (1598-1680) chose Carrara marble. The Italian saying goes that if you visit the Trevi and throw a coin you will surely return to Rome. It was true for me.

The Appian Way (Via Appia Antica). During the third century BC the Romans built a monumental network of roads 85,285 km (53,000 mi) long spanning Europe, Greece and Mesopotamia that took them one hundred years to complete (Von Hagen 8). Twenty roads ensued from Rome and all roads led back to Rome (fig. 3.21). It is no wonder this Roman endeavor is considered by many the largest construction project ever undertaken in history. The main objective for these roads was to dispatch troops to various locations quickly and expand the empire (Adkins 172). Besides military use, the

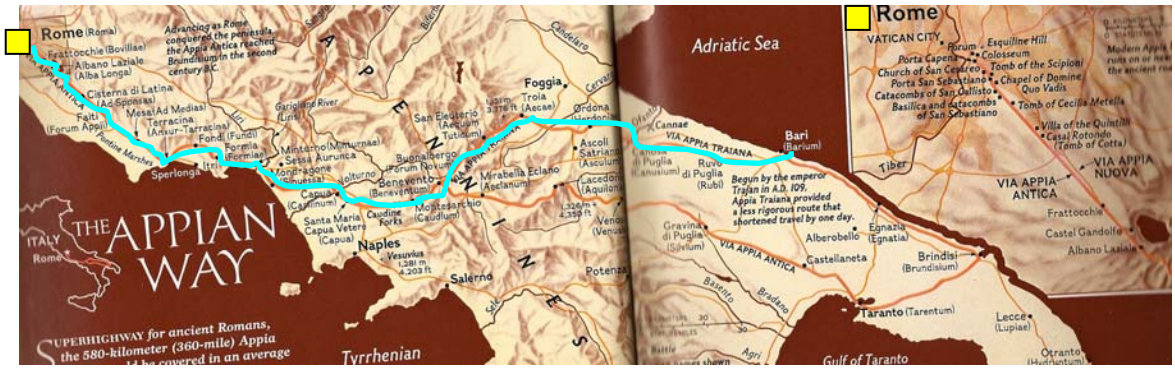


Fig. 3.21. "The Appian Way." Modified from Down The Appian Way, James Cerruti in National Geographic (Washington, D.C.: National Geographic, 1981) 722-723. Yellow square is Rome. Appian Way from Rome to Bari outlined in blue.

Fig. 3.22. "Life on the Appian Way." Down The Appian Way, James Cerruti in National Geographic (Washington, D.C. National Geographic, 1981) 736-737.

road had economic uses for the government and the Roman citizens. The first of these roads was the Appian Way (Via Appia) sometimes referred to as the "Queen of Roads." Mail was dispatched along the Appian Way, it connected people to agricultural regions, and it was a means of transport for private citizens and their goods (fig. 3.22) (Laurence 101).

The Appian Way was built in the 312 BC by Appius Claudius. It is a model of the Romans' superb utilization of the local geology taking advantage of not only the perfect building materials but also the terrain. The Appian Way in the region of Rome was built along the Capo Di Bove (head of the ox) (refer back to fig. 3.4) lava flow from the Faete volcano in the Alban Hills (Heiken, Funiciello, and De Rita 119). The Romans capitalized on the flat, smooth and stable surface of the Capo di Bove lava flow. Utilizing this flow's surface to build the Appian Way made for much easier construction. In addition, the building material they needed was right there. They carved the blocks of

basalt from on site and eliminated labor for transporting the material (Heiken, Funiciello, and De Rita 118).

Geologists today understand properties of rocks such as physical and mechanical strength. However, in ancient Rome selecting the right building material for a project was probably due to trial and error. They have proven that they chose well. Just the mere fact that the Appian Way still stands in some areas just as it did two thousand years ago is a testament that they made the best choices of building materials from what was available. Their choices illustrate a keen awareness of geology and the physical properties of rocks. The fact that rocks on the Appian Way are still in place is an example of their amazing engineering and stone mason skills as well as the rocks' properties. The main building

Fig. 3.23. "Close Up of Basalt and Wheel Tracks on the Appian Way, Rome." Personal photograph by author. 21 Jan. 2008.

materials used for the Via Appia near Rome are basalt tuff, limestone, Roman concrete, sand, pebbles and gravel (Nardo 212). While in Rome you can walk on the very roads the Romans did over two millennia ago. In certain areas the tracks of chariot wheels can still be seen (figure 3.23).

The Romans chose basalt to top the Appian Way mostly in important places like cities. It appears to me that Roman knowledge of basalt went beyond just its strength properties. I think this is demonstrated by the way they cut and placed basalt blocks on the road. The basalt they chose to cap the Via Appia was cut into very large polygonal

Fig. 3.24. "The Appian Way, Rome." Personal photograph by author. 21 Jan. 2008.

blocks. They quarried large blocks from nearby mountains and chipped them to form a perfect fit-together-shape which they then set firmly on the foundation. Hamblin and Grunsfeld quote the Greek historian Procopius who wrote about the intricate application

of the stones and his respect for the Via Appia nine hundred years after the Appian Way was built:

> [The Appia stones] were fastened together so securely and the joints were so firmly closed that they give the appearance…not of being fitted together, but of having grown together. (151).

Incredibly, this pattern of cutting and placing basalt is perfectly suited to its natural characteristics and increases its durability. Large rock sections made it a lot less likely to fracture, and the polygonal shape is the natural shape basalt may take when it is extruded adding to its strength.

When cooling basaltic magma may form what is known as columnar joints. In nature, these basaltic columns actually form into hexagonal to polygonal shapes, very close to how the Romans cut them for the Via Appia. The question is, how did this aspect of basalt become apparent to them? Perhaps they found some columnar basalt deposits in the region. I would like to think they figured it out themselves due to their skill as superb engineers. To fully appreciate this Roman insight about basalt, compare the two images in figures 3.25-3.26. Figure 3.25 shows columnar basalt joints formed naturally and not touched by human hands, while figure 3.26 a part of the Via Appia's surface built with basalt blocks that were cut into these shapes by the Romans. Incredibly, they appear very similar!

Other important building materials used by the Romans are the pozzolane rosse (reddish pink scoria) a type of basalt and pozzolane nere (black scoria). Pozzolana (pozzolane) is loose volcanic ash that the Romans mixed with lime to make very strong concrete. Pozzolana was a very important component to building construction because it offered strength to the structures that was otherwise not possible. Although the Greeks had invented concrete the Romans improved its strength dramatically with the pozzolana

Fig. 3.25. "Columnar Basalt." 28 Mar. 2007. <www.planetware.com/photos/GB/IRNGNT3.HTM>.

Fig. 3.26. "Via Appia." Von Hagen 26.

volcanic ash. Roman concrete has stood the test of time with the most famous example being the Pantheon (all gods). This magnificent structure even has a dome made of concrete. As Rome prospered extending trade throughout the Mediterranean and beyond, its economic stature increased, and the Romans used higher grade building materials even importing marbles form many areas outside the region and Italy (De Rita and Giampaolo 128).

The volcanic rocks around Rome have another significance besides for use as building material. It is well known that volcanic soils are very fertile and this is very true for the region surrounding Rome. The area grows several varieties of grapes for wine as well as wheat and other grains. This was also another factor that contributed to the selection of the region for settlement (Karner, Marra and Renne, 185).

The Gran Sasso D'Italia – How Did the Biggest Mountain in Italy Get There?

We are now leaving Rome travelling east on the Autostrada A-24 through the Apennines to the Gran Sasso D' Italia. The mountain, part of the Apennine chain, is located in Italy's Abruzzo region just 132 km (82 mi) from Rome in the Gran Sasso e Monti Della Laga National Park (fig. 3.27). I call the Abruzzo region "from the mountains to the sea" because within an hour you can be from the highest mountain in Italy to the Adriatic Sea's beaches. The Gran Sasso is located just 50 km (31 mi) from the Adriatic coast of Italy, and it is 2912 m (9554 ft) high. The rugged Abruzzo region is 10,794[2] km (4168[2] mi) two thirds of it being mountainous. It is home to two other

national parks, the Parco Nazionale D'Abruzzo Lazio and Molise and the Parco Nazionale De La Majella.

Being a geologist I was naturally drawn to leave the city and see Italy's tallest peak also known as the Corno Grande (great horn). The three peaks in the park are the Gran Sasso, the Corno Piccolo and Pizzo Intermesoli. The Calderone glacier located on

Fig. 3.27. "Gran Sasso D'Italia, Campo Imperatore." Personal photograph by author. 20 Jul. 2006.

Corno Piccolo is Europe's southernmost glacier. Like most glaciers worldwide it is melting at an alarming pace. In the eastern section of the Corno Grande is the Campo Imperatore (Imperial Fields) or otherwise known by the locals "Little Tibet." It is a high

plateau filled with glacier and river sediments. A very scenic road leads you through the park and Campo Imperatore and you can reach several medieval historic cities such as Castel del Monte. You will most likely observe wild horses and shepherds herding sheep as I did with Maremma sheepdogs that originated in this region (fig. 3.28).

On the day of my first visit the sky was clear and I saw the mountain. I was lucky because on a subsequent visit two years later in the fall of 2008 most of the mountain was covered by clouds, and it was not visible. This is characteristic of mountains. They

Fig. 3.28. "Wild Horses Licking Salt, Campo Imperatore." Personal photograph by author. 25 Sept. 2008.

create weather, and the weather can change suddenly and without warning. This occurs because warm air meets the mountain and it is forced upward. The rising air cools forming clouds that then produce rain or snow.

Paleoenvironment of the Gran Sasso. Let us visualize now the paleoenvironments that formed the rocks comprising the Gran Sasso Range. I should mention that those processes formed all the Apennines not only the Gran Sasso Range. Traveling back in time to the Mesozoic Era (around 65 my) the Mediterranean region was quite different both in physical character and life forms. The climate was exceptionally warm around the globe during the end of the Mesozoic Era. It is a time of very rich animal diversity, and even a few species of dinosaurs are roaming the region. It is also a time of abundant plant speciation and richness. The Italian peninsula was not on the map yet. In its place were warm shallow seas where calcium carbonate was deposited on the ocean floor called carbonate platforms. Recall from chapter one that these are deposits of marine invertebrates (mollusks, sponges, corals etc.). There are other sediments including muds, terrestrial sediments, animal skeletons, debris flows and the pelagic margin sediments of this paleoenvironment. These are distinguishable at the Gran Sasso Range.

During the Oligocene (about 35 my) the collision of the African and European plates caused these packages of sediments to stack up (also assisted by the opening of the Tyrrhenian and the Liguro-Provencal Seas) in western Italy. The sediments were compressed from the west, thrusted, migrated in thrust sheets eastward and lifted. Then during the Pliocene (last 5 my) extension began on the west coast of Italy forming basins in the Apennines. There is also a foreland basin (a depression that develops adjacent to a mountain belt) along the Adriatic coast. It has a great volume of accumulated sediments from the Apennines but it is beneath the Adriatic Sea so we cannot see it.

Some believe that concurrent with all this tectonic activity on the eastern coast of Italy "passive subduction" began along the Adriatic foreland basin. This means the Adriatic micro plate (of continental crust) is moving westward under the Italian peninsula. The term passive subduction is sometimes used to refer to tectonic situations when the normal subduction processes model (slab-subduction-melting) are not present but a revised type of subduction process is taking place without actual melting. I want to make note here that there are several interpretations as to the Earth processes taking place on the east coast of Italy today. It has also been postulated that the Adria micro plate is pushing against the eastern coast of Italy due to the continuing tectonic movement of the plates in the Mediterranean region.

Formation of Gran Sasso. In chapter one I said some mountains are volcanoes others are not. The Gran Sasso is not a volcano. The story of how the Gran Sasso got there can be told by describing how the rocks formed and the subsequent events that formed the Apennine Mountains of which the Gran Sasso is a part. It is a story that spans about 60 million years and involves multiple processes, sometimes operating simultaneously. In this region of Italy the mountains are called the central Apennines. The Gran Sasso is located in central Italy roughly in the central region of the Apennines that stretch roughly north-south along the entire length of Italy. Some refer to the Apennines as the "spine" of Italy. It will help us visualize the structure of the Gran Sasso if we look at some figures of its structure. It is a composite structure of two limbs, one that trends E-W, the other limb rotated counterclockwise and trending east.

Figure 3.29 shows the orientation of the thrust sheets (mountain units). This figure is like a bird's eye view with the left side being the west coast of Italy and the right the east. The different symbols represent different rock units differentiated by age and sediment type. Notice the thrust faults with the black teeth are oriented more or less N-S but the Gran Sasso units (represented by the two orange triangles) are oriented E-W.

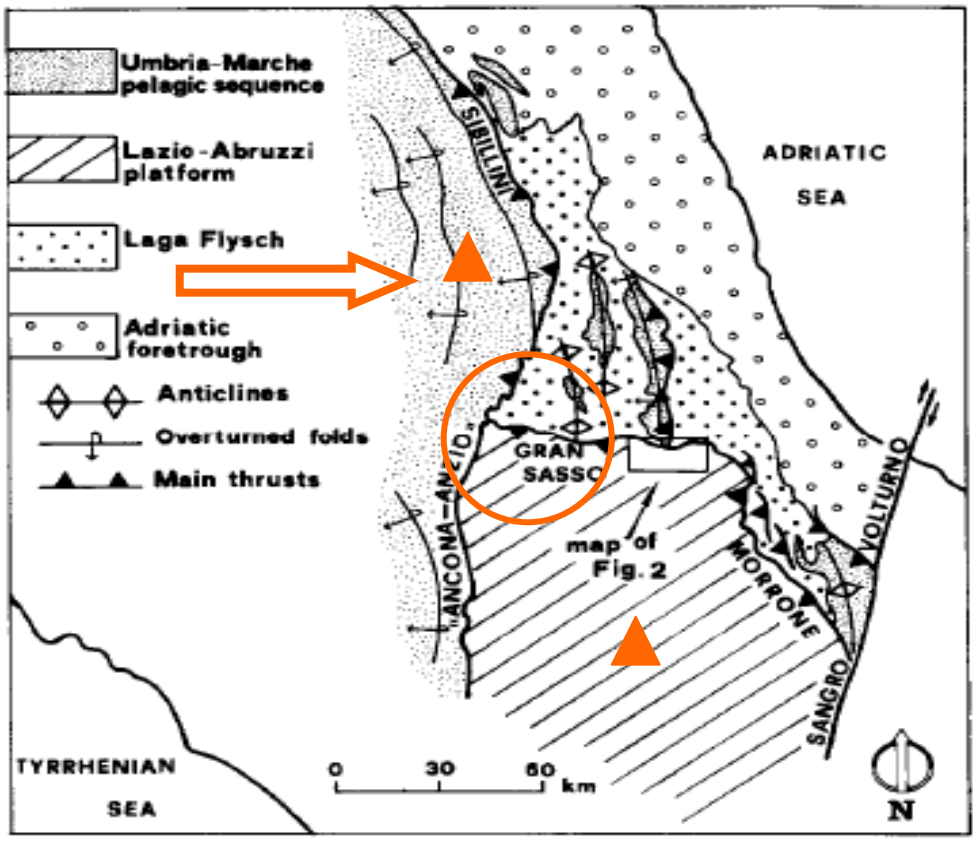
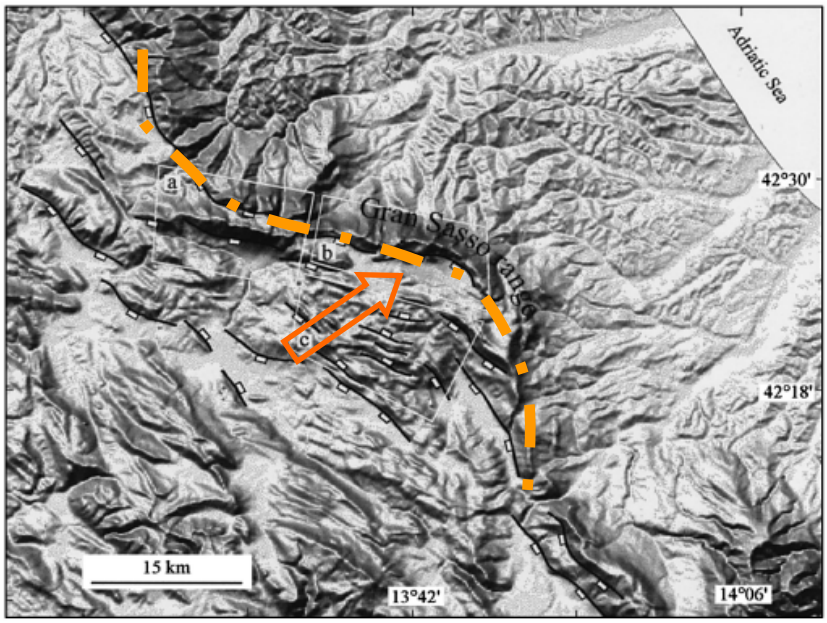


Fig. 3.29. "Sketch Map of Gran Sasso Thrust System in the Geological Setting of Central Apennines." Modified from Ghisetti, Francesca. "Mechanisms of Thrust Faulting in the Gran Sasso Chain, Central Apennines, Italy." Journal of Structural Geology 8 1987: 955.

This is unique to the Apennines. The large hollow arrow is pointing eastward because this is the direction of compression that formed the Apennines. I am just repeating the

stack of books analogy here in the central Apennines. Our stack of books (the Apennine Mountain units) are being pushed from the west to the point that they are actually overturned in places and the mountains formed thrust sheets (stacks). This causes what geologists call shortening of the crust meaning Earth's crust gets shorter because it gets bunched up crumbled up and raised upward.

You might be able to visualize the deformation of the rocks better if you pretend that the books are made of clay. Imagine how deformed the clay books would become if we were to keep pushing them together. This is exactly what was happening to the Apennines. Where the circle is indicated in figure 3.29 notice it is the area of three



W E

Fig. 3.30. "Shaded Relief Map of Gran Sasso and Surrounding Areas." Modified from D'Agostino et al. 234.

mountain units (speckled, dotted and crosshatched) coming together. It is thought that the Latzio-Abruzzi platform of rocks may have been rotated and detached from the thrust

belt (the Apennine mountain thrust sheets moving along as a unit) and this is why it is rotated E-W rather than N-S the rest of the Apennines' orientation (Dela Pierre et al. 335). In our clay book example, this movement by the mountains would be as if one of the books fell and rotated perpendicular to the rest of the stack. It appears that there is just a lot of compression in a small area of units that has caused the Gran Sasso to rise up so high.

The highest point of the Gran Sasso occurs at the collision of two similar packages of sediments known as the Apulian carbonate platforms limestone (sediment made up of limestone full of marine fossils) and the Latium-Abruzzi carbonates (sedimentary rocks composed of limestone or dolomite) (D'Agostino et al. 233). It is thought that the Gran Sasso is actually a range that has travelled tens of kilometers along as a thrust sheet or along the thrust plane (Speranza et al. 185). This is analogous to a conveyor belts moving mountains over great distances. This is a rather remarkable thought in and of itself. Figure 3.30 shows the faults by the dark lines with the blank teeth.

Thus far, I have been describing compression that formed the Apennines. However, there are also various basins (areas of low relief appear lighter) in figure 3.30. These basins have been formed by regional extension ongoing in the Apennines. The large arrow in figure 3.30 points to one such structural basin, the Campo Imperatore. This figure also shows nicely the curvature of the Gran Sasso Range as indicated by the dashed orange line.

Strong Earthquakes. The Abruzzo region in the central Apennines has a long history of earthquakes of high magnitude (please see postscript at end of chapter). Extension means the crust is being stretched, forming normal faults and that means earthquakes. The seismic map in figure 3.31 shows the intensity of earthquakes in this part of Italy between 1981-1996. The size of each circle indicates magnitude. You can see that there have been many earthquakes in the region. The 1984 Abruzzo earthquake was particularly devastating. It is linked to two large faults that intersect from different

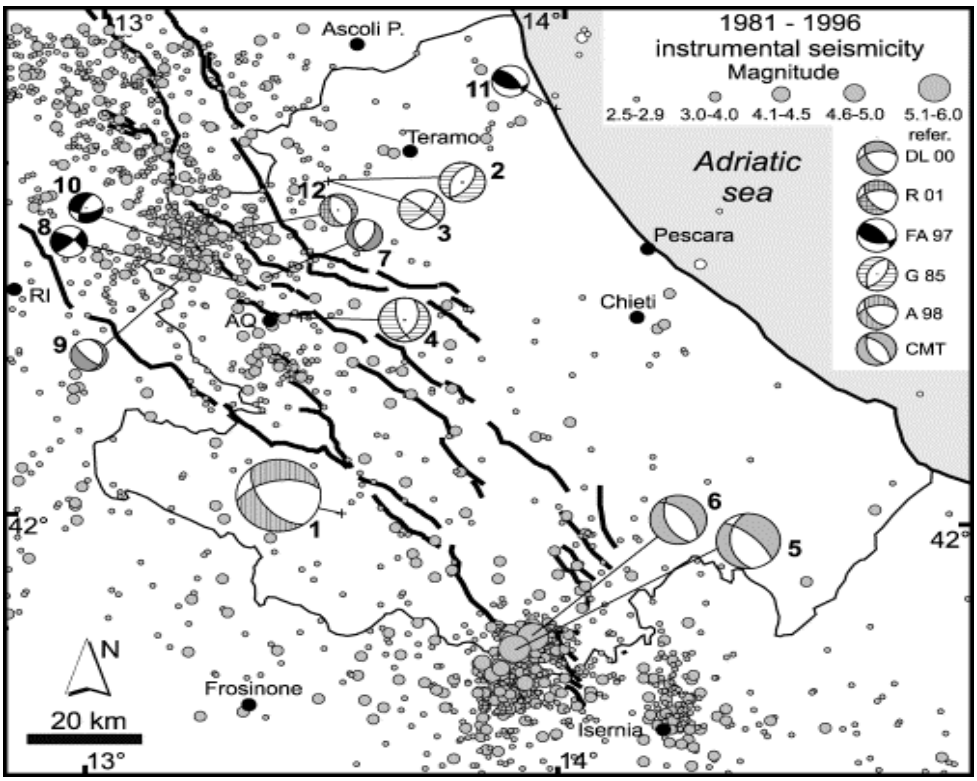


Fig. 3.31. "Epicenters of Instrumental Earthquakes Recorded From 1980-1996 by the Istituto Nazionale di Geofisica e Vulcanologia." Pace, Boncio, and Lavecchia 240.

orientations, one called the Barrea fault oriented SSE and the Greco fault oriented E-W (Pace, Boncio, and Lavecchia 237). It is thought that older faults may become re-

activated causing further earthquakes accounting for the vast number of earthquakes in the region. (Pace, Boncio and Lavecchia 237). Pace, Boncio, and Lavecchia found that the faults in this region of the Apennines are of the Quaternary age (last 1.5 my), complex, and often controlled by differently oriented pre-existing structures.

Cultural Adaptation to the Rugged Landscape: The mountainous landscape of the Gran Sasso region has been home to Italians for centuries. Key roads such as Claudia Nova connected the Romans to the Adriatic coast through these mountains. One adaptation to living in the mountains since about the tenth century took the form of castle building (Continenza and Ruggieri 2). Castles were built in strategic places that afforded views of the surrounding country side and could protect people from danger. The structures were walled and fortified (Continenza and Ruggieri 2).

Another adaptation to living in the mountains was to farm in the valleys surrounding the higher hills. This required people to leave the villages and travel by paths to their farms, a strenuous activity but a necessary adaptation due to the rugged terrain. Certain farming techniques were practiced to avoid total devastation of crops due to weather that could then mean famine. I mentioned that mountains create severe weather. Extreme weather can occur at any time and can pose a great danger to crops. One way to minimize risk of crop failure was to plant in small units, with the farms placed at different altitudes, with different slopes and exposure. This had the added benefit of allowing for a greater variety of crops to be grown. This is a clever and wise farming technique adapted by the inhabitants of these mountains (Continenza and Ruggieri 3).

Sheep herding has been a long tradition in the Gran Sasso region. Campo Imperatore, the large valley at the feet of the Gran Sasso, provides an excellent grazing site not only because it is flatter terrain but for a geologic reason. There is a dominance of limestone in the valley, and the grass grown there takes up the calcium from the limestone. When the herds eat this grass they get very strong bones, and the cows produce more milk.

Quite by accident while browsing post cards at the Hotel Campo Imperatore located at the ski resort in Gran Sasso I discovered that it was in this hotel that Benito Mussolini was imprisoned from August 28 to September 12, 1943. He was dramatically rescued by German paratroopers who crashed gliders on the mountainside and landed on this high plateau. It was a daring and successful mission that resulted in taking Mussolini to Austria. The Italians at the time thought that the mountains of central Italy due to their extreme physiographic features are good places to hide such a famous prisoner.

Italy's Parks: Italy's national parks are not well known and I thought perhaps it would be useful to provide the official Italian parks web site. There are a total of twenty three listed on the website and they are scattered throughout Italy: http://www.parks.it/indice/NatParks.html.

Conclusion:

Examining the rocks Rome was built on we discovered that volcanic rocks occupy a major portion of the city's foundation. It is a small wonder considering the volcanic fields of the Sabatini and Alban Hills surrounding Rome. Indeed the famous Seven Hills of Rome were the "palette" of the Tiber River as it and its tributaries carved them out of

the tuff deposits from the volcanic fields. Arriving in Rome we visited several monuments that are examples of how well the Romans used the regional geologic material to suit the structures they built. There are many magnificent examples of travertine, tuff and basalt use in Rome. This material found abundantly in the region of Rome can be been in places like the Colisseum, the Forum and the Appian Way. The Romans even distinguished from the several varieties of tuffs and welded tuffs using the strongest for basement foundation rocks. Marbles were brought in from other regions of Italy. All this exemplifies mastery of stone masonry and keen knowledge of the physical and mechanical properties of the area's rocks. It is a story of the close bond between humans and their ties to the region's geology.

Leaving Rome we traveled through the rugged Abruzzo mountainous region to the tallest mountain in Italy, the Gran Sasso D'Italia. Reviewing the evolution of the region we saw how sediments in an ancient sea have been raised and slowly stacked up like books on a shelf over the last 60 million years to form the Gran Sasso. Earth processes operating very slowly but for millions of years caused tectonic plates to collide, to open oceans, and then to close them forming this mountainous and rugged part of Italy.

Post script:

I was saddened that on April 6, 2009 just days before I submitted this manuscript as though to underscore that the Apennines are indeed moving, a magnitude 6.3 earthquake struck the medieval town of L'Aquila (the eagle). The city is located at the foothills of the Gran Sasso region the very area I have covered here. Figure 3.32 is a United States Geological Survey (USGS) map of the quake. The USGS monitors

earthquakes worldwide through the USGS Earthquake Hazards Program. As I write this, the death toll is at 293, with 1500 injured and 40,000 people left homeless. Is there any question these mountains are restless?

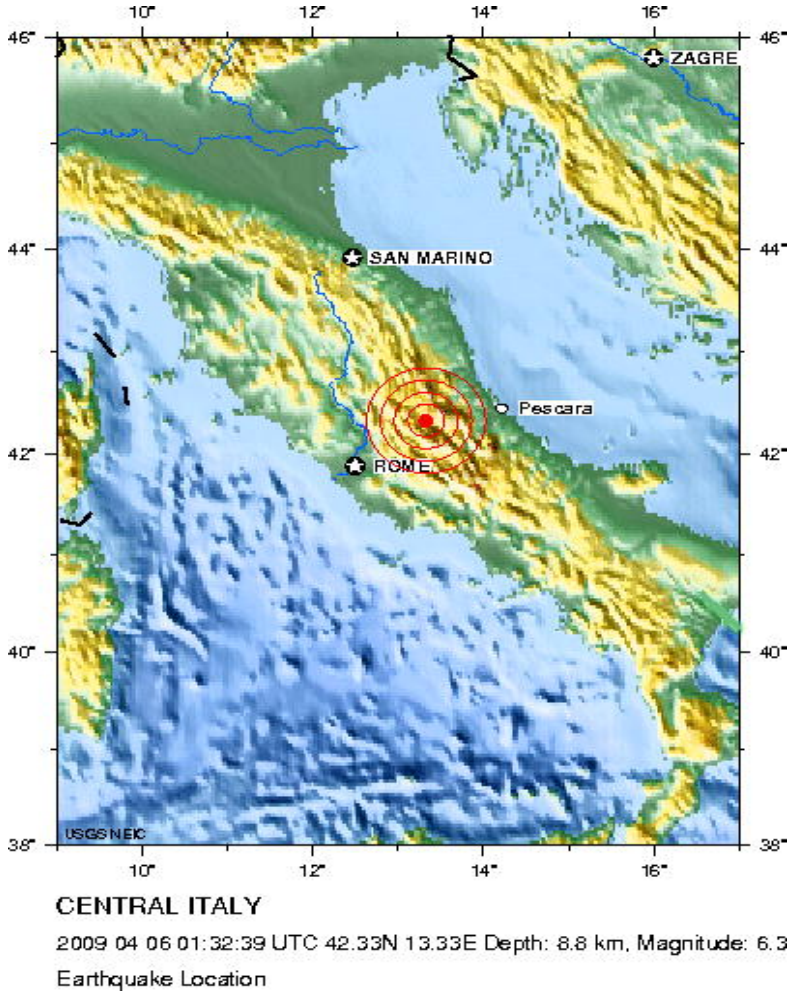


Fig. 3.32. "Earthquake Location in L'Aquila Italy." USGS Earthquake Hazards Program. 6 Apr. 2009. 6 Apr. 2009. <http://neic.usgs.gov/neis/eq_depot/2009/eq_090406_fcaf/neic_fcaf_l.html>.

CHAPTER 4: A SLICE ACROSS NORTH-CENTRAL ITALY
Orvieto, The Geologic History of the Alps and Apennines, The KT Boundary in Gubbio, Florence, Pisa and Larderello
The Regions of Tuscany, Umbria and Marche

Fig. 4.1. "Tuscany, Umbria and Marche Regions of Italy." Modified from Wikipedia, The Free Encyclopedia. 4 June 2009, 14:35. Wikimedia Foundation, Inc. 5 June 2009. <http://en.wikipedia.org/wiki/Italy>. Tuscany is blue, Umbria is green, Marche is pink, route is yellow.

We are now in what I call the north-central part of Italy that encompasses the regions of Tuscany, Umbria, and Marche pronounced "*Markay.*" It is a region of rolling hill topography that serves as a backdrop to the high Italian Alps. We will visit some of the most important geologic and cultural highlights of this region to understand how the

land has evolved and how humans have connected to their geologic roots. Leaving Rome we will begin our journey by travelling northward along the center of Italy to the hilltop town of Orvieto. Here I will tell the story of the formation of the region's hilltops that serve as "pedestals" for many cities in this region. Wine made in Orvieto is among the best in the world, and I will examine why it was advantageous to make it in caves beneath the city. Continuing northeast to Lake Trasimeno where Hannibal defeated the Romans in 217 BC I will explain the lake's origin. The geologic history of Trasimeno will reveal that unlike the Roman lakes it is not of volcanic origin.

The discussion about the geologic history of the northern Apennine Mountains is similar to that of the central Apennines I discussed in chapter three because they are part of the same mountain belt. In this section I will include a more comprehensive evolution of the Apennines starting around the Mesozoic Era (about 144 my). The evolution of the Alps involved some of the same processes as the evolution of the Apennines; therefore, I will discuss the history of the Alps as well. The Medieval city of Gubbio, nestled in the region's Apennines, will serve as the focal point to talk about a theory of how the dinosaurs disappeared. The rocks of Gubbio (Scaglia rossa) hold the evidence for this theory. Changing direction we will then head westward to the city of Florence.

Florence was the birthplace of the Renaissance and holds many examples of art from that period. Florence's Cathedral (Duomo) is the Basilica di Santa Maria del Fiore (Saint Maria of the flower). The exterior stonework represents harmony between design and color. It is done in the pleasing colors of green, white, and pink rocks from the region. The Cathedral's building materials serve as an example of the direct connection

of the people to the local geology. Likewise, Michelangelo's masterpiece "David" is made of Carrara marble, the purest white marble available. It is quarried from the Carrara Mountains close by. The purity of Carrara Marble has a direct connection to the deformation events that have shaped the Alpi Apuane Mountains (part of the Northern Apennines). Leaving the city of Florence we will travel westward to the town of Pisa where we'll discover why the famous Leaning Tower of Pisa is leaning. Our journey will end just south of Pisa in the town of Larderello where I will discuss the oldest site in the world where geothermal energy is used to produce electricity.

Northward to Orvieto.

It was a very hot summer day in August of 2005 when I arrived in Orvieto. I was exploring Tuscany. From several kilometers away, I could see Orvieto raised 40-70 m (131-230 ft) above the surrounding valley as though set on a pedestal (fig. 4.2) (Cencetti, Conversini, and Tacconi 107). Orvieto is about 1500 m long (4900 ft) and about 700 m (2300 ft) wide (Cencetti, Conversini, and Tacconi 107). It turns out that formation of the city's pedestal has to do with the region's geologic events. It is typical to have hilltop

Fig. 4.2. "City of Orvieto." Orvieto on Line. 27 Apr. 2009. <http://orvietoonline.com/catalogo.php?ling=E&regione=Umbria&id_loc>.

Fig. 4.3. “Orvieto Cliff.” Baranov, N. Brodyaga.com. 27 Apr. 2009. <http://www.brodyaga.com/pages/viewlarge.php?id=1614&cty=Orvieto&place=Italy%20Umbria>.

cities in this area of Italy. There is often a wall surrounding them that gives them the look of a perched walled fortress. It reminded me a little of the mesas (nearly level isolated landmasses) I have seen in Arizona but with towns on top. I am certain the high vantage point had a great advantage to protect the towns’ people during the various wars that have taken place in the region (fig. 4.3).

To get to the top of the mesa where the city of Orvieto is located, one can take the funicular (a cable railway) to the city center or one can drive the winding road around the mesa to the top (fig. 4.3). The question is how did the landscape evolve to form this high mesa for the city of Orvieto? In this case, geologists are lucky because the rocks of Orvieto’s foundation are exposed all around the city’s base. Let us start then by examining the rocks beneath Orvieto to see what they tell us. Figure 4.4 is a geological

schematic section of the Orvieto Rock. It is very much like a stratigraphic column except it is drawn like a cross section of the city designating the type of rocks. This makes it

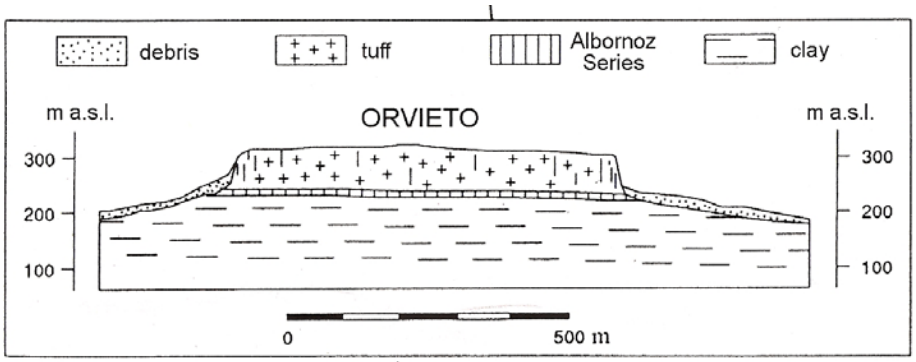


Fig. 4.4. "Geological Schematic of the Orvieto Cliff." Cencetti, Conversini, and Tacconi 106.

easier to visualize the rocks in relation to the city. It will serve as a guide to identify the order of the rocks and by extension the geologic events that made them. As we look at each of the rock units, I will interpret their paleoenvironments and explain the processes involved in forming them. In this manner, we will slowly undo the layers of Earth's events to see exactly how the rocks of Orvieto formed and how Orvieto wound up perched on the mesa. We are off on a mission to reconstruct the geologic history of the region.

The geological schematic in figure 4.4 identifies four rock types. The bottom layer is clay. It constitutes the entire base and the largest part of the stratigraphic sequence. The clay dates to the Middle Pliocene (about 3 my). It is described as marly clay (a mixture of limestone and clay) with relatively high percentage of $CaCO_3$ (calcium carbonate) (Cencetti, Conversini, and Tacconi 105). This means they were formed in a

marine environment. That paleoenvironment was close enough to the shore to have received clay from the land such as from rivers bringing it and depositing it in their deltas. Refer to chapter three, figure 3.4 to review if necessary. You can see from the geological schematic of figure 3.4 that the thickness of these clays is over 100 m (328 ft). This represents a thick sequence of clays. A similar geologic setting and deposition was occurring in the region of Rome south of Orvieto.

The clays are followed by the Albornoz Series (Cencetti, Conversini, and Tacconi 105). This series dates to the Lower Pleistocene (about 1.5 my) and is only about 15 m (49 ft) thick (Cencetti, Conversini, and Tacconi 105). Corrado Cencetti describes the series as fluvial-lacustrine in origin, which means they were deposited in rivers and lakes. From the bottom up the Albornoz Series (fig. 4.4) is composed of: sandy conglomerates (river deposits) containing blocks of basaltic lava; a layer of silts and pumice cinders (these are river and volcanic deposits); then a layer of white limestone containing diatoms and fresh water fossils (indicate a lake environment). This is followed by some pumice cinders (volcanic); and a final layer of pumice clasts with ash that marks the transition into the large tuff deposit (volcanic) (Cencetti, Conversini, and Tacconi 105). Once again an analogy is appropriate to the Roman region during the same period. It too has the same type of volcanoes.

The paleoenvironments of the Orvieto region have changed quite a bit in the last 3 million years. First there was a shallow warm sea that covered the region and received river deposits to an environment where the sea receded and was gone by about (1.5 my) (Cencetti, Conversini, and Tacconi 104). We will see evidence of this sea again at our

next stop in Lake Trasimeno. After the sea was gone, lakes and rivers deposited their sediments while volcanoes were also depositing basalt. The volcanoes are associated with the extension front that was migrating from west to east across Italy and has been ongoing since 5 my. The same extensional front left behind a normal fault near Orvieto that will play a key role a little later in geologic time. This region was then dominated by volcanoes (the magmatic activity of the Vulsin Apparatus) depositing ash and forming the massive tuffaceous plateau (Alfina Plateau). There has been quite a lot of change in a small region over a short period of time!

The deposits I have described are the rocks upon which Orvieto is built. However, at this point in the story we have left the landscape as a massive volcanic plateau, not isolated buttes and mesas like it is today. Something else must have occurred to erode the landscape and leave the isolated erosional remnants like the one Orvieto is built on. Cencetti, Conversini, and Tacconi attribute the dismemberment of the large tuffaceous plateau to the Paglia River an important tributary to the Tiber (105). We know that the Paglia that currently flows at the foot of the Orvieto mesa cut its bed along the

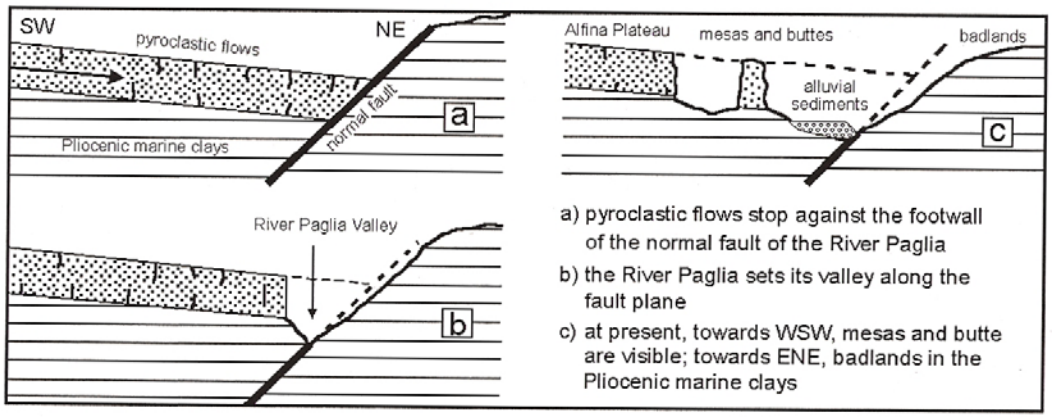


Fig. 4.5. "Schematic Evolution of Orvieto During the Quaternary." Cencetti, Conversini, and Tacconi 105.

displacement of the normal fault (fig. 4.5a). It turns out that the river is the key to forming Orvieto's isolated setting on the eroded mesa of tuff.

Geologists have identified the normal fault. The upthrown block of the fault acted like a dam for the pyroclastic flows (fig. 4.5b) (Cencetti, Conversini, and Tacconi 105). Then along came the Paglia River and eroded some of the plateau leaving the mesas and buttes (Cencetti, Conversini, and Tacconi 105) (fig. 4.5c). We have evidence for this because the river left behind the sediments we see today. Isn't it interesting the way geologists "read" the rocks that stand as evidence of past events? It is my hope in writing this work that you will view rocks in a totally different way realizing they hold the keys to Earth's past and that they have an important story to tell. This is a story that can help us understand our current world.

If you have read chapter two on central Italy you will realize that Orvieto's story is very similar to the events that shaped the Roman region during the last 5 million years. We had parallel processes operating in these two regions. Rome was also built on a volcanic plateau (a different one than Orvieto) but nevertheless a tuffaceous plateau. And just like in Orvieto a major river (the Tiber and its tributaries) carved the plateau into the mesas and buttes of this region. The Tiber and its tributaries chiseled the famous Seven Hills of Rome in the same way the Paglia River chiseled the mesa that Orvieto was built on. It is amazing to think that grain-by-grain rivers can make such dramatic change in the landscape!

Orvieto is very unstable and has been plagued for centuries by landslides particularly at its SSE flanks (Cencetti, Conversini, and Tacconi 108). There are several

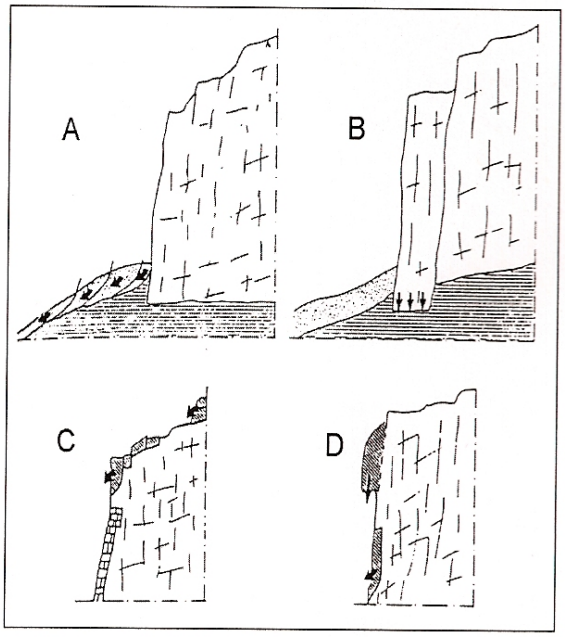


Fig. 4.6. “Mechanisms of Instability of Orvieto Rock.” Cencetti, Conversini, and Tacconi 108.

types of landslide movements along the hill and pedestal rock of Orvieto depending on the rocks present. For example along the base (fig. 4.6A) the landslides involve detritus (loose rocks removed mechanically from the slope). The detrital landslides generally become mobile as a response to becoming saturated by heavy rains. Another form of landslides is fracturing of the rocks along the base and causing toppling (fig. 4.6C). Other mechanisms of failure along the perimeter of the tuff are caused by fracturing of the tuff mass. The fractures on the walls of the tuff are evident as you drive past them up to the city.

The largest cause of the landslides is the fact that Orvieto sits on a large base of clay that is highly erodible, and Orvieto is sinking (Cencetti, Conversini, and Tacconi

103). In other words the base of the city is not made of stable material. If it was tuff it would be much more stable because tuff resists weathering more than clay. Another factor that has not helped the city's stability is the removal of tuff by humans for use as building materials especially carving out the huge underground city (Cencetti, Conversini, and Tacconi 108).

In response to these landslide issues, stabilization laws have been enacted. Major works to stabilize the city have been ongoing since the 1970's. The entire drainage system of the city has been rebuilt, and gullies have been diked to reduce erosion. The slopes have also been reinforced by planting trees and building support structures into the hillsides (fig. 4.7). The edge of the rock around the city was also reshaped by building walls. These works are monitored for movement by numerous sensors attached to the rock walls.

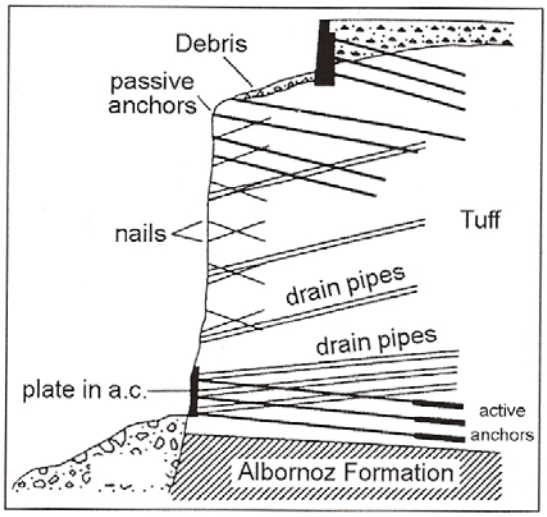


Fig. 4.7. "Strengthening Scheme of Orvieto Rock." Cencetti, Conversini, and Tacconi 109.

Orvieto's Duomo, the Underground City and Cultural Links to Geology.

Let us turn our attention now to some of the connections linking man and the geologic environment in the city of Orvieto. After I arrived in Orvieto and checked into a hotel it was time to visit the city's Cathedral, the Duomo of Orvieto. Construction on the Duomo began in AD 1290 and like most cathedrals of its era continued for several hundred years. It is another imposing Romanesque to Gothic style cathedral leaving no doubt in the visitor's mind about what is the most important structure of the city (fig. 4.8).

Fig. 4.8. "Orvieto Cathedral." Personal photograph by author. 17 Jan. 2008.

Being a geologist I immediately focused my attention on the building rocks of the Duomo. One can learn a lot about the local geology by looking at building materials assuming they are quarried from local sources. The outside facade of the Duomo is richly decorated with colorful mosaics, marble reliefs, and black and white stripes. The

Fig. 4.9. “Orvieto Cathedral Stained Glass-Travertine Window.” Personal photograph by author. 17 Jan. 2008.

Fig. 4.10. “Close Up of Orvieto’s Travertine Window.” Personal photograph by author. 17 Jan. 2008.

black stripes are basalt, the black-greenish rock is volcanic rock, and the white material is travertine. Inside the Duomo the columns along the sides and the walls of the nave also repeat the black and white striped theme giving the cathedral a rather austere feel (fig.

4.9). To me one of the most interesting parts of the Duomo's interior is the windows along the nave wall. They are decorated half with stained glass images and half with travertine (the same sedimentary rock we found on the exterior of the Colosseum). By cutting the travertine into very thin slices it allows light to pass through it giving the travertine the effect of stained glass (fig. 4.10). The light coming through the travertine has a soft glow of translucence in golden sunset hues. It is very soothing light for the eyes.

The time I first saw the Orvieto Cathedral I knew very little about Italian geology. However, as I contemplated the Duomo's building rocks I thought that perhaps they are of local origin. It made me eager with anticipation to learn more about the geology of this region. I wondered about the origin of the basalt as I thought that there must have been volcanoes nearby to produce it. I was guessing that in all likelihood the basalt was locally quarried due to the logistics of bringing building material from far away places and particularly to a place so elevated from the surrounding landscape. This theory turned out to be correct. Geologists think of the Earth in different terms, and it is not unusual for us to wonder about such things when we find ourselves in unfamiliar areas. Discovering what has transpired geologically gives a geologist an entirely new dimension to an area.

My second day in Orvieto was rainy so it was the perfect time to investigate the city's rocks by taking a tour of the underground city (Città sotterranea). You can inquire about this tour at the tourist information office across from the Duomo. There exists an entire underground city below Orvieto. It was very exciting because for a geologist there

is nothing like being able to see rocks up close. Yet time did not allow searching for outcrops and I did not have enough background to know how the rocks that I might identify fit into the regional geology. Thus the underground tour proved a great way to see close up rocks that I knew make up the city's foundation.

As we began our tour, the guide led me along a narrow path that follows the city's outer wall. She began the story of the underground city's history. As we entered the iron gate leading to the underground we passed small narrow window like openings carved into the rock from where I could see the valley landscape below. You can see quite a distance out over the lovely rolling hill countryside with orchards and farmhouses. I was sure similar windows were used by the ancient people of Orvieto (the Etruscans) to survey the countryside for approaching enemies.

We made our way from room to room and I noted that it was all dug from volcanic tuff, the same building material I described in the region of Rome (chapter three). Examining the rock up close I could see bits of dark glass and ash imbedded into the tuff unmistakably identifying it as volcanic rock. The underground has been used to make and store wine for centuries. The caves stay at a constant 53-55º F year round making it an ideal place to preserve the qualities of the town's world known Orvieto Classico wine as well as protecting the workers from the elements.

Grapes for the Orvieto Classico are grown in the surrounding hills of Orvieto up to 500 m (1600 ft) high. The soils are a mix of clay, sand, and limestone over volcanic tuff and are ideal for the varieties of grape used to make Orvieto Classico; Trebbiano Toscano, Verdello, Grechetto, and Canaiolo Bianco (Bastianich and Lynch 433). The

true Mediterranean climate of the region protected by the Apennine Mountains is another factor for the grapes' success. You can see how geology has given us the landscape, the soils and to some degree the climate for the Orvieto Classico wine.

Orvieto's underground extends below most of the city though only a small portion has been excavated and was part of the tour. Most of the houses in Orvieto have an underground portion often used to store the family's wine. At times of war, most recently WWII, Orvieto's citizens used the underground as a place to hide. It has also been used as a protected place to press olive oil and grind wheat. At other times the underground has been used as a space to raise rock pigeons in small pigeon-size holes (still in place) carved into the tuff that the birds used as their homes (fig. 4.11). The pigeons were used for food.

Fig. 4.11. "Pigeon Holes in Orvieto Underground." Personal photograph by author. 17 Jan. 2009.

After my underground journey it was time to find dinner. It turned out to be one of my most favorite dinners in Italy. The small restaurant in one of the narrow alley streets of Orvieto was nearly empty but the smell when I entered told me I should stay. The way pizza is made varies throughout Italy. In Orvieto the crust is very thin, light and crispy like a wafer. It was served brushed with olive oil, and topped with truffles (mushrooms). White truffles are very flavorful and prized for culinary use. They grow exclusively in association with the roots of oak trees (ectomycorrhizal) in the nearby area of San Miniato. The fungi connect to the oak's roots and actually facilitate the trees' uptake of nutrients. In this region the oak trees grow because of the sweet limestone soils and the dry weather required for their success. It will not forget my meal of white pizza topped with truffles and accompanied by a glass of chilled Orvieto Classico wine, especially refreshing on that hot August day.

Northward to Lago Trasimeno.

We take A1/E35 the Autostrada (Italian highway) to our next stop at Lago Trasimeno (Lake Trasimeno) (fig. 4.12). I had the joy of spending a day in Lake Trasimeno on another beautiful sunny day in July 2005. The lake is quite large covering approximately 120^2 km (about 46^2 mi). We saw in chapter three that the satellite image of Italy (fig. 3.6) clearly shows several volcanic calderas near Rome that are now lakes. Is Lake Trasimeno another collapsed volcanic caldera? I certainly did not know at the time but I would have guessed that it is from its round shape. However, geologists say it is not. The rocks in the lake sediments will tell a different story.

Fig. 4.12. "Aerial View of Lago Trasimeno." Provincia di Perugia. 27 Apr. 2009. <http://www2.provincia.perugia.it/Guide-tema/Ambiente-e/Il-lago-tr/Interventi/index.htm>.

The lake's geologic history began in the late Miocene (about 6.7 my) (Barchi et al. 54). During that time the Apennines' compressional phase was ending. Where the lake is now located stood a set of mountains that faced WSW. Following the compression the landscape changed dramatically because the set of mountains were eroded when sea level dropped during a period known as the Messinian Salinity Crisis. This was a time about 6.7 my when the Mediterranean Ocean actually dried up! This sounds dramatic enough, but let us imagine it for a moment standing on the western shores of Italy and looking into a vast empty basin perhaps 4-5 km (almost 3 mi) deep! I wonder what we would see. Would it look a little like the Death Valley basin in southern California? Certainly some portions of Death Valley today lie well below sea level but of course the empty Mediterranean would have been much deeper. I think it would have

resembled what must have looked like a landscape perhaps more appropriate for the Moon rather than Earth.

About 1 – 2 million years after the Messinian Salinity Crisis, a time called the Early Pliocene (about 5 my), a large basin was formed along the western portion of this region (the Valdichiana) due to extensional processes associated with the opening of the Tyrrhenian Sea. This time Earth's crust rather than being compressed was being pulled apart and in so doing it formed normal faults and the Valdichiana Basin. The extreme sea level drop of the Messinian Salinity Crisis induced high levels of erosion from the surrounding mountains. The basin was filled with sediments from the adjacent mountains, and it deepened and subsided meaning it sank into the crust because it was laden with the accumulation of heavy sediments. It is not unusual for an area on Earth laden with sediments to sink to some degree. Today this is happening in various parts around the world along mountain belts and particularly at river deltas where a lot of sediment is unloaded. In the United States the Mississippi River's delta is subsiding in a similar fashion due to overloading of sediments carried there by the river.

Geologists have conducted seismic studies of Lake Trasimeno by bouncing sound waves into the lake bottom to "see" the rocks that lie beneath the lakebed. This produces seismic profiles (images of the subsurface). The images can give them a sense of the region's history as it is recorded in the sediments. Geologists have other ways of finding out what kind of rocks and sediments are beneath a lake. They could have drilled down, bringing up actual sediment core which would then be analyzed to determine the kinds of

sediments, fossils etc. beneath the lake's bottom. The seismic profile has given geologists sufficient information to reconstruct the lake's past.

There is an indication that beneath the lake bottom is a set of marine sediments (Barchi et al. 54). These sediments are interpreted to mean that at some point a sea rested over the area. Barchi and his colleagues concluded that about 3 my the Tyrrhenian Sea actually encroached into the Valdichiana basin from the west causing the region to look more or less like a gulf with higher areas protruding as islands (54). We know this because Lake Trasimeno is a fresh water lake today yet there are marine sediments beneath the lake. The basin was controlled by the activity of a normal fault on its western boundary that was oriented towards the east (which geologists call east dipping) (Barchi et al. 54).

We now move forward in time another few million years to the Early Pleistocene (about 1.6 my). The next sequence on the seismic profiles is interpreted to be fluvial sediments (from rivers) and they consist of sands and gravels. During this time the Tyrrhenian Sea had retreated and no longer occupied this area. The region became a wide river valley that received a succession of sands and gravel deposits from a paleoriver. The subsiding region was now controlled by another fault this time on its western margin oriented towards the west (west dipping). In the final phase of development since the Late Pleistocene (about 10,000 years) the area was characterized by lake deposits. Today Lake Trasimeno is a fresh water lake that is not fed by any rivers and its water level fluctuates with the seasons.

Lake Trasimeno is also historically important because during the Second Punic War in 217 BC a battle was fought on the lake's shores between the Carthaginians under Hannibal, who controlled the western Mediterranean and the Romans under Gaius Flaminius, who had interests in areas controlled by the Carthaginians. Hannibal became a legend in this area because he attacked after entering Italy from the north and crossing the Northwestern Alps into Turin during the winter with some elephants. Most of his elephants did not survive but Hannibal still defeated the Romans. Hannibal chose a hilly forested area on the shores of Lake Trasimeno because it was very suitable for an ambush while cutting off the Roman retreat route. This is an example when the landscape can be useful to gain military advantage.

The Evolution of the Alps and Northern Apennines and the Extinction of the Dinosaurs in Gubbio.

Travelling eastward less than an hour from Lake Trasimeno we arrive in one of the best examples of a medieval town in Italy, the city of Gubbio. It is situated among central Italy's northern Apennine Mountains. We covered some of the recent geologic events that shaped the Orvieto mesa and Lake Trasimeno. Here in Gubbio I will provide a complete geologic history of the Apennines. To do that I will first describe the origin of the Alps since the two orogenies (mountain building events) are related. I chose Gubbio because it contains rocks (the so-called KT boundary) that provide evidence for a major theory about how the dinosaurs disappeared from the Earth. The rocks of the KT boundary are also part of the Apennine's geologic history. You can visit the rocks of the KT boundary following the directions I have listed at the end of this section.

Let us pick up the story by first describing the evolution of the Alps. We will go back to the time when the rocks of the KT boundary were deposited. There was a long

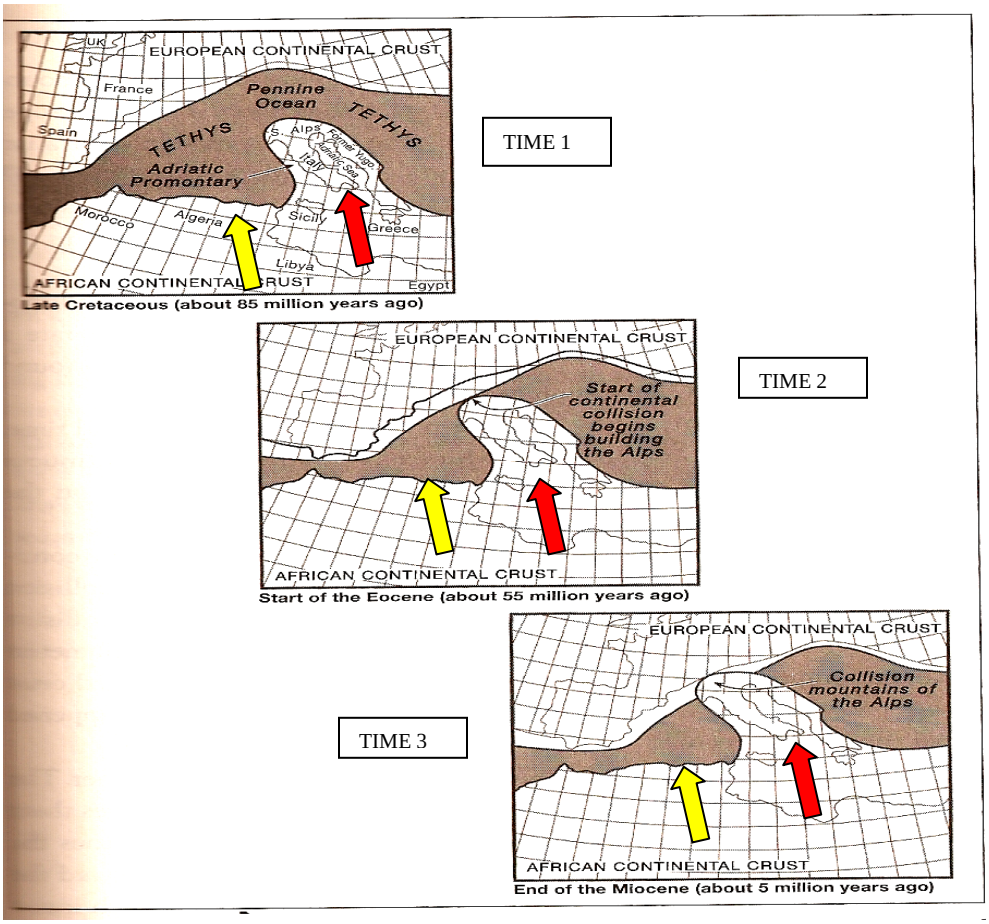


Fig. 4.13 "Adria and the Adriatic Promontory Converging Northward Towards Europe." Modified from Alvarez, 165. Yellow arrow points to direction of plate movement, red arrow points to Italy.

period of deposition that had begun about 200 my but I will start the discussion about 144 my. I mentioned before that the landscape during this time was something like the Bahama Banks (the submerged carbonate platforms that makes up the Bahama archipelago). Italy was a promontory (like a finger); part of the African crust extended

towards Europe, and was receiving sediment (fig. 4.13). So yes, Italy even today is on the African crust! At this time, there was Africa in the south, with the African promontory of Italy pointing northward, the Tethys in the middle, and the European continent to the north. This is how the continents were situated before the deformation that produced the Alps and the Apennines.

Little by little, the remnants of dead marine organisms settled on the ocean floor for millions of years of this deposition. The result was deposition of sediment sequences from the near shore limestones to deep water marls (clay mixed with limestone). All these sediments including the KT rocks were uplifted by tectonic processes to become the northern Apennine Mountains. Figure 4.14 indicates these rocks in the Botaccione Gorge located behind Gubbio where the KT boundary exists.

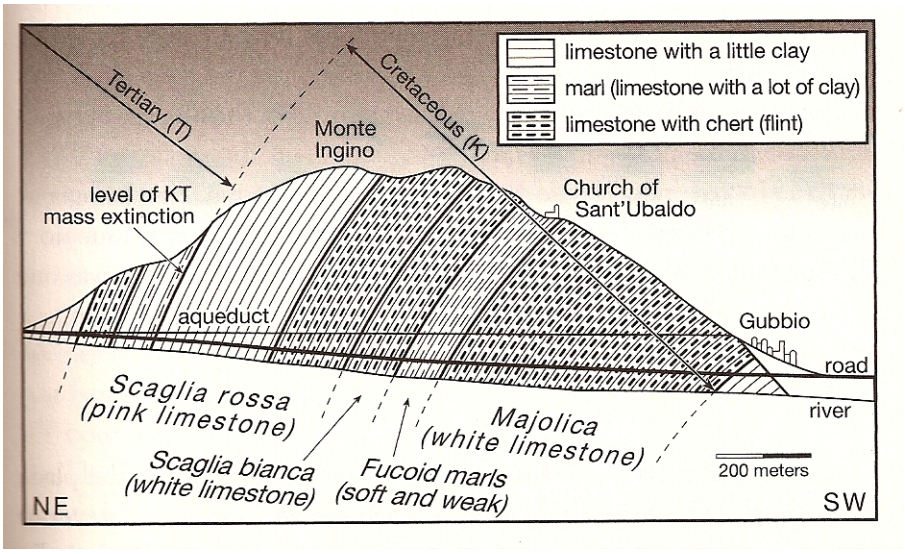


Fig. 4.14. "The South Side of the Bottaccione Gorge." Alvarez 103.

While all this sedimentation is ongoing the Tethys Ocean is closing and dragging with it two huge landmasses. On the south is Africa, to the north is Europe, and between them is the Pennine Ocean (a part of the Tethys Ocean) as seen in figure 4.13. The European continent was the part of the plate that was being subducted in the Tethyan oceanic closure. The two continents eventually collide closing the Pennine Ocean completely. Continental-continental compression continues until the present causing great deformation along the leading edges of the two continents while building the Alps. Continued compression causes the rocks to get uplifted in a massive pile up. They are raised higher and higher as they became more compressed and deformed.

George Alvarez, one of the world's leading geologists and a professor of geology at the University of California, Berkley, spent most of his life studying Italian rocks. Often collaborating with Italian geologists, he has conducted extensive research in central Italy including Rome's Forum and the rocks of Gubbio. Alvarez (greatly simplifying the geology of the Alps) describes them as a geological sandwich, where the lower slice of bread is made of the continental crust of Europe including its sedimentary cover (163). The upper slice of bread is the continental crust of Italy that is called Adria (the African promontory) together with the sediments it had received during the long period of sedimentation. The filling of the sandwich is described by Alvarez as the smeared and deformed remnants of the Pennine Ocean. In this analogy Italy was in effect driven over the European continent since the European plate was the one being subducted. This caused the rocks of the Pennine ocean to get scraped off the subducted oceanic crust and get caught in between the two continents (these detached parts of oceanic crust are called

ophiolites) (Alvarez 163). This is how the Alps were formed, and compression continues even today which means they are continuing to get higher.

Now it is time to build up the Apennines. During the Middle to late Miocene (about 10-15 my) a period of compression started in the west coast of Italy pushing the sediments (laid down during the Cretaceous) eastward. Tectonic forces of compression from the west raised the Apennines higher and higher out of those shallow seas trending them in a NE/SW direction. The Apennines in this part of Italy formed as a series of anticlines or folds containing packages of sediments that are like huge arches (recall the stacked books analogy I have used before). This is how the rocks near Gubbio wound up on their side in figure 4.14. The Apennine folds can be seen in high relief maps of Italy and continue in a northeast pattern all the way to the Adriatic Sea where some are actually beneath the waters of the Adriatic.

The folds push against each other forming thrust faults that move the mountains eastward, and geologists can document many of these in the Apennines. It is remarkable to think that rocks fold and move many kilometers as packages along these thrust faults but they do. It is possible because certain rocks that contain a high percentage of clay (Fucoid marls) are easily erodible while the rocks above and below do not contain clay so they are much less erodible. This allows the less erodible limestones to detach and move across the clay rich limestones (marls) below (Alvarez 141). The Fucoid marls act like the grease allowing the mountains units to slide along the thrust faults. I am thankful for this folding because if it had not happened, Italy would not have mountains and I cannot imagine the loss of such beautiful landscapes.

A different motion beneath the Apennines began during the Oligocene (35 my) and is actually causing all the anticlinal folds I described to migrate as a unit northeastward! Imagine now that not only are the Apennines growing upward and folding but they are also sliding northeastward as a unit since the middle Miocene (about 14 my) (Cantini et al. 26). Geologists call this the propagating thrust array. This movement of the Apennines is something like a stack of leaning books on a moving conveyor belt. If you are wondering like me what is driving this migration of mountains, geologists have a theory based on analysis of the igneous rocks from the Tuscan region. It is thought that a portion of the lower continental crust below Italy is actually broken off (delaminated) and is sinking into the mantle. As it sinks it is driving the continental movement. Alvarez makes the point that the thrust ramps below the Apennines actually involve the continental crust (Alvarez 196). This means the Apennines are not just a superficial belt of mountains but have deeper roots that involve the continental crust (Alvarez 197).

We are still not at the end of the Apennine evolution story because yet another movement began about 5 my that is actually tearing the Apennines down (Cantini et al. 26). This time the movement is extensional or pulling apart the Earth's crust beneath the Apennines forming normal faults. As I mentioned in chapter three extension is still occurring in the Apennines today. The resultant normal faults in effect create a low area for the taller slopes of the basin to erode into. In fact, the normal faults are what give Tuscany its characteristic rolling hill landscape (Alvarez 207). I am sure you never

considered that the idyllic setting of this much sought after area of Tuscany is because Tuscany has faults!

Gubbio and the KT Boundary. Now let us go to Gubbio and to the Cretaceous/Tertiary (KT) boundary to learn about the theory of how the dinosaurs disappeared. KT stands for the abbreviation of the periods Cretaceous (about 144-65 my) and Tertiary (about 65-0 my) in the geologic time scale chapter one (fig. 1.1). When we say boundary we mean the rocks are simply deposited one on top of the other. In this case the Cretaceous rocks are below the younger Tertiary rocks. The KT boundary is a boundary between sedimentary layers of rocks. The boundary is also found in other places of the world but for us it is conveniently exposed in Gubbio, Italy. The theory says that a catastrophic worldwide event occurred that caused the dinosaurs to die about 65 my (Alvarez 105). This event is recorded in the sediments of the KT boundary because the boundary marks the end of many fossils including the dinosaurs that do not reappear again in the geologic record.

Have you ever wondered why there are no dinosaurs living today? The theory for their disappearance was developed by George Alvarez in 1980 while studying these rocks in Gubbio. Alvarez and his colleagues were studying the Scaglia rossa, a very pure limestone deposited in the early Cretaceous (about 144 my). During the 1970's micropaleontologists (geologists that study microscopic fossils) were using micro fossils to date the rocks that contain these fossils. Foraminifera (forams) are a particular micro fossil (barely visible to the naked eye) very useful in this process because each species existed only during certain periods of geologic time. Therefore, the forams served as

markers for certain geologic time markers. It had been noted by micropaleontologists that a genus of foram called *Globotruncana* completely disappeared or went extinct in a certain section of the Scaglia rossa never to reappear.

This mass extinction that occurred 65 my is defined as the end of the Cretaceous Period. Alvarez found this boundary at 347.6 m (about 1140 ft) of the Scaglia rossa limestone where *Globotruncana* suddenly disappeared. Until this time geologists thought the KT mass extinction had occurred over a long period of geologic time (Alvarez 106). However, in Gubbio Alvarez found that the extinction of the *Globotruncana* was recorded only in a little bed of clay half of an inch thick (Alvarez 106). This discovery meant that the mass extinction had occurred very quickly.

The next step in the development of the dinosaur extinction theory was that Alvarez's team found high concentrations of iridium in the thin clay bed of the Scaglia rossa (same bed) as where the *Globotruncana* disappeared. Iridium it turns out is very rare on Earth but exists in very high concentrations in asteroids and comets. This suggested that a comet or asteroid may have hit Earth producing a large dust cloud that obscured the sun causing the plants to die and by extension the creatures that depended on those plants for food also died (Alvarez 106). The presence of the iridium was a key that led George Alvarez and his research partners to arrive at the hypothesis that a giant impact had caused the KT extinction not only of the *Globotruncana* but also of the dinosaurs as well as many other types of animals. Imagine how large this body must have been to cause dust clouds over vast sections of the Earth for a prolonged period of time!

One more piece of information remained unsolved at the time amidst the controversy surrounding this new theory. Where was the impact crater? Ten years later a large crater was discovered called the Chicxulub in Mexico's Yucatan peninsula. It is the supposed impact site for this catastrophic event. The crater is close in size to the one approximated by Alvarez's group and dates to the exact time as the mass extinction in the KT boundary. Many geologists and paleontologists agree with Alvarez's theory but not all. There are other theories about why and how the dinosaurs disappeared. As for myself, I would not be certain which side to support until I did further research on the topic. However, I will say that I am glad that dinosaurs are not on Earth because I fear that if they had survived perhaps humans would not inhabit the Earth.

The KT boundary is located near the city of Gubbio. Here are directions to the cite starting in Gubbio and an image (fig. 4.15) of the site both provided by my colleague Jim Coleman.

1) From the intersection of Via Leonardo da Vinci and Viale Paruccini (near the Roman amphitheatre), go north on Viale Paruccini 0.31 mi to the intersection with Viale Teatro Romano; turn left (NW).
2) Drive approx. 0.1 mi to the Largo della Pentapoli; turn right (NE) onto Via Fosso
3) Continue NE on Via Fosso and then Via Giove Pennino (a.k.a, Strada statale Eugubina) (SS 298) towards Fornacette.
4) Near where the old aqueduct (on the east) comes "down" to the climbing road, on the right, there is a gravel pull-out and a marker (approx. 43°21'55.63"N, 12°34'57.40"E). The pullout is protected from the road by concrete barriers and leaving the pullout can be pretty scary as you have little or no acceleration room and a couple of semi-blind curves on either side. Fortunately, the traffic, though fast, is not too busy to eventually allow you to pull back on to the road safely.

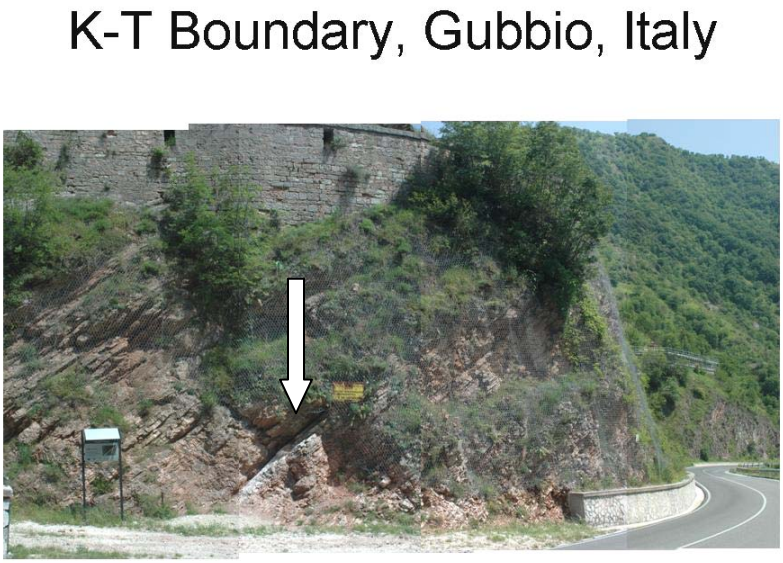


Fig. 4.15. "KT Boundary and Scaglia rossa Limestone, Gubbio." Modified from photograph by James L. Coleman. 26 June 2008. Courtesy of James L. Coleman.

You could also go to the city of Gubbio and ask around for directions to the site. It is close by. I have found Italians almost without exception very willing to direct me. Surely someone in the main piazza will know and will tell you. Don't be shy to ask. The best place might be a coffee bar where you can also enjoy a cappuccino before you embark on your short journey. The site has been visited by many geologists and scientists since 1980. It would be interesting to have a (sort of) log posted at the site with entries from the scientists who visit for the public to see.

Onward to Florence: Birth Place of the Renaissance.

We have certainly been through a lot of geologic discovery in the last section seeing how both the Alps and the Apennines were formed. This gave us a context for the

Fig. 4.16. "Tuscan Hillside." Tuscany-Italy.co.uk. 16 Jan. 2009. <http://www.tuscany-italy.co.uk/images/tuscany_panorama2.jpg>.

geology of this region. In Florence, the capital of Tuscany, a short distance northwest from Gubbio we will encounter some examples of the Florentines' close link to their geologic heritage. This region of Tuscany is well known among those who idealize a vacation in Italy of a villa nestled among rolling hills that seem to be dotted with those tall and straight cypress trees. To me the trees resemble soldiers lined up to defend their hills. Images like figure 4.16 have made Tuscany among the most coveted place to buy real estate in Europe both for Italians and for foreigners wishing to live in an idyllic setting. After our last section, you now know that these hills are not so idyllic because indeed they have many faults!

It brings me great gratification to know that the reader will understand what I mean by faults and will know that these Tuscan hills are there for a reason and perhaps understand a little more about the geologic events that have shaped this part of Italy. When they look at the Apennines they will know that these are not static mountains but

that they have travelled great distances and great heights to be where they are. I also hope it enhances your experience of the Italian countryside. It is intended to make you think of Italy in a very different way as you look at the landscape and everything from the cathedrals to the Apennine Mountains.

The Arno River. Like Rome's Tiber River, Florence has an important river running through it called the Arno. It empties into the Ligurian Sea. The Tiber follows a fault system in part because cracks in the Earth provide an easier path for the water to travel. This is also the case with the Arno River. Geologists have compared the rivers of Italy that drain to the west coast versus those that drain to the east coast (Alvarez 209). They noticed that those rivers draining towards the west coast of Italy in the Tyrrhenian are long and winding appearing to take the longer route to the sea, while the ones that drain to the east in the Adriatic are shorter and straighter (Alvarez 209). The reason for these differences is in the extensional regime and corresponding faults that has been taking place in the Apennines.

Extension forms the normal faults, and the Arno follows the down-dropped blocks to the sea. To help us understand this concept let us do an experiment. You will need two small pieces of wood and a quarter cup of pancake syrup. Start with two blocks of wood about the size of a brick (maybe 2"D x 7"L x 5"W). Set one block on a table standing on its narrow (2") end. Incline the piece about 30º and pour just a little pancake syrup from the top of the wood down the plain facing you. The syrup should take a straight path down the face of the wood. This is analogous to the rivers on the east coast of Italy following a straight path of the sea. Now we will create a normal fault by taking

the other piece of wood and leaning it against the inclined piece to create a sort of step effect. This time when you pour the syrup down the plane of the first piece of wood the syrup will not go straight but will drop to the lower step and follow the lower block of wood traveling horizontally on its way down to the table surface. This is exactly what the Arno does as it sinuously follows down-dropped fault blocks on its way from the Apennines to the Tyrrhenian Sea. Just as in Rome we see in Florence the path of rivers is influenced by the local geology.

The Arno has experienced many major flooding episodes. Like the Tiber, it has man-made embankments along its banks to protect the citizens and important art from flooding events. Some historical evidence in paintings shows the Arno had more of a braided flowing pattern but today due to the man-made embankments and dams it has a narrow sinuous channel similar to the Tiber. The most notable flood was in 1966 reaching 6.7 m (22 feet). It destroyed many masterpieces of art in Florence and killed 101 people. The weather event that caused the flood was an extreme severe cyclonic system of widespread scale affecting areas all the way to Venice in the north (Malguzzi et al. 1). To mitigate damage and save lives from flooding, the Arno River Basin Authority has sponsored the Regional Atmospheric Modeling System since 2000, a multi-agency approach to forecasting based on real time data for precipitation, temperature, water levels, discharge, hydrological models and expert analysis (Meneguzzo et al. 38).

The Geology of the Duomo's Building Materials. Florence is my second favorite city in Italy, only surpassed by Venice, even if we do share the same name. The city's most important landmark is its Duomo the Cathedral of Santa Maria del Fiore (fig. 4.17).

This section will address the stones used to build this magnificent structure. Then we will stop at another site that is a good example of Italian geology and culture intertwined at the famous sculpture by Michelangelo the "David."

When I traveled to Florence for the first time as a geology student in 2004, I was stunned by the beauty of the Duomo's exterior rocks whose colors of green and pink outlined in white make a dramatic statement to the Cathedral's renaissance architecture (bridging Greek and Gothic). It is such a stunning color combination (fig. 4.18). Feeling once again it was necessary to discover something about the city's geologic roots by

Fig. 4.17. "Façade of Florence's Duomo." Wikipedia, The Free Encyclopedia. 23 Oct. 2007. Wikimedia Foundation, Inc. 27 Apr. 2009. <http://en.wikipedia.org/wiki/Orvieto_Cathedral>.

Fig. 4.18. "Detail Design of Florence's Duomo". Over There Interactive Inc. 27 Apr. 2009. <http://www.eurocheapo.com/blog/florence-tip-free-duomo-tours.html>.

examining its building materials, I went up close to the Duomo's exterior with my hand lens (a small magnified lens used by geologists to examine rocks up close) to see what kind of rocks they might be. I could identify the white marble and a green metamorphic rock. I truly must have looked strange to the many tourists who were waiting in line to get inside. I did not linger long and thankfully, I did not attract the attention of the security. Recent work on identifying the rocks of important monuments in Florence including those of the Duomo was published in honor of the 32nd International Geological Congress hosted by Florence in 2004. It is a succinct work identifying and describing the origin of the Duomo's rocks and I shall refer to in my discussion of the Duomo's façade.

The Santa Maria del Fiore's ground stone was laid on September 2, 1296 but it took 140 years before it was dedicated, and work continued even beyond that time. Several famous architects were involved in its design including Filipo Brunelleschi, who

Fig. 4.19. "Dome of Florence's Duomo." Wikipedia, The Free Encyclopedia. 29 June 2006. Wikimedia Foundation, Inc. 25 Jan. 2009. <http://en.wikipedia.org/wiki/File:Santa_Maria_del_Fiore.jpg>.

is responsible for the dome that offers spectacular views over the city at the top balcony. The dome is a magnificent accomplishment - the largest dome at the time built without scaffolding. I contemplated this as I looked over the city standing on the dome about 100 m (328 feet) high and was amazed at the fearless people who built it. It is built with four million bricks as a shell within a shell, the inside shell supporting the exterior dome (fig. 4.19).

It turns out the red stone decorating the façade is a marly limestone (Malesani et al. 253). These are the marls I mentioned in the prior section on the evolution of the Apennines. The green rock outside the Duomo is a rock called serpentinite (Malesani et al. 254). It is indeed a metamorphic rock probably originating form peridotite, part of the Earth's upper mantle located about 400 km (248 mi) below the Earth's surface (fig. 4.20). We know that the serpentinite shows up in suites of rocks called ophiolites. They are blocks of oceanic lithosphere that are caught up in intense metamorphism through burial

at the margin of an oceanic closure. I mentioned ophiolites earlier when I was discussing the Penninic Ocean's demise. They are quarried from the northern Apennine Mountains that hold rocks from the closure of several oceanic basins.

The white rock on the Duomo is marble, another metamorphic rock whose original form was limestone a sedimentary rock (Malesani et al. 253). The white marble was quarried from the Apuane Alps (Alpi Apuane) near the region and is of Oligocene to lower Miocene age (27-10 my) (Malesani et al. 253). It was during this period that tectonic forces were compressing together the Apennine Mountains of the region and exerting such force that over time the limestone sediments become buried and subjected to high temperatures, resulting in the metamorphosed marble now on the Duomo's exterior.

Fig. 4.20. "Rocks of Florence's Duomo." Personal photograph by author. 8 Jan. 2004.

I may be the only person I know who is astonished when I think about the origin of these rocks and the long journey they traveled, over many millions of years to finally connect with humans and wind up on the most important monument in Florence.
It is as though they are poised to be admired by all especially by those who understand their long journey! I contemplated why the people who decided upon the rocks for the Duomo's façade chose the marls, the serpentinite and the marble? They could have built the Duomo's facade out of brick like the dome or with elaborate mosaics to make the designs stand out like other cathedrals in the region. However, they considered these stones more important, more beautiful and elegant in fact, important enough to decorate the outside of their city's symbol.

It was the Medici family (a very prominent family that ruled the region) that redid the façade during the seventeenth century. At the time Florence was a very important city, birthplace of the Renaissance, center of art and architecture, a center of trade and finance, and the capital of the Kingdom of Italy. It seems to me those involved in this decision process, the Medici family stone masons, cutters, and architects, thought these rocks made the dramatic statement suitable only for the Duomo. The rocks of the Duomo's exterior are what everyone experiences when they first see the Cathedral. The three dramatic colors give us a sense of the city's importance, the culture's preference for material and the statement they wished to make for this important city. They are witnesses of a city's bond to its geologic roots.

Michelangelo's David - a Man From Carrara Marble. Michelangelo di Lodovico Buonarroti Simoni, commonly known a Michelangelo, sculpted a masterpiece sculpture

called “David,” the biblical hero who killed the giant Goliath. It is housed in the Galleria dell’Accademia in Florence. The work is based on the artistic discipline of “disegno” that means knowledge of the human form. When you gaze upon David’s nude body and see the veins on his arms and the perfect proportion and placement of all the muscles, you understand that Michelangelo understood and knew extremely well the human form to its ultimate detail (fig. 4.21). Most amazing to me is that he was able to recreate it from a block of rock. Michelangelo chose the marble himself for the sculpture from the Alpi Apuane Mountains (part of the Apennine Mountains of Northern Italy) at the famous Carrara quarries located close to Florence (fig. 4.22). It is said that Michelangelo treasured Carrara marble above all others, and it is not difficult to imagine why he chose

Fig. 4.21. “David (Michelangelo).” Wikipedia, The Free Encyclopedia. 23 Apr. 2009, 23:07 UTC. Wikimedia Foundation, Inc. 26 Apr. 2009. <ttp://en.wikipedia.org/wiki/David_(Michelangelo)>.

it for the David. The sculpture of a man's body it its most accurate anatomical form demanded a marble of the purest quality.

Carrara marble is known for its chemical purity, its homogeneous microstructure and what geologists call isotropic structure, meaning that the marble's crystals are arranged in no specific orientation. It is a metamorphic rock having undergone two phases of metamorphic cycle deformation. One event had to do with the compressive deformation of the Apennines and the other had to do with the regional extension (Attanasio et al. 258). The limestone was deposited during the Upper Triassic (about 200 my) (Attanasio et al. 258). Recent field studies of the Alpi Apuane showed that the two

Fig. 4.22. "Carrara Quarry." Wikipedia, The Free Encyclopedia. 28 June 2006. Wikimedia Foundation, Inc. 28 Apr. 2009. <http://en.wikipedia.org/wiki/File:Carrara01.jpg>.

deformation events are related to subduction, nappe stacking, and exhumation, that are all part of the history of these mountains. Just to give you a sense of the intense

temperatures and pressures required for this type of metamorphism to change limestone to marble, it has been calculated that the purest Carrara marble was subjected to temperature ranges of between 400° C - 350° C (752° F - 662° F) (Attanasio et al. 258). In addition, it was subjected to the pressures estimated to be between 3-4 Kbars (kilobars are units of pressure). This equates to about 43,500 – 58,000 pounds of force per square inch! In its purest form Carrara marble has a very pure brilliant white color. The most common variety of Carrara marble has blackish veins. Carrara marble has been the choice for countless other important works all over Italy including the Pieta (the pity) in Rome, the Virgin Mary with the body of Christ (fig. 4.23), and Trajan's Column in Rome.

The City of Pisa's Leaning Tower - A Lesson to Build on Solid Ground.

We have left Florence and are travelling west to the Tyrrhenian shores, our

Fig. 4.23. "The Pieta." Wikipedia, The Free Encyclopedia. 3 Mar. 2008, 3:38. Wikimedia Foundation, Inc. 26 Apr. 2009. <http://en.wikipedia.org/wiki/File:Michelangelo %27s_Pieta_5450_cropncleaned_edit.jpg>.

Fig. 4.24. “Leaning Tower of Pisa.” Personal photograph by author. 9 Jan. 2004.

destination being the city of Pisa. Only an hour by train from Florence, Pisa makes for a good day trip from Florence. The Leaning Tower of Pisa is actually the bell tower built for the cathedral of Pisa situated nearby (fig. 4.24). Construction began in AD 1173 and it was completed about AD 1370. The tower is 56 m high (184 ft) and 19.6 m (64 ft) in diameter and weights 14,500 tons. It is built as a hollow cylinder of white marble, and you can climb as I did to the top balcony by 296 steps or 294 on the north-facing staircase. The marble comes from the historical quarries of Monte Pisano located about 10 km (6 mi) from Pisa (Franzini and Lezzerini 217).

After five years into its construction on the fourth story, work was stopped because the tower was already leaning. Speculation is that the tower was leaning due to differential settlement though there is no written document to this effect (Burland,

Jamiolkowski and Viggiani 91). Work began and stopped several times possibly due to the tower's leaning and perhaps influenced by strong earthquakes centered near the region (Burland, Jamiolkowski and Viggiani 92). In 1838 the tower was leaning approximately 4.8º from the vertical, an angle that was exacerbated due to a wall dug around its base that was encroached by water. The ground water in the locality of the tower is only 1-2 m (3-6 ½ ft) below the ground surface.

Have you ever wondered as I had, why the tower is leaning? By the time I visited the Leaning Tower of Pisa I had taken some basic geology courses like sedimentary geology where learned about sediments, and a geomorphology where we learned about Earth's landforms including river deltas. I figured the tower had to lean

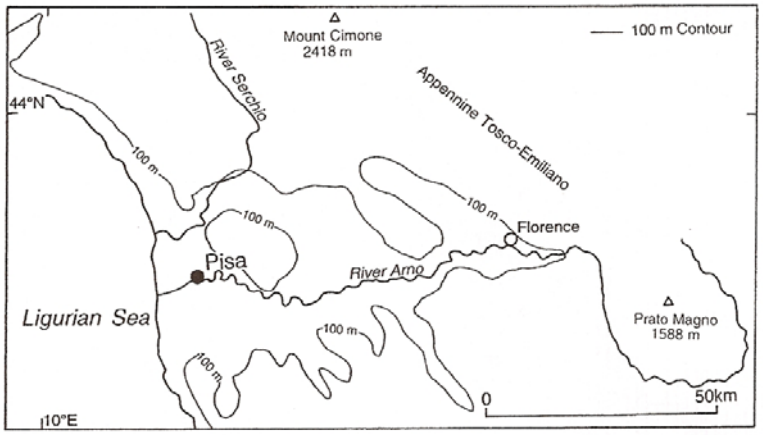


Fig. 4.25. "Geological Map of Pisa Area." Burland, Jamiolkowski and Viggiani 92.

for one of two reasons, it had faulty engineering or it was situated on a bad underlying foundation. The latter turned out to be partly correct. It turns out the setting of the tower is right in the path of the Arno River's flood plain (fig. 4.25).

During the last glacial age 23,000 and 15,000 yrs BP, sea level dropped and the Arno cut a valley into this area. Then when sea level rose again, the valley filled back up with alluvial material (river deposits). Figure 4.26 is a geologic map of the Pisa area showing the symbol "Qc" for the Quaternary (1.64 my). The symbol indicates estuarine/fluvial (deposits from rivers, streams, and estuaries) in the area of Pisa (Burland, Jamiolkowski, and Viggiani 93). These deposits are layers of sand and clay and boreholes of the area indicate they go down to a depth of 300 m (984 ft) (Burland, Jamiolkowski, and Viggiani 93). The town of Pisa is built on these deposits.

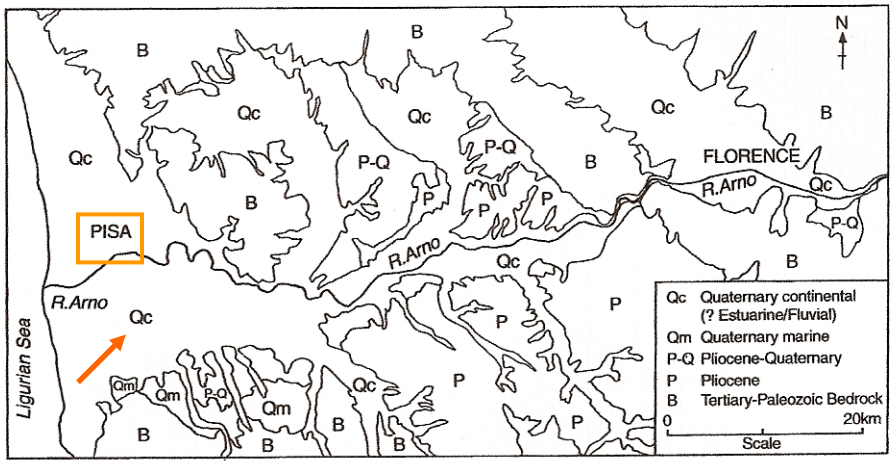


Fig. 4.26. "Geologic Map of Pisa Area." Burland, Jamiolkowski and Viggiani 93.

The tower is situated only 3-4 m (9-13 ft) above mean sea level in other words very near the sea (Burland, Jamiolkowski, and Viggiani 93) (fig. 4.26). Sea levels have been rising during the past 10,000 and the deposits are marine or estuarine depending on the rate of sea level rise. These more recent deposits are up to 10-m thick (33 ft) of sand and clay (Burland, Jamiolkowski and Viggiani 93). Figure 4.27 shows all the deposits

under the tower to a depth of 15 m (50 ft). Notice how one of the clay layers (Pancone) gives way to a curved space below the tower. The Pancone, a marine clay, is a delicate

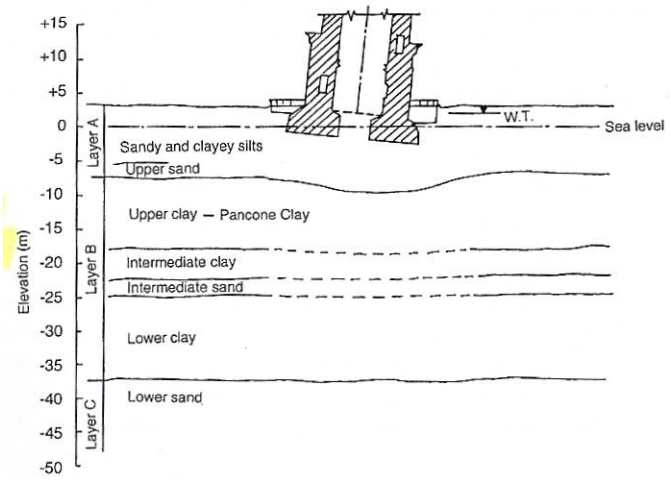


Fig. 4.27. "Soil Profile Beneath the Tower." Burland, Jamiolkowski and Viggiani 93.

deposit that loses strength when disturbed (Burland, Jamiolkowski and Viggiani 93). This would impact the stability of the tower.

It is inferred from a NNW-SSE fault only 5 km (3 mi) from Pisa that another fault passes under the town of Pisa (Burland, Jamiolkowski, and Viggiani 93). It is not clear how the region's earthquakes have affected the tower. But it has been noted that the tower leans with the seasons. In September, it inclines towards the north coinciding with heavy rains, while in the summer there is little north/south inclination (Burland, Jamiolkowski and Viggiani 95). It appears that the tower also responds to temperature fluctuations in an east/west inclination in late September, moving towards the east and in February moving back towards the west (Burland, Jamiolkowski, and Viggiani 95).

The reason for the tower's leaning has to do with physics and the local geology. It has been shown in numerous studies that the tower's rapid inclination has to do with a phenomenon called "leaning instability." This is due to the ground's insufficient stiffness not to its lack of strength (Burland, Jamiolkowski, and Viggiani 95). A tall narrow structure will lean at a critical point in height when the resistance from the ground reaches that critical point. It is evident based on this phenomenon that the combination of the very soft ground beneath the tower and its geometry resulted in the tower of Pisa reaching its critical height (Burland, Jamiolkowski, and Viggiani 95). The authors make the analogy that it is similar to when children build brick towers on a soft carpet.

There have been stabilization efforts under way for many years. For a while it was thought that injecting grout into the foundation masonry would strengthen the structure, but those efforts actually caused the tower to lean even further, either due to the ground disturbance or the displacement of the ground water (Burland, Jamiolkowski, and

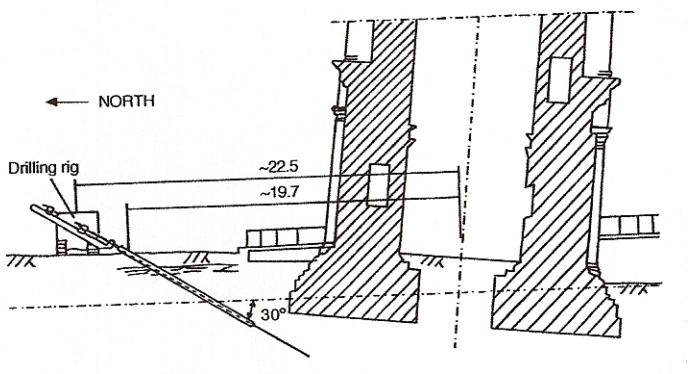


Fig. 4.28. "Proposed Method of Inducing Subsidence by Soil Extraction." Burland, Jamiolkowski, and Viggiani 98.

Viggiani 95). At present, there is a new approach to stabilizing the tower by doing the reverse of what was done before. Essentially, it involves creating space in the ground beneath the high side of the tower by pulling out soil and waiting for the tower to settle into the empty space (fig. 4.28) (Burland, Jamiolkowski, and Viggiani 98). This geologic story is reminiscent of the Roman Colosseum's setting that is also built partly on river deposits (chapter three). We saw that the Colosseum's side situated on the Tiber's sediments did not fair very well either.

It is interesting to learn why the famous tower is leaning, but it also underscores the theme from chapter three of building on a bad geologic substrate. It is not a good idea financially or from a human suffering perspective. We have analogs closer to home for what happens to structures built on river floodplains. These are called geologic hazard areas. New Orleans was built on the flood plain of the Mississippi River. Although New Orleans faces additional problems than are not present at the Leaning Tower of Pisa both are built on a river's floodplain. Today parts of the city of New Orleans are 3 -5 m (9-16 ft) below sea level due to several factors including sinking into the river's muddy sediments (Dixon et al. 587)! To make matters worse the crust in the region is subsiding due to the Mississippi River's heavy sediment load and if you combine global sea level rise it spells little hope for the city.

Although levees have been built to keep the sea from encroaching into New Orleans, it seems the wiser land use approach is to refrain from building in these settings. Today, we do have the means to extract information about the subsurface in order to determine suitability for building. In the long run, the cost in terms of lives and

destruction to property that gets paid by the taxpayers could be avoided. The people who built the Leaning Tower of Pisa, the Colosseum and the city of New Orleans did not understand about geologic foundations. Today we do understand yet we continue unwise land use practices particularly building homes adjacent to rivers and the sea.

Larderello's Geothermal Energy - Electricity from Volcanoes.

The village of Larderello is located a short distance south of Pisa. We are interested in this town because it is the site of intense underground heat and steam produced from volcanic activity. More importantly, it is the site of the Larderello geothermal field that has been exploited industrially since 1818 and has been producing electricity for over one hundred years from Earth's heat (Batini et al. 240). Today it provides enough electricity to power about one million households or about 2% of Italy's electricity (Bertani 653). This is an excellent example of human exploitation of the local geology to benefit the lives of people.

What is geothermal energy? The Geothermal Energy Association defines it as heat derived from the Earth. Figure 4.29 shows on the left side the temperatures of

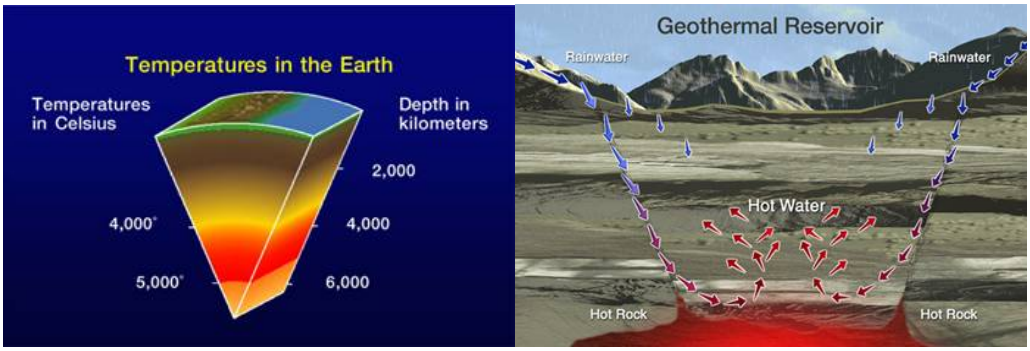


Fig. 4.29. "Geothermal Reservoir." Geothermal Energy Association. 26 Apr. 2009. <http://www.geo-energy.org/aboutGE/basics.asp#whatis>.

heat within the Earth. The right side of the figure shows a geothermal reservoir the source from which to harvest the heat. Heat from the Earth continually flows upward. Underground magma may heat a nearby body of rocks and or water sometimes to temperatures reaching 700º C (1292º F) and water or steam can be produced below the surface forming the geothermal reservoir.

One of the keys to harvesting the heat is the depth of the reservoir. It must be at a depth that is accessible. In Larderello, the reservoir is located very close to the Earth's surface because the magma is very near the Earth's surface. This makes Larderello extremely conducive to geothermal power production. It must be pointed out however, that although the geologic situation is perfect in Larderello it is not necessary to have close to the surface heat for harvesting. There are different technologies that can harvest geothermal heat in many parts of the world that may not contain hot rocks immediately beneath the surface. The volcanic field in Larderello experiences occasional phreatic activity (explosive outbursts of steam trapped beneath the surface). There are about twelve volcanic craters in the region; the largest is the Vecchienna (old one) crater that last erupted around AD 1282. It is now filled by a lake.

The use of geothermal heat is documented back to Roman times, a prime example being the Roman baths. More recently Italians realized over a century ago that the steam and heat could be turned into electricity. In 1904 they used a generator powered by the volcanoes' steam in Larderello to light five light bulbs proving this point (fig. 4.30). It was a practical application of the use of local resources. Thus, Larderello earned the distinction as the world's first energy plant converting steam and heat from the

Earth into electricity. Appropriately, the plant is located in the Valle De Diavolo (Devil's Valley), a name it probably got due to the landscape's steaming vents looking rather like where the devil might live (fig. 4.31).

Now let us look to the wise people of a little Italian village in the northern Apennines of Tuscany for wisdom and to learn how Earth can help us produce power,

Fig. 4.30. "First Geothermal Energy Plant Italy Producing Electricity from Geothermal Steam With its Inventor Prince Piero Ginori Conti." US Department of Energy (Washington, D.C.) Energy Efficiency and Renewable Energy Geothermal Technologies 27 Apr. 2009. <http://www1.eere.energy.gov/geothermal/history.html>.

that is cheap, virtually nonpolluting and renewable. Let us examine the geologic setting in Larderello to understand the conditions that formed this source of heat. After the continental collision between the micro plate that Sardinia and Corsica are riding on had collided with the Adriatic micro plate building up the Apennines, the next chain of events opened the Tyrrhenian Sea. Extension processes began in the late Miocene (about 6 my) to open the Tyrrhenian Sea. These events built up magma and geologists call this area

the Tuscan Magmatic Province (Dini et al. 1).

Beneath the surface geologists know there is a large pluton (fig. 4.32) (Dini et al. 1). Plutons are intrusive igneous bodies of magma or crystallized magma within the Earth's crust. The magma in a pluton by definition does not reach the surface. Plutons cool slowly, sometimes giving off heat for millions of years. When the heat comes in

Fig. 4.31. "The Larderello Valley – ("Devil's Valley") in a 19th Century Print." From Batini, Fausto, Andrea Brogi, Anotio Lazzarotto, Domenico Liotta and Enrico Pandeli. "Geological Features of Larderello-Travale and Mt. Amiata Geothermal Areas (Southern Tuscany, Italy)." Episodes 26 (2003): 240.

contact with ground water it produces steam that has to escape which his why there are many vents in Larderello. Plutons can be massive or small. It is inferred that a large body of magma is beneath Larderello at about 9 km (29,000 ft) down (Villa and Puxeddu 415). As I mentioned this is fortunately very near Earth's surface making it easier to access. Additionally, researchers Villa and Puxeddu measured the temperatures in five

wells and found a range of 330° C - 450° C (626° F - 842° F) which means it is also hot enough to be useful (416).

How is steam converted into electricity in these geothermal areas? Electricity from geothermal energy is generated using several techniques depending on the type of reservoir. In Larderello the type of plant is called direct-steam (DiPippo 1). Superheated pressurized steam from the underground is forced into a turbine on Earth's surface that in turn generates electricity (fig. 4.33) (Geothermal Energy Association). It is a rather simple process and costs very little once the plant is built. It produces no CO_2, very little if any pollution, plants can operate at very high capacity, and there is plenty of clean reliable energy available 24 hours a day 365 days a year. Wells can be eventually depleted of heat. Some shallower steam vents in Larderello whose heat was depleted,

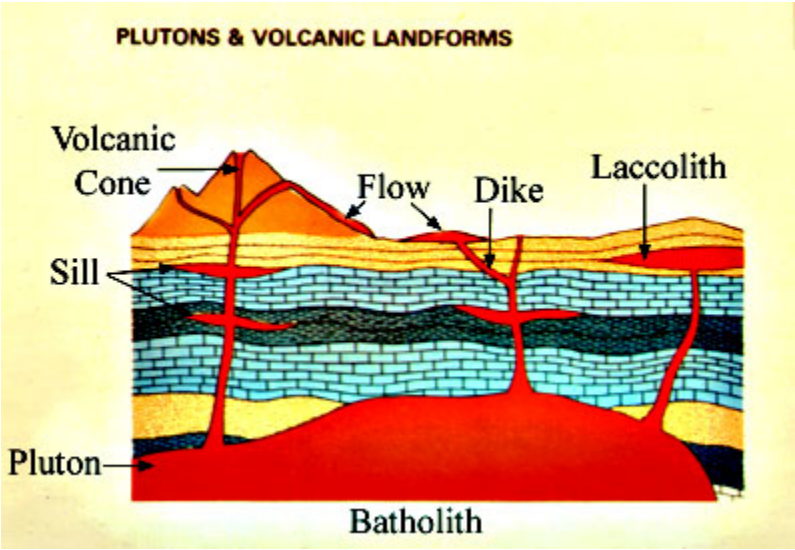


Fig. 4.32. "Diagram of a Pluton." Indiana University. 7 June 2009. <http://www.indiana.edu/~geol105/images/gaia_chapter_5/dike&sill.jpg>.

have been replaced with new ones whose heat reservoir is deeper in Larderello (Bertani 668).

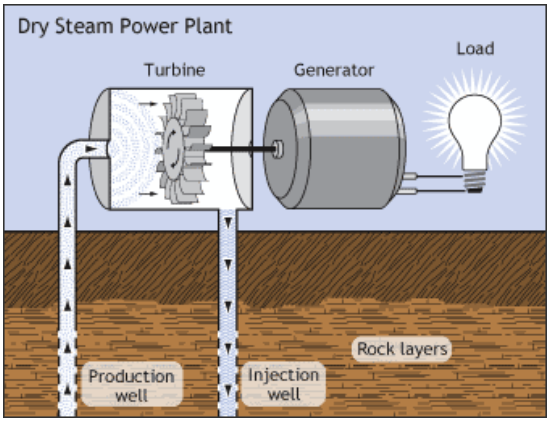


Fig. 4.33. "Dry Steam Power Plant." US Department of Energy (Washington, D.C.) Energy Efficiency and Renewable Energy Geothermal Technologies Program. 28 Jan. 2009. <http://www1.eere.energy.gov/geothermal/powerplants.htm>.

Table 1. "Geothermal Fields in Italy Electricity Production 2005." Bertani 669.

Geothermal fields in Italy

Location	Installed capacity (MW_e)[a]	Number of units[a]	Annual electricity production (GWh/year)[b]
Larderello	543	21	3606
Travale-Radicondoli	160	6	1109
Mt. Amiata (Bagnore and Piancastagnaio)	88	5	625
Total	791	32	5340

[a] Early 2005 data.
[b] 2003 data.

Table 1 shows the capacity and annual electricity production of all three fields. Note the units (MW_e)[a] means installed capacity in megawatts (10^6 watts), that is the

target output when the plant is operating under peak design conditions (Bertani 652). The units GWh/year[b] means gigawatts (10^9 watt-hours per year) of energy produced. Table 2 indicates how Italy compares to other nations in producing electricity from geothermal resources. Figure 4.34 shows the approximate location of all the geothermal plants in Italy. They are all located in close proximity in the same region. Geothermal heat has some limitations, for example, the heat or steam is difficult to transport great distances because distance degrades the pressure and temperature so the plants must be near the source. However, once it is converted to electricity, it can be transported long distances.

Table 2. "Worldwide Geothermal Power Generation in Early 2005." Bertani 653

Worldwide geothermal power generation in early 2005

Country	Installed capacity (MW_e)	Running capacity (MW_e)	Annual energy produced (GWh/year)[a]	Number of units	Percent of national capacity	Percent of national energy	Source of data
Australia	0.2	0.1	0.5	1	Negligible	Negligible	WGC05
Austria	1.2	1.1	3.2	2	Negligible	Negligible	WGC05
China	28	19	96	13	30% of Tibet	30% of Tibet	WGC05[b]
Costa Rica	163	163[c]	1145	5	8.4	15	WGC05[d]
El Salvador	151	119	967	5	14	22	WGC05
Ethiopia	7.3	7.3	0	2	1	n/a	WGC05
France (Guadeloupe)	15	15	102	2	9	9	WGC05[e]
Germany	0.2	0.2	1.5[f]	1	Negligible	Negligible	WGC05
Guatemala	33	29	212	8	1.7	3	WGC05
Iceland	202	202[g]	1483[h]	19	13.7	17.2	WGC05[i]
Indonesia	797	838	6085	15	2.2	6.7	WGC05[j]
Italy	791	699	5340	32	1.0	1.9	WGC05
Japan	535	530	3467	19	0.2	0.3	WGC05
Kenya	129	129	1088	9	11.2	19.2	WGC05[k]
Mexico	953	953[l]	6282	36	2.2	3.1	WGC05[m]
New Zealand	435	403	2774[n]	33	5.5	7.1	WGC05[o]
Nicaragua	77	38	271	3	11.2	9.8	WGC05
Papua New Guinea (Lihir island)	6	6	17[p]	1	10.9	n/a	WGC05[q]
Philippines[r]	1930	1838	9253	57	12.7	19.1	WGC05[s]
Portugal (Sao Miguel island)	16	13	90	5	25	n/a	WGC05
Russia	79	79[t]	85	11	Negligible	Negligible	WGC05
Thailand	0.3	0.3	1.8	1	Negligible	Negligible	WGC05
Turkey	20	18	105	1	Negligible	Negligible	WGC05
USA	2564	1935	17,917[u]	209	0.3	0.5	WGC05[v]
Total	8933	8035	56,786	490			

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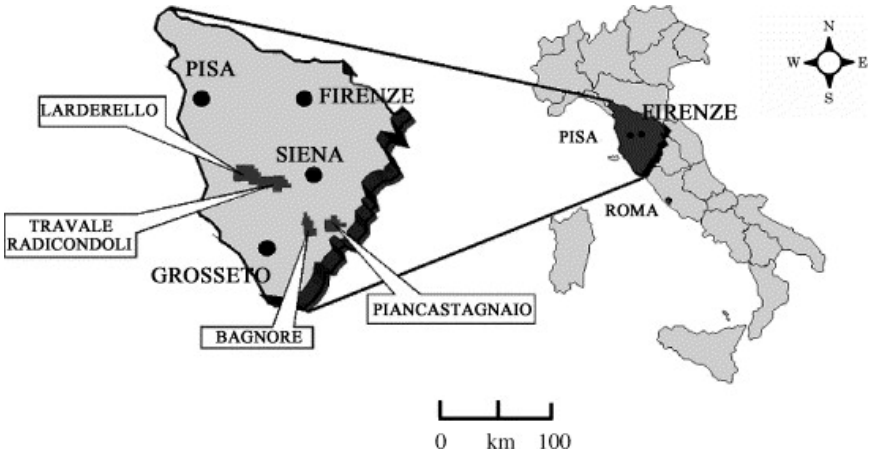


Fig. 4.34. "Locations of the Regions Containing Geothermal Plants in Italy." Bertani 669.

I wanted to tell you the geologic story of geothermal heat not only to demonstrate that Italians have yet again incorporated the local geology into their culture in a very practical way, this time being at the vanguard of geothermal energy, but because it is a topic we should all be aware of. We are living during a time of worldwide energy challenges. Energy conflicts including wars between nations including the US date to before WWII (Klare 80). Our traditional energy resources utilizing fossil fuels (gas and oil) are fast running out, warming the planet and causing serious global problems. I am not suggesting geothermal heat is the silver bullet to the energy crisis, but it is a viable alternative that combined with other energy sources can be a good part of the solution to the energy needs of the future. Thank you to the Italians who looked at this geologic resource and figured out its capability long before there were energy demand issues in

effect giving the world a gift.

Conclusion.

The regions of Tuscany, Umbria and Marche are among the most scenic in Italy. Travelling to Orvieto, we saw the rolling hills of Tuscany as a testament to extension processes and the region's many normal faults. The Paglia River near Orvieto shaped that city's foundation just as the Tiber shaped the Seven Hills of Rome. It was impressive to see how a river can alter the landscape so much. The foundation rocks of Orvieto and the Orvieto Classico wine are closely connected in the local soils that are so well suited to growing Orvieto's grapes. Lake Trasimeno's history it turns out was not volcanic but tectonic. The landscape has undergone transformation in the region of Lake Trasimeno from an ancient ocean to the present day lake. The Earth is in a constant mode of change.

We saw how the evolution of the Alps and Apennine Mountains shaped the region and laid out the foundation for Gubbio's rocks that contain the KT Boundary. The boundary provides us with a theory of how the dinosaurs disappeared, while the rocks of Florence's Duomo took us back to the metamorphic processes that have shaped the Apennines. It is said Michelangelo believed that the David was already present in the Carrara marble he used and that he only set it free. It was impressive to see the journey of the Carrara Marble. It began as an ultra pure limestone in the warm sea many millions of years ago then underwent two deformation events of the Apennine orogeny that buried the limestone deep in the Alpi Apuane Mountains metamorphosed it into marble then

exhumed it near the surface where it is now quarried. The ancient marine creatures gave us the limestone but it took the Apennines to transform it to the Carrara marble.

The Leaning tower of Pisa as with the Colosseum yet again demonstrated the importance of building on a strong geologic foundation. Larderello is an example that shows inventiveness and looking at local resources that may provide some innovative solutions to energy problems. This is a concept very relevant today in our energy-challenged world. These are but a few examples of how humans have incorporated the Earth's geologic products into their lives. I hope you have enjoyed this geologic journey through north-central Italy.

CHAPTER 5 – NORTHERN ITALY
Comparing Alps to Apennines, Lake Como, The Dolomites, Bolzano and Venice
The Regions of Lombardia, Trentino-Alto Adige, and Veneto

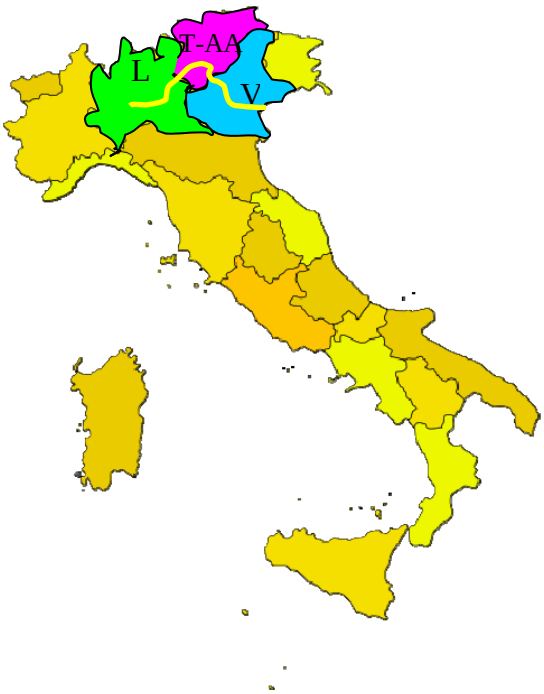


Fig. 5.1. "Lombardia, Trentino-Alto Adige and Veneto Regions of Italy." Modified from Wikipedia, The Free Encyclopedia. 9 June 2009, 21:23. Wikimedia Foundation, Inc. 9 June 2009. <http://en.wikipedia.org/wiki/Italy>. Lombardia is green, Trentino-Alto Adige is pink, Veneto is blue, route is yellow.

The region I am defining as northern Italy encompasses Italy north of Tuscany. It spans the geographic regions of the Po Valley, the Piemonte (the base of the Southern Alps), and the Italian Alps. I discussed in chapter three the evolution of the Alps and the Apennines. In this section, I will compare and contrast them so that we might get a better

sense of Italy's two mountain chains. This material will lay the foundation for discussing a few of the region's interesting geologic cultural connections such as the "Sacri Monti" (sacred mountains) chapels used for worship. We will start in western Italy working our way eastward and then proceed south to Venice. One of our first stops will be Lake Como located in what are known as the Italian Alps in the lake district of Italy. The region encompasses four large lakes, and some say it is the most beautiful region of Italy. I will discuss how the lake was formed.

We will see that structures like the sacred shrines for worship built on steep mountainsides are a cultural adaptation to the region's rugged terrain. Traveling eastward, we will climb the Dolomite Mountains. They are part of the Italian Alps but have distinct and different morphology (external structure and form) in part due to their composition of dolomite. Continuing our eastward route, we will stop at the city of Bolzano. It is located in the Southern Alps of northeastern Italy near the border with Austria. It is the home of Otzi the "Ice Man." Otzi as he is called was an ancient inhabitant of these mountains when he was entombed in the glaciers about 5200 years ago (Hall 70). Leaving the city of Bolzano and the Alps we will travel in a southeast direction down to where the Po Valley meets the Adriatic coast and visit undoubtedly the most beautiful and unique city in Italy, Venice. It is a city built on the water. I will tell the story of why Venice was built there and how Earth's processes and humans have shaped it over time.

<u>Alps vs. Apennines Compare and Contrast.</u>

In this section, I will compare and contrast various aspects of Italy's two mountain chains. Northern Italy is bordered by the Southern Alps also known as the Italian Alps. Figure 5.2 indicates the approximate location of Italian Alps stretching horizontally below the black line. The Alps are located along the Italian border and stretch across Europe as an E-W trending crescent-shaped mountain belt. From a geologic standpoint there are technically two major sections of the Alps joined together by what is known as the insubric line that is of Oligocene-Miocene age (35-23) my. It is actually a fault

Fig. 5.2. "Insubric Line or Periadriatic Seam Along the Alps." Wikipedia, The Free Encyclopedia. 29 Mar 2009, 16:26 UTC. Wikimedia Foundation, Inc. 2 May 2009. <http://en.wikipedia.org/wiki/Periadriatic_Seam>.

running E-W along the Alps in a sense suturing together the European and African plates. Figure 5.2 shows the insubric line running parallel to the Alps. The insubric line is a fault that runs for about 1000 km (621 mi). It seems logical that the two great continents

would be sutured along a great boundary. The insubric line is a good way to think of that seam between Africa and Europe. I will refer to the Alps north of the insubric line as the European Alps and those to the south as the Southern or Italian Alps.

The Alps stretch through the countries of France, Germany, Lichtenstein, Switzerland, Austria and Slovenia. They are a two verging (facing) mountain belt. The Northern Alps face north towards northern Europe while the Southern Alps face south towards Italy. To me the Italian Alps make Italy look as if she's wearing a crown of diamonds. To those who liken Italy's shape to a boot, the Alps with their snow cover could be the white fur cuff of the boot (fig. 5.2). The orientation of the Alps is exactly opposite that of the Apennines. The Apennines by contrast are a one verging belt facing east. They are oriented more or less in a N-S direction running along the entire length of Italy forming what I have called the spine of Italy. Italy's two mountain chains are oriented roughly perpendicular to each other with the Apennines running more or less N-S and the Italian Alps E-W (fig. 5.2). In figure 5.2 the Alps are represented by the blue line, the red line represents the Apennines and the yellow line represents the Po Valley.

Italy was the byproduct of two events namely the Alpine and the Apennine orogenies. It is accurate to say that if the Alps and Apennines had not developed Italy would not have either. I liken the two mountain belts to Italy's parents. This is to say they are absolutely necessary to Italy's genesis and evolution. Just as a quick refresher, I will briefly reiterate the main mountain building events of the two mountain belts and then compare them.

During the Middle Mesozoic, the large Tethys Ocean was separating two great continents. Adria also known as Argand's African promontory (of African continental crust) was in the south and the European continent was located to the north (see chapter two) (Dal Piaz, Bistacchi and Massironi 175). As we know oceans open, oceans close,

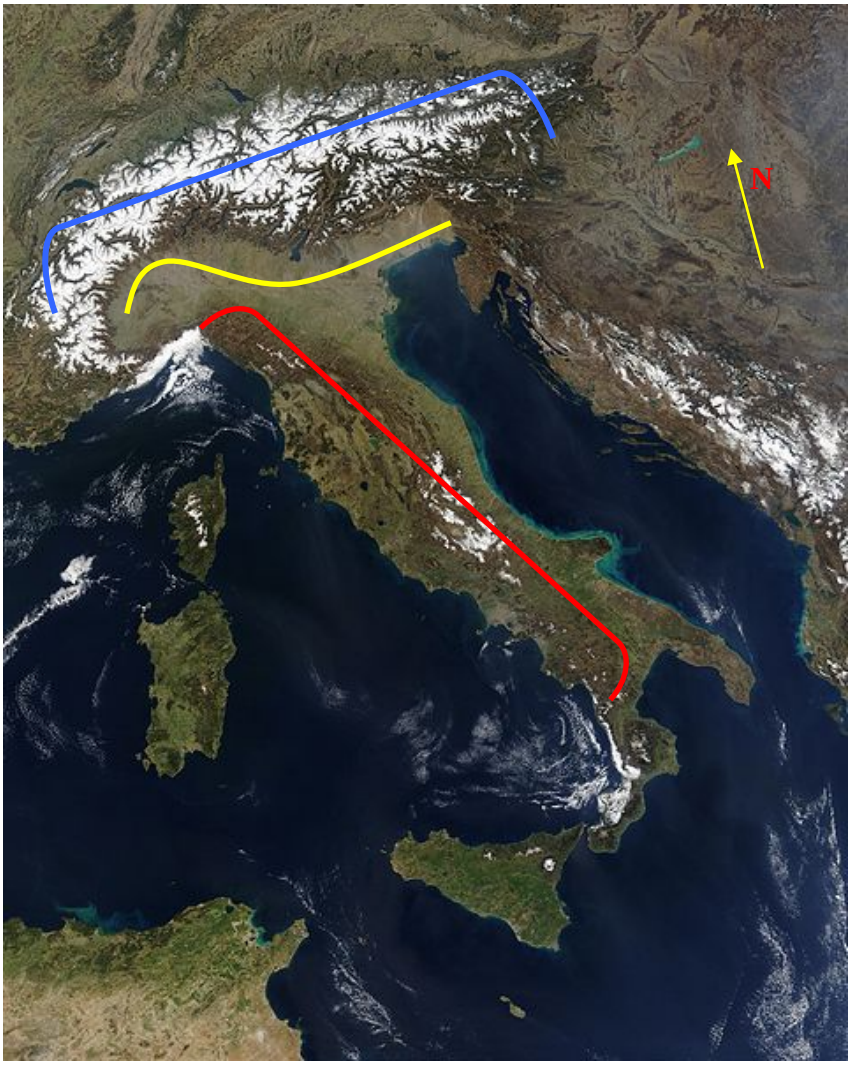


Fig. 5.3. "Italy - Topography." Modified From Wikipedia, The Free Encyclopedia. 28 Jul. 2008, 16:11. Wikimedia Foundation, Inc. 3 May 2009. <http://en.wikipedia.org/wiki/File:Satellite_image_of_Italy_in_March_2003.jpg>. Red bracket indicates the Apennines, blue bracket indicates the Alps, yellow line indicates the Po Valley, yellow arrow indicates north.

and the Tethys Ocean was closing during this time. When the Tethys Ocean closed, the two continents were brought together. The European continent subducted all the oceanic crust beneath the northward moving African/Adria continent as Africa/Adria overrode the European continent. Recall that the arrangement we ended up with is the great sandwich analogy with the top piece of bread being the African plate, the bottom being the European plate and in between the much deformed remnants of the Tethys Ocean.

It was the collision of the two continents that started the Alpine orogeny raising the Alps to great heights starting during the Eocene (about 56 my). Great nappes (those large sheets of rocks that have slid long distances) started stacking to form the Alps. The Alpine nappes formed from south towards the north perpendicular to the direction of compression. At the northern most part of this front are representative rocks from the African passive margin plus oceanic crust from the subducting Tethys Ocean.

Similar to the Alpine nappes the Apennines also formed nappes starting much later in the Middle Miocene (10-15 my) as compression at that time began on the western part of Italy. The Apennine nappes also formed perpendicular to the motion of compression moving from west to east. The nappes of the Alps are steeper and more deformed than those in the Apennines (Doglioni and Scrocca 141). Continued compression from the south formed great recumbent folds in the Alps forming thrust belts (folded rocks). Compression from the west formed thrust belts in a similar way in the Apennines. These great folds of rocks broke off from the adjoining layers and slid one over the other forming great thrust faults in both mountain chains.

There are widespread outcrops of basement rocks (the oldest metamorphic and igneous rocks that form the crust of continents) in the Alps while the Apennines are mainly composed of sedimentary rocks (Doglioni and Scrocca 141). This is because the Alps have involved deep rocks that have been exhumed to the surface due to intense metamorphism and deformation while the Apennines have involved shallower rocks that have undergone a lower degree of metamorphism and deformation.

The Apennines began forming during the Middle Miocene (10-15 my) while the Alps are considerably older, having been in the process of formation since the Early Cenozoic (56 my). The Alps' highest peak is Mont Blanc 4810 m (15,800 ft) while the Apennines' highest peak at almost half the height is the Gran Sasso at 2914 m (9600 ft) (see chapter three). The Alps have many glaciers while the Apennines have only one on the Gran Sasso's Corno Grande peak.

Figure 5.4 is of the Matterhorn, a well-known peak in the Alps. It is located on the Swiss and Italian borders and both countries claim parts of it. This figure shows three different types of rocks exhumed and raised high including the highest rocks at the peak that are from the African continent! Different layers of rock can be seen on the photo: the lower part consists of sedimentary rocks (5.4C) the middle part consists of greenschists from the Tethyan oceanic crust (5.4B). The peak itself above the seracs (jagged pinnacle) is composed of gneisses, which come originally from the African continent (5.4A).

The Alps have no back arc basin while the Apennines have the well-developed back arc basin in the Tyrrhenian Sea. The Alps have been eroded several tens of

kilometers whereas the Apennines have reduced overburden (the upper part of a sedimentary deposit) only by a few kilometers (Doglioni and Scrocca 141). There are not many examples of subduction-related volcanism in the Alps while there is a larger abundance present in the Apennines (Doglioni and Scrocca 141).

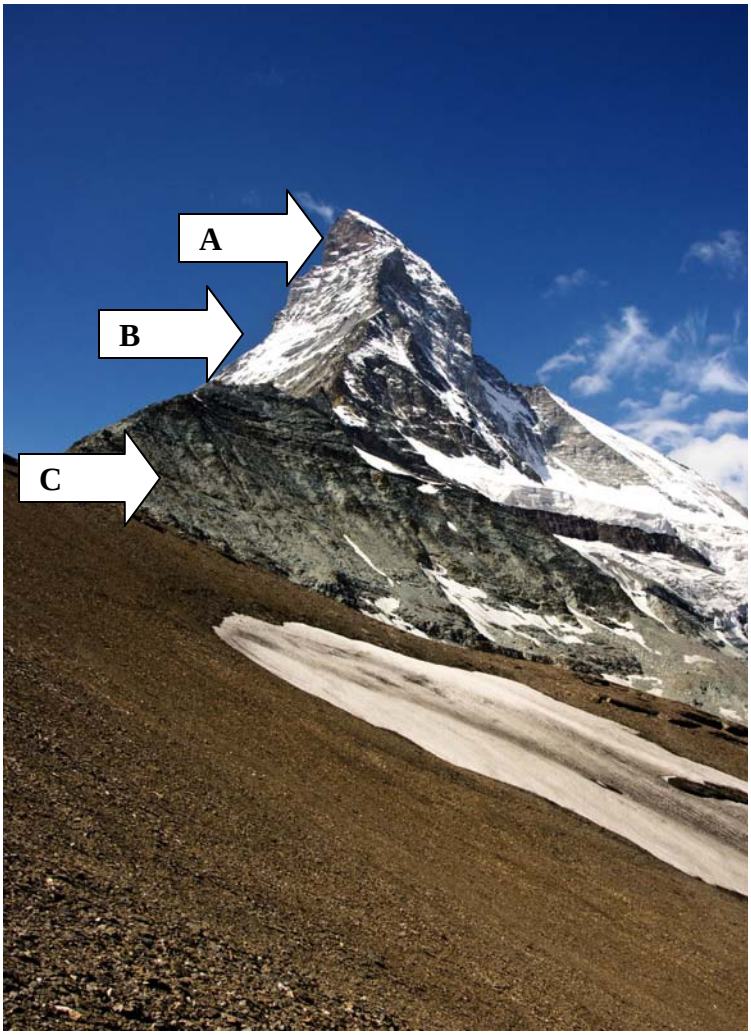


Fig. 5.4. "Matterhorn." Modified From Wikipedia, The Free Encyclopedia. 12 Dec. 2008. 20:48. Wikimedia Foundation, Inc. 3 May 2009. <http://en.wikipedia.org/wiki/File:M atterhorn002.jpg>. A, B, & C arrows represent different rock formations.

The Alps face in two directions and they have what is called the antithetic (opposite facing) retrobelt being the south-verging Southern Alps and the north-facing European belt. In contrast, the Apennines do not have such an antithetic belt; they have slow subsidence rates and are not buried. By contrast the Apennines' single thick foreland basin with fast subsidence is buried deep in the Adriatic Sea (Doglioni and Scrocca 141). Doglioni and Scrocca point out that these differences in the foreland basins are a paradox because we would expect just the opposite. The larger and thicker mountain chain (the Alps) should have a thicker and deeper foreland basin.

Stepping back and looking at one underlying reason for the differences in the two mountain chains I can say that it is attributed to the great pressures exerted upon the Alps that have not been present in the Apennines. Of course this is due to the fact that the Alps were formed by a continental-continental collision but the Apennines were not. In addition the considerably longer period of time over which these pressures have been exerted upon the Alps (56 my) vs. 10-15 my on the Apennines has resulted in raising the Alpine rocks to very high elevations. It follows geologic reason that the greater the compression in a continental-continental collision the higher the mountains, the greater the chance of exhuming deep rocks, and the greater the degree of metamorphism.

Another major factor that contributes to the structural and geomorphic differences in the two chains is that the Alps developed vertically while the Apennines developed laterally. The Alps also have developed a thickened lithosphere versus the shallower one of the Apennines (Doglioni and Scrocca 144). Figure 5.3a, topographic map of Italy, shows nicely the morphology of the high Alps covered with snow and the much lower

morphology of the Apennines without much snow. I crossed the Alps by train in January of 2006 from Zurich into Italy. It was amazingly beautiful scenery (fig. 5.5).

Fig. 5.5. "Italian Alps." Personal photograph by author. 11 Jan. 2006.

Lake Como.

Let us now visit Lake Como in the Southern Alps. It is located in Italy's Lake District that stretches from Milan to Verona (fig. 5.6). Lake Como is situated along the Italian Alps a short distance north of Milan. There are several large lakes in the region but I will focus the discussion only on Lake Como. Lake Como is located in the region of Lombardy and has a catchment area of 4522 km (2810 ft) and a depth of over 400 m (1420 ft) (Fanetti and Vezzoli 115). It is surrounded by tall mountains of up to 2500 m (8200 ft) making it a very dramatic landscape (fig. 5.7). It is a favorite destination and recreation area for tourists and Italians alike.

The first question we must ask ourselves is why and how did the lake get here? Looking at figure 5.6, we notice all the Alpine lakes in this region are running parallel relative to each other and they stretch into the Alpine valleys as elongated bodies of water. Sometimes these geomorphic characteristics give geologists clues in

Fig. 5.6. "Terrain Map of Italy's Lake District." Modified from Google Earth Tele Atlas Europa Technologies. 2009. 5 May 2009. <http://www.google.com>. 45°12'16.72"N and 75°33'31.71"E. Arrows indicate Italian lakes in the Alps. Yellow line is northern Italian border.

understanding their origin but they do not tell the entire story. Further investigation is usually needed of the regional geology including the structure of the rocks to unravel the geologic history. I am thankful to the many Italian and international geologists who have done so much work to advance our knowledge of the Alps.

Geologic study of the rocks in the region has provided some answers to the lake's origin. In connection to the movements between Europe and Adria the Southern Alps underwent E-W extension during the Middle Mesozoic (about 170 my) (Bertotti, Siletto, and Spalla 273). This produced a number of normal faults in these mountains including the Lugano fault that borders the Monte Generoso sedimentary basin with a vertical displacement of at least 6-7 km (19,000-23,000 ft) (Bertotti, Siletto, and Spalla 273).

Fig. 5.7. "Panorama of Lake Como." Wikipedia, The Free Encyclopedia. 28 Apr. 2009, 14:48 UTC. Wikimedia Foundation, Inc. 20 Jan. 2009. <http://en.wikipedia.org/wiki/Lake_Como>.

There is a continuous lineament coinciding with Monte Grona (Mt. Grona) and the combined tectonic lineament is referred to as the Lugano-Val Grande fault (Bertotti, Siletto, and Spalla 273). The Lugano fault's footwall is in the west and the hanging wall is located to the east side of the Monte Generoso basin. During the early stage the large regional fault established and controlled sedimentation and drainage in this area. The fault's evolution also controlled the morphology of the lake.

Beginning in the Late Cretaceous (about 70 my) the area underwent shortening

(the opposite motion) in a N-S direction. This new motion caused a section of the crust to fold in nearby Monte Cecci (Mt. Cecci) forming a syncline (Bertotti, Siletto, and Spalla 273). A syncline is a downward-curving fold of rocks that forms in response to compression while an anticline is an upward-curving fold in response to compression (fig. 5.9). You can do a small experiment to see how anticlines and synclines form. If you place your hands on a tablecloth and move them towards each other, you will find that the tablecloth becomes deformed into a series of up and down folds replicating what

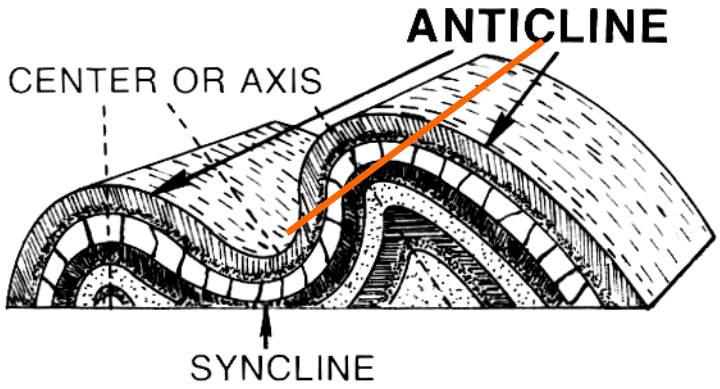


Fig. 5.8. "Syncline/Anticline." Modified from Wikipedia, The Free Encyclopedia. 2 Mar. 2009, 04:00 UTC. Wikimedia Foundation, Inc. 4 May 2009. <http://en.wikipedia.org/wiki/Syncline>.

happens when Earth's crust responds to compression by folding. One way older rocks can be exposed in an anticline is to erode the top of the anticline as though we take a horizontal slice off the top (see orange line in figure 5.8). Due to the immense history of compression in the Alps, there are numerous anticlines and synclines like Mt. Cecci in the region. Further motions exposed older rocks and also steepened the Lugano fault that changes direction to W-E until it reaches Lake Como (Bertotti, Siletto, and Spalla 273).

Figure 5.9A indicates Lake Como's generalized rocks and their ages. They range from warm shallow sea sediments of Lower Jurassic age (190 my) to old volcanics of Permian age (282-251 my) to very old basement rocks of Variscan age (380-280 my). The orange arrow in figure 5.9 indicates that the Mt. Cecci syncline terminates at Lake Como and indicates the major faults as a line with "teeth" marks. Figure 5.9B shows the evolution of the Lugano fault during rifting in the Mesozoic and later during compression.

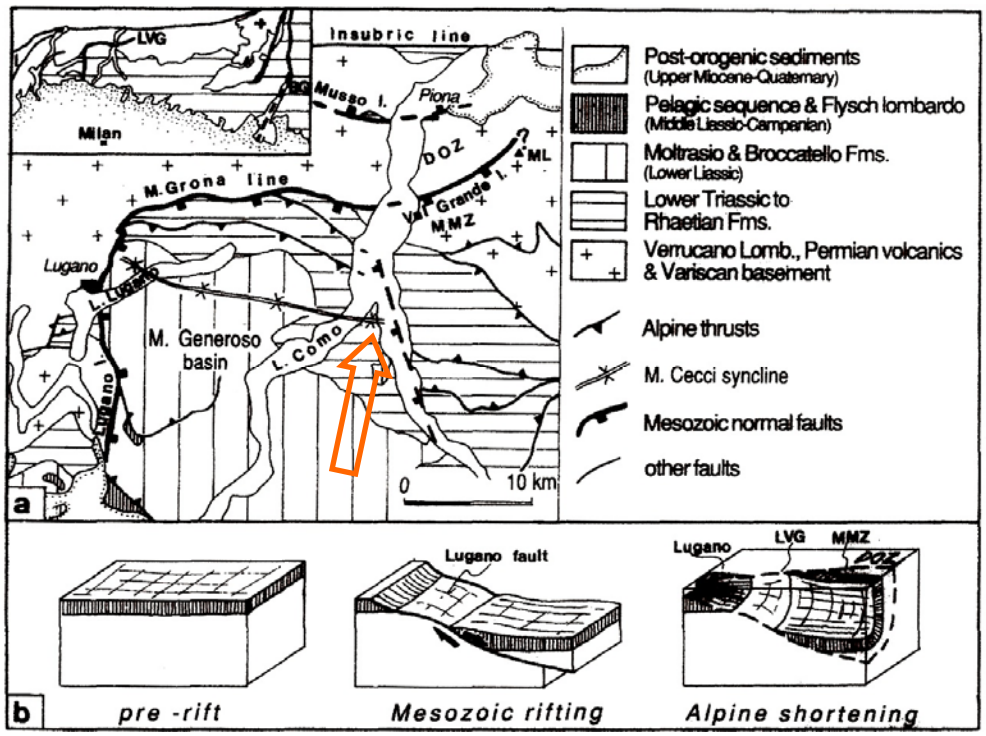


Fig. 5.9. "Schematic Geological Map of Lake Lugano – Lake Como Region." Bertotti, Siletto and Spalla 271. Orange arrow indicates terminus of Mt. Cecci anticline.

There are several rivers that drain into Lake Como including the Breggia, the

Greggio and the Adda. The latter continues through the lake to join the Po River. During the last Ice age (about 10,000 years ago) the lake was glaciated. When the glaciers retreated they left a large "U" shaped valley now occupied by Lake Como. The large faults (crustal fractures) formed a natural place for the regions' rivers to drain thereby providing water for Lake Como.

The slopes of Lake Como's surrounding mountains provided the perfect place in AD 1635 to build what Italians call the Sacro Monte di Ossuccio (Sacred Mount of Ossuccio) (fig. 5.10). It is a chapel for worship. The Sacro Monte di Ossuccio is one

Fig. 5.10. "Sacro Monte di Ossuccio." Wikipedia, The Free Encyclopedia. 21 Oct. 2007, 19:21. Wikimedia Foundation, Inc. 4 May 2009. <http://en.wikipedia.org/wiki/Sacro_Monte_di_Ossuccio>. The sanctuary as depicted in a fresco in capella (chapel) XIV - The Assumption of the Virgin.

of nine sacri monti (sacred mountains) in the region built between the late sixteenth and seventeenth century. They hold great importance in terms of art, and they are considered very beautiful, particularly the way they have been integrated into the mountainsides. They are reached usually by pilgrimage. The idea of building a sacred place on a

mountain was started by the Christians in this region. The model for a sacred mountain is to build the chapel on a mountain slope with a series of smaller chapels containing scenes from the life of Christ as places for devotion. The Sacro Monte de Ossuccio, located on a crag above Lake Como, was inscribed on the UNESCO list of World Heritage Sites in 2003.

I can imagine people of the 1600's finding themselves in a beautiful, isolated, peaceful setting and being religiously inspired (as landscapes like this often do) deciding this is the place to build special places of worship. The character of the landscape must have engendered a deep spiritual meaning so they associated the mountainsides as places dedicated to God. The rugged terrain made access difficult to the sacri monti which made the journey arduous. This perhaps made those who made pilgrimage more worthy to worship at the sacri monti. The cultural tradition of building sacri monti later spread beyond Italy to other parts of Europe.

Lake Como today is a major destination for vacationers who enjoy the lake's many attractions using a well developed ferry system that links the towns along the lake's

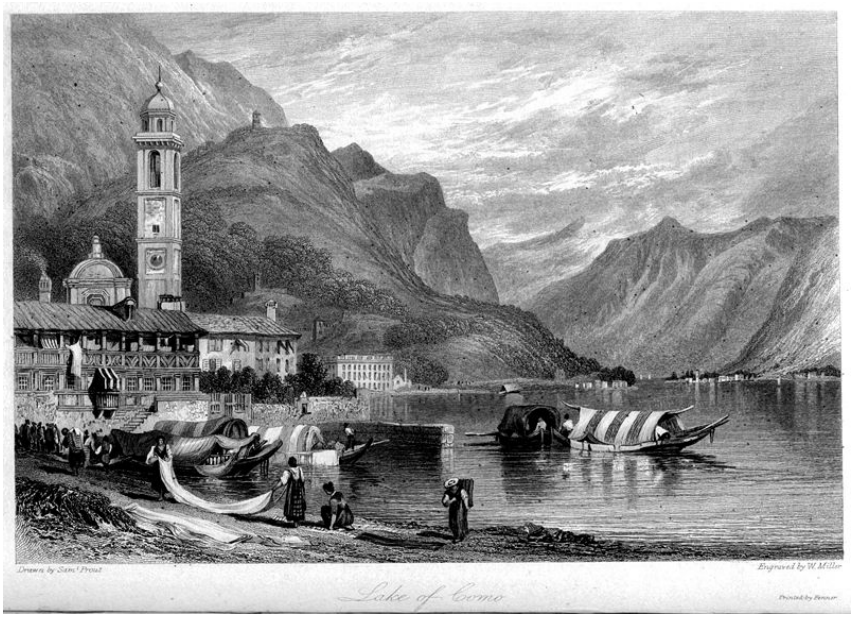


Fig. 5.11. "Lake Como Engraving by William Miller After S. Prout, 1829." Wikipedia, The Free Encyclopedia. 5 Dec. 2007, 04:53. Wikimedia Foundation, Inc. 4 Jan. 2009. <http://commons.wikimedia.org/wiki/File:Lake_of_Como_engraving_by_William_Miller_after_S_Prout.jpg>.

perimeter. It is also well known for its princely grand villas which have been built on the hillsides for many centuries. Some of the villas have elaborate terraced gardens, fountains, and sculptures belonging to important families. I would like to end this section on Lake Como with an old engraving of the lake (fig. 5.11) followed by a poem describing the lake's beauty written by Henry Wadsworth Longfellow. It is titled "Cadenabbia," which is one of the small communities on the west shore of Lake Como that he visited in 1875.

Cadenabbia

Lake of Como

No sound of wheels or hoof-beat breaks
  The silence of the summer day,
As by the loveliest of all lakes
  I while the idle hours away.

I pace the leafy colonnade,
  Where level branches of the plane
Above me weave a roof of shade
  Impervious to the sun and rain.

At times a sudden rush of air
  Flutters the lazy leaves o'erhead,
And gleams of sunshine toss and flare
  Like torches down the path I tread.

By Somariva's garden gate
  I make the marble stairs my seat,
And hear the water, as I wait,
  Lapping the steps beneath my feet.

The undulation sinks and swells
  Along the stony parapets,
And far away the floating bells
  Tinkle upon the fisher's nets.

Silent and slow, by tower and town
  The freighted barges come and go,
Their pendent shadows gliding down
  By town and tower submerged below.

The hills sweep upward from the shore,
  With villas scattered one by one
Upon their wooded spurs, and lower
  Bellaggio blazing in the sun.

And dimly seen, a tangled mass
  Of walls and woods, of light and shade,
Stands, beckoning up the Stelvio Pass,
  Varenna with its white cascade.

I ask myself, Is this a dream?
  Will it all vanish into air?
Is there a land of such supreme
  And perfect beauty anywhere?

Sweet vision! Do not fade away;
  Linger, until my heart shall take
Into itself the summer day,
  And all the beauty of the lake;

Linger until upon my brain
  Is stamped an image of the scene,
Then fade into the air again,
  And be as if thou hadst not been.

The Dolomite Mountains.

Our journey now takes us eastward along the Southern Alps to the Dolomite Mountains (fig. 5.12). They are located mostly in the Italian region of Veneto, Trentino and Alto-Adige. They are limited to the north by the insubric lineament, to the south by the Val Sugana (Sugana Valley), to the west by the Adige River, and to the east by the Piave Valley. Their characteristic form makes them a spectacular mountain chain. They are derived from the passive margin of the ancient Adria plate (Bosellini, Gianolla, and Stefani 181). Although the ages of the sedimentary rocks span from the Middle Permian

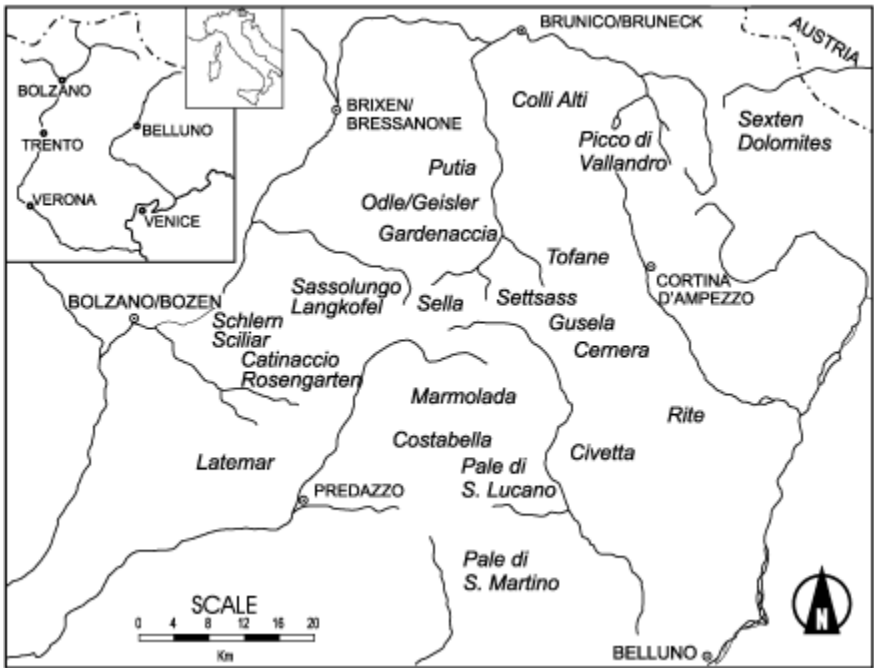


Fig. 5.12. "Location Map of the Dolomites and Most Important Platforms." Bosellini, Gianolla and Stefani 181.

(270 my) to Cretaceous (144 my) most of the spectacular exposed units were formed during the Triassic (250-200 my) in warm shallow seas.

The Dolomite Mountains are comprised predominantly from massive dolomite, some limestone, and some volcanics (Bosellini, Gianolla, and Stefani 181). What is dolomite that gives these mountains their distinct shape (fig. 5.13)? The term dolomite is applied to both a rock formation and the mineral. Dolomite used to be limestone but it was altered to the dolomite form when magnesium replaced some of the calcium. The important concept here is that both limestone and dolomite originate in similar marine

Fig. 5.13. "Dolomite Mountains of Italy." Seba.it. 3 Jul. 2008. 10 June 2009. <http://www.flickr.com/people/seba_photos/>.

environments (warm shallow seas) like the Bahama Banks today.

Let us go back in time to see the environment in which the dolomite developed before it was ever in the mountains of the Southern Alps. Our geologic time machine is set back to the Triassic about (200-250 my). At this time, the new Tethys Ocean was opening. I have spoken about the Tethys before that separated the Adria/African and European continents. It was during this time that the sediments that formed the Dolomites were deposited. The general depositional environment of the Dolomites (as limestones) was the passive margin of the Tethys Ocean and included a number of depositional settings ranging from terrigenous (shallow marine deposits eroded from the land surface) deposits to shallow platform areas, shallow water reef settings, intertidal areas, muddy banks and even isolated high relief buildups (Preto et al. 136). The deposits are very thick, as much as hundreds of meters high, making this a classic area where geologists study Mesozoic stratigraphy (rock layers) (Bosellini, Gianolla, and Stefani 181).

There are also volcanic products in the mountains associated with the opening of Tethys such as pillow lavas and basaltic dykes. Eventually, when this ocean closed and Adria collided with Europe these sediments were raised during Neogene times (about 10 my) to become the Dolomite Mountains (Bosellini, Gianolla, and Stefani 181). Their geometric form is what geologists call a synclinorium (a composite of several synclines).

There is some debate as to how and under what conditions the limestone became dolomite. It is known that massive dolomite forms in deeper water and with elevated temperatures. The limestone is replaced by dolomitizing fluid, but the details are not resolved (Carmichael and Ferry 785). It is thought that palaeoclimatic fluctuations from arid to moist and vice versa are a factor in the replacement process (Preto et al. 136). It is

Fig. 5.14. "Dolomite Mountain Talus Fans." Modified from David Bressan. PYRN Org. 14 Sept. 2008. 6 May 2009. <http://pyrn.ways.org/relict-rockglacier-odle-mountains-dolomites-italy>. Arrows indicate talus fans.

also thought that subaerial (above the surface) exposure, due to tectonic events lifting up the platform, was another contributing factor. Yet others believe the change from limestone to dolomite could have occurred when hydrothermal fluids mixed with the limestone (Preto et al. 136).

Let us now turn to the connection between the dramatic Dolomites and human culture. The Dolomites are weathering in a way that forms large talus fans (piles of rocks) at their feet (fig. 5.14). Intense weathering, particularly frost shattering is a main cause of the talus fans. Talus fans are formed when pieces of rock are separated from the mountain due to frost and thaw cycles, breaking and loosening the material from the mountainside. The end result of this weathering is an accumulation of talus at the base of mountains. The white areas in figure 5.15 represent talus fans. You can see in relation to the mountain how large they are. They present a geologic hazard because they can become mobile as debris flows and flow into high density population areas such as the town of Cortina d'Ampezzo. They can injure and kill people and often migrate into roads, which interferes with transportation (Pasuto and Soldati 59).

Cortina d'Ampezzo is a town located in a valley surrounded by the Dolomite peaks in the northern sector and is plagued by these talus landslide hazards. The valley in which Cortina is located was glaciated during the last ice age. When the glaciers retreated they left a "U" shaped valley that has talus slopes covering easily erodible sediments (Pasuto and Soldati 60). The morphology of the valley is controlled by the local geology that is made of lower and middle slopes where the weathered or more erodible rocks crop out and tall steep dolomite walls rise above them.

In 1977 there were several debris flows with serious consequences. They occurred following heavy rainstorms of short duration when the water quickly saturated the debris that then detached itself and slid down the slope (Pasuto and Soldati 60). The climate in this region is such that intense rainstorms occur from spring to July (Pasuto and Soldati 60). Intense water on the unstable slopes is just the condition that can saturate and start the debris flowing. Due to the region's high tourist traffic as well as the necessity to protect towns like Cortina d' Ampezzo, it has been necessary to formulate mitigation strategies to safeguard the population.

A study of the region by Pasuto and Soldati found that the debris-flow hazard has significantly increased in both frequency and intensity during the past ten years (69). Some of the reason seems to be that the frequency of high-intensity/short-duration precipitation events has increased since 1960 (Pasuto and Soldati 69). The authors suggested several strategies of remediation. Two retaining walls were built capable of holding $11{,}000^3$ m ($388{,}500^3$ ft) of rock debris (Pasuto and Soldati 70). Another project was proposed to divert the main debris-flow track toward an abandoned quarry and possibly build a discharge tunnel for the debris under the road (Pasuto and Soldati 70).

The Dolomite Mountains are full of alpine paths for hiking and many places for rock climbing. The Dolomites are a popular winter resort for skiing and in the summer a respite from the heat in other parts of Italy. There are eight national parks in the region. The tallest peak of the Dolomites is Marmolada at 3344 m (10,970 ft). Cortina D'Ampezzo at 1224 m (4016 ft) is a popular ski resort and is the hub for three local languages; Italian, German, and Ladin (an ancient language close to Latin). The town

was scheduled to host the 1944 winter Olympics but the event was cancelled due to World War II. Instead, Cortina hosted the 1956 Winter Olympics.

During the First World War the line between Italian and Austro-Hungarian forces ran through the Dolomites. There are several "outdoor museums" where you can get a sense for the war in the mountains through a collection of galleries, tunnels, entrenchments, and artillery emplacements. People of this region and probably other regions of Europe have used the rugged terrain to their advantage to guard against outside enemies. Other evidence of wars in these mountains is the stronghold feudal tower houses and lofty medieval bastions built in the mountains so that the enemy might be seen approaching and defensive strategies prepared. Mountainous terrain also serves as a good place to hide in times of war. Another adaptation to the rugged and high mountains dating to ancient times was to create large pastoral areas that are separated by a network of refugi (temporary houses). Shepherds used them as well as people travelling through the mountains. Many of these are still preserved and they can be visited to learn about living practices. Many other refugi provide food and shelter due to the high level of mountaineering activity in the Alps. This density of shelters is uncharacteristic in other mountains chains around the world.

Let us now travel a short distance to the city of Bolzano tucked right in the Dolomite region to learn about a 5000-year-old inhabitant of these mountains. There is a saying that the Trentino-Alto Adige is a region of dual identity, Trentino-Alto Adige keeps one foot in Italy and the rest of the body in the South Tyrol with its spirit adrift somewhere in the mountains. I personally found this to be true in the city of Bolzano

where I was constantly reminding myself I was still in Italy. Though the cuisine has Austro-Hungarian influences the language is torn between German and Italian. The many strudels and German pastries in bakery displays were a feast for the eye and reminded me of the northern influence in this part of Italy. There are 20,000 Ladins who live in this region and they still speak Ladin. They claim to have settled in the region more than 2000 years ago. I was lucky to encounter a Ladin speaking native at the auto rental office in Bolzano.

Bolzano is a beautiful city in the Trentino-Alto Adige region and is one of the best places to see how early humans lived in this region of high mountains because it is home to the Ice Man or Otzie as he is called (fig. 4.15). Otzie is displayed at Bolzano's South Tyrol Museum of Archaeology. He was found by a couple German tourists as they were climbing down from the Finailpitze peak in the Otztal Alps near Bolzano in 1991. Otzie is the best-preserved mummy from 5300 years ago. He is only partially decayed because he died on the Schnalstal glacier and was quickly covered with ice. He was

Fig. 4.15. "Otzi the Iceman." Wikipedia, The Free Encyclopedia. 6 May 2009, 6:53 UTC. Wikimedia Foundation, Inc. 2 Jan. 2009. <http://en.wikipedia.org/wiki/%C3%96tzi_the_Iceman>.

discovered as the ice melted in one of the hottest summers on record. Along with his body were his copper ax and other tools. There has been extensive investigation as to his birth place and home. It is thought he probably lived about 50 km (31 mi) north of Bolzano. There is speculation he might have been hunting on the mountain. He still has an arrow embedded in his shoulder and he suffered a blow to the head, very likely the reason he died. Examination of Otsie's tibia, femur and pelvis indicated he walked long distances over hilly terrain leading some researchers to postulate that perhaps he was an Alpine shepherd.

To me one of the most interesting parts of Otzie is his axe, which is made of nearly pure copper. To a man of his time the axe was arguably the most important tool he carried. He needed it for food, to build shelter, to gather wood for fire and to fight off enemies. It is known that Bronze Age Europeans in this region did smelt copper (Heiss and Oeggl 211). Heiss and Oeggl say that the regions of Schwaz and Brixlegg a little north of Bolzano in the Austrian Alps were pivotal copper sources in prehistoric Europe. In addition they say that the Eastern Alps contain a number of profitable ore deposits and that the region has a long tradition of copper mining and making of artifacts from the fourth millennium (Heiss and Oeggl 211). In fact Heiss and Oeggl believe that archaeological evidence points to a sort of "early industrialization" in the Eastern Alps based on the rising demand for bronze in Europe. The demand for copper probably led to higher populations and larger settlements, increases in agriculture and trade, leading to expansion of arable land, and to the region's extensive road network (Heiss and Oeggl 213).

We know there was copper smelting in these mountains and Otzi was most likely involved with it because analysis of his hair showed high levels of copper and arsenic, which is associated with copper smelting. It is a good bet that the copper for Otzi's axe came from this region, but where exactly is uncertain. Heiss and Oeggl say that the local geology is dominated by the Northern Alpine Greywacke (a sandstone rich with clay) zone which holds deposits of tetrahedrite-tennantite (fahlore/grey copper ore), a mineral closely associated with dolomite rock (fig. 5.16) (Heiss and Oeggl 211). Dolomite is

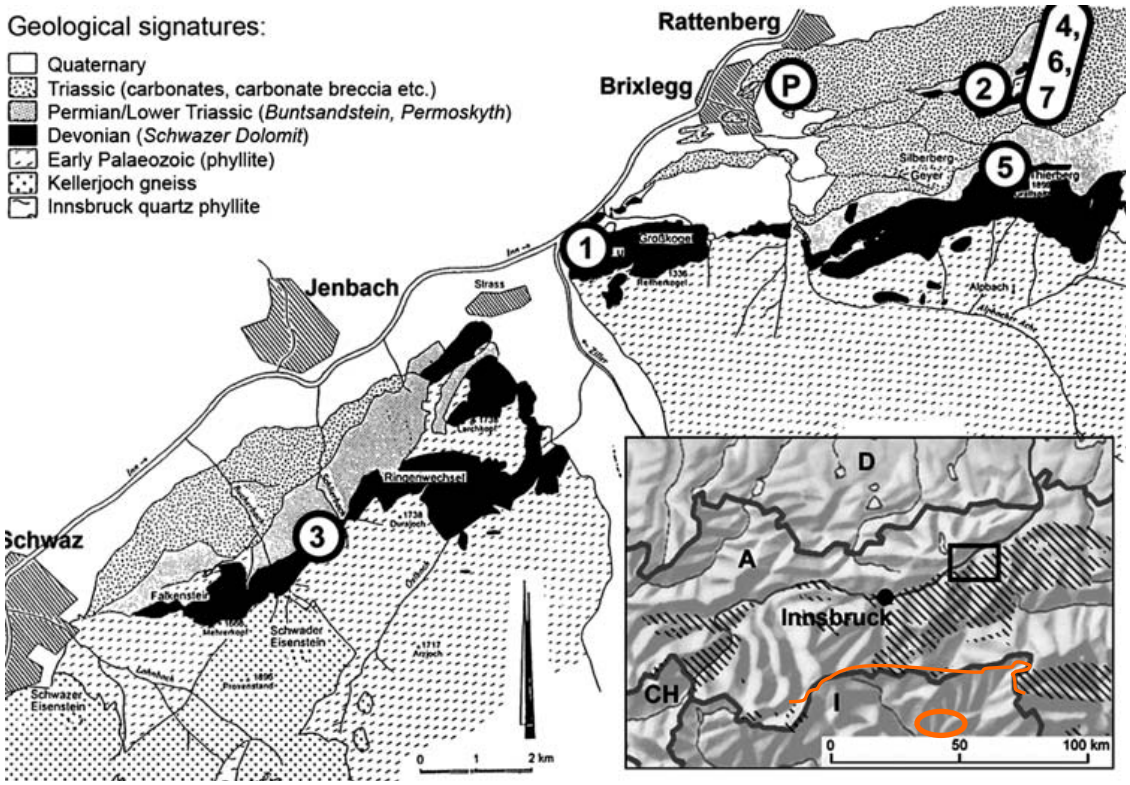


Fig. 5.16. "Alpine Greywacke Zone (hatched areas) and Regional Geology." Modified from Heiss and Oeggl 212. Orange circle denotes Otzi's probable home. Orange curved line is part of Italian border with Austria.

Fig. 5.17. “Prehistoric European Mines Using Wood Fire Setting Techniques to Crack Dolomite.” Heiss and Oeggl 212.

well represented in the areas of Schwaz and Brixlegg. Figure 5.17 from Heiss and Oeggl shows how wood was burned underground to break up and mine the dolomite.

Fire setting took advantage of the dolomites’ susceptibility to crack. The fires were set close to the wall causing surface layers to crack, which allowed the miner to process the dolomite wall with simple tools like wooden rods and stone mallets (Heiss and Oeggl 212). I find it interesting to contemplate how the prehistoric “Otzies” of these regions even discovered copper and copper smelting. Could it have happened accidentally? Perhaps by putting copper-ore dolomite around a campfire they first noticed the copper melting out? This is probably not plausible because copper smelting

requires high heat, but it makes for interesting contemplation. How good of Earth's processes to form the Dolomite Mountains that provided the prehistoric inhabitants with the copper they needed to make their weapons and improve their civilizations. It appears that copper mining had a large impact in this region and it spread to other parts of Europe in terms of trade, agriculture and even the road network, that exists in the Dolomite Mountains today.

Venice - the Sinking City that Sits on Remnants of Mountains.

I am very glad we are finally in Venice and I can tell you the geologic story of this enchanted city. It remains my favorite city in Italy and the place that held the most curiosity and fascination to me as to its geologic history. A multitude of information has been written about Venice covering the city's history and people. In more recent times there has been scientific inquiry by many scientists and international organizations to the reasons for the city's sinking and flooding episodes. These efforts provide information that can help to preserve what is unquestionably a very important cultural and artistic center for western civilization. Venice's environmental issues have attracted notoriety and garnered international attention, and there has been a collaborative effort by scientists around the world to preserve the city.

Why all the attention on Venice? Because Venice is a city in peril due to the fact that it is sinking! I will explain why it is sinking and how the local geology along with global sea level rise are the main culprits, though humans have also contributed to subsidence, especially during the last century. I hope when you visit Venice you will not only be amazed by the city's serene beauty and unique character, but you will be able to

also understand that the setting that makes her uniquely beautiful is also the city's biggest enemy.

I will start by giving you a clue to the geologic story of Venice and then I will develop the rest of the saga. Here it is: the city of Venice sits in the Adriatic Lagoon along the Adriatic Sea. Figure 5.18 is a satellite image of Venice in the Golfo di Venezia (Gulf of Venice) on the Adriatic Sea. Let us now discuss the geologic evolution of the Po Valley, the area surrounding Venice, and then I will talk about the impact of human settlement on the city.

Fig. 5.18. "Satellite Image of Venetian Lagoon." DATA SIO NOAA U.S. Navy NGA, GEBCO Image 2009 Digital Globe. 8 May 2009. <http://google.com>. 45°26'15.63"N and 12°20'10.59"E.

This time we will not go far back into the past but we will set our time machine to rather recent geologic time, about 1-2 my. During this time the Adriatic Sea stretched into Northern Italy covering all the Po Basin almost to the western border with France (fig. 5.19). The other process operating during at this time is regional extension, recalling our earlier Northern Apennine discussion. Extension equals normal faults and that equals

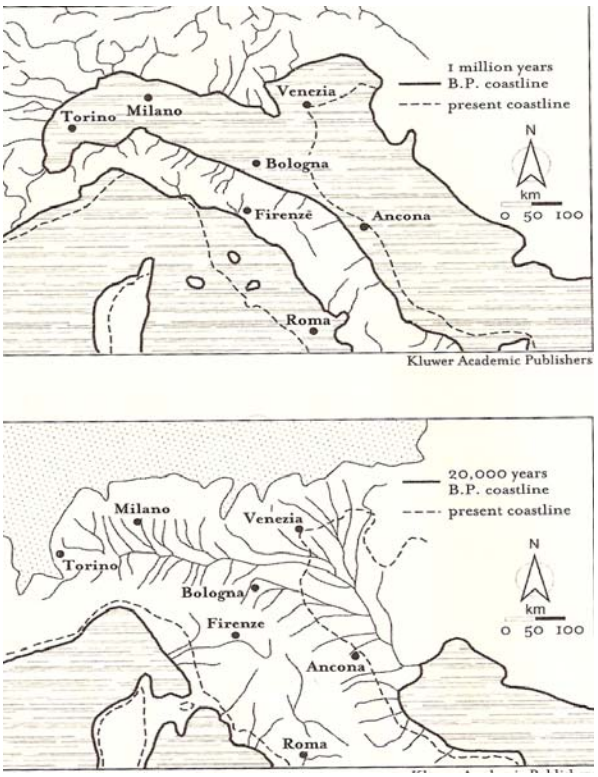


Fig. 5.19. "Past and Present Coastline of Northern Italy." Keahey 22.

basins. The Po Basin was formed because of this regional extension and the surrounding mountains provided the sedimentation that was deposited in the Po Basin. Figure 5.20 shows the evolution of the Po Basin.

The Po Basin is a structural foreland basin that pinches both the Northern Apennines to the south and the Southern Alps to the north. The Southern Alps are facing southward and their platform is pushing southward over the Po Basin while the Apennines are pushing northward doing the same thing. Part of the Northern Apennines are indeed buried under the thick basin sediments (Carminati and Martinelli 241). There is a lot of weight bearing down in this part of the Italian crust .

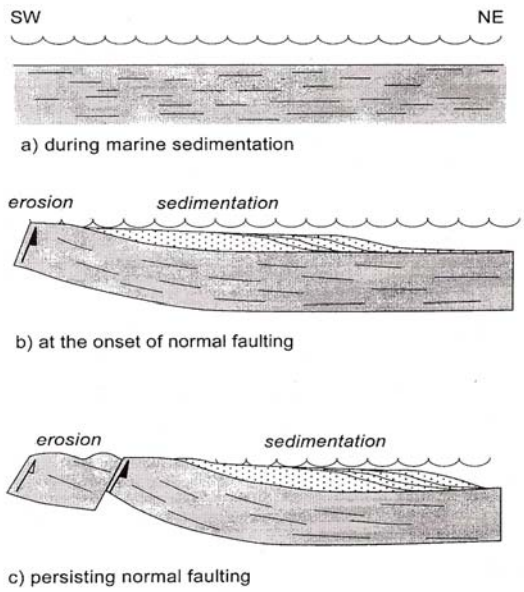


Fig. 5.20. "Cartoon Showing the Relationship Between Tilting and Erosion/ Sedimentation Pliocene to Lower Pleistocene Marine Shales." From Bertotti, G., R. Capozzi and V. Picotti. "Extension Controls Quaternary Tectonics, Geomorphology and Sedimentation of the N-Apennines Foothills and Adjacent Po Plain (Italy)." Tectonophysics 282, 1997: 298.

The Po Basin has thousands of meters of sediments eroded from these mountains by the rivers Adige, Bacciglione, Brenta, Sile and Piave as they have scoured the mountains and deposited their sediment. This is what I meant in this section's title that

Venice is sitting on remnants of mountains. Many sediment cores from the region indicate there is approximately 5000 m (16,400 ft) of sediment in the basin, and in fact, the basin is so loaded it is subsiding (fig. 5.21) (Brambati et al. 265). The basin is

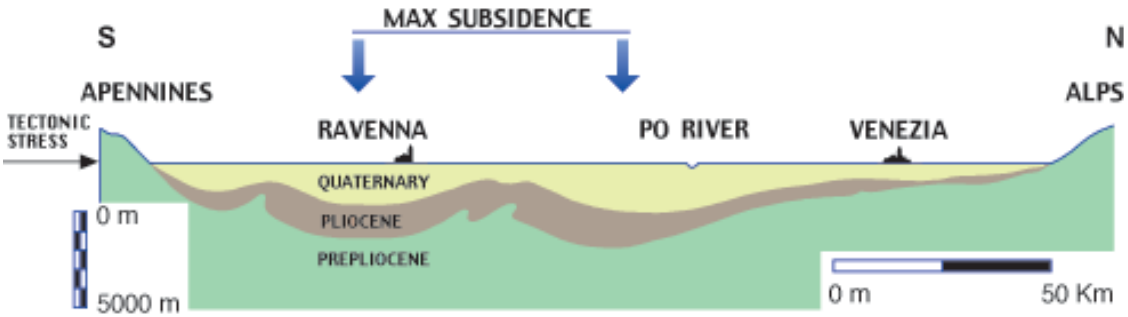


Fig. 5.21. "Schematic Geological Section Across the Eastern Po Plain." Brambati et al. 265.

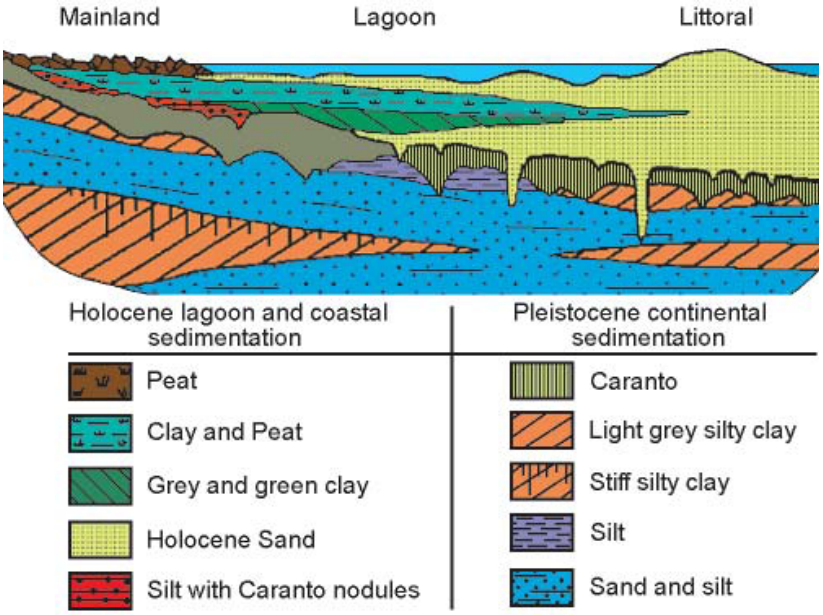


Fig. 5.22. "Holocene-Pleistocene Stratigraphical Sequence Across the Central Lagoon of Venice." Brambati et al. 267.

subsiding (sinking) due to the heavy weight of the sediments. Figure 5.22 indicates the various sediments beneath the Venetian Lagoon deposited during the last 1.6 my (Brambati et al. 265). You can see that it is just sequences of peat, sand, silt, and clay. This is not stable material suited for building cities.

Now let us return to our time machine to see the evolution of the area from 2 my. During this time, Venice was not there because there is a sea covering the region encompassing all the Po Valley all the way to Italy's easternmost town of Trieste, contained to the north by the Southern Alps and to the South by the Northern Apennines (fig. 5.19). Then a dramatic sea level drop began, eventually reaching a drop of 120 m (393 ft) (Keahey 25). This was caused by extensional activities that caused sedimentation in the basin, tilting towards the NE, and unloading of the footwall of a regional normal fault called the Bologna fault. The sea level lowering exposed new real estate, and the rivers filled the area with sediment so that by 20,000 years ago the area of the present Gulf of Venice became completely filled with sediment (Keahey 25).

Following this sedimentation, the Earth was at the end of the last glacial period and the glaciers in the nearby mountains were melting. Melt water flowed into the area of Venice, reclaiming the area again as part of the sea. These processes are all very common in coastal areas, and areas like the Venetian Lagoon have long histories of sea level changes. About six thousand years ago the Venetian lagoon formed. It was a marshy area adjacent to the Adriatic Sea with shallow water and grasses that formed extensive regional wetlands (Brambati et al. 264).

Human Settlement's Relationship to the Geology of Venice. It was in this environment that people settled in the year AD 421. Human intervention into Earth's processes has played a major role in the evolution of the Venetian Lagoon for over 1600 years. In fact, were it not for human settlement Venice might not exist today because the continued filling-in of sediment by several rivers that emptied into the lagoon could have

Fig. 5.23. "Quiet Morning in Venice." 1885. Walter Launt Palmer. 29 May 2009. Hawthorne Fine Art Web Site. 29 May 2009. <http://www.hawthornefineart.com/under20.html>.

filled it in leaving it as dry land or the land might have been reclaimed by the sea. In AD 421 the lagoon looked very different than it does today. It was a series of low sand banks with salt marshes and reeds. Figure 5.23 by Walter Palmer painted in the seventeenth century depicts what Venice might have looked like in the early days of settlement. Several large rivers including the Po and Piave drained into the lagoon, feeding the lagoon with very fine sands and muds. A lagoon is the brackish water area interchange

between fresh water and salt water that separates from the deeper water by exposed sandbanks, barrier islands and even reefs.

About four centuries after Christ Rome had lost much of its power. Although Rome collected taxes it did not protect the people in this region. The inhabitants of the coastal Adriatic Sea realized they could hide in the marshes and hoped they would not be followed there by the horse-riding barbarians from the north (Keahey 58). The marshes, reachable only by water, were great places to hide from the invading barbarians namely the Huns followed by the Lombards and others. The marshes had tall grasses maybe 3 m (10 ft) tall and actually made good hiding places.

It worked very well against those invaders but also against any invasion by sea since outsiders did not know exactly where the deep channels were and as a result avoided the region because their boats often got stuck in the mud banks (Keahey 58). Initially the inhabitants of this region hid in the marshes, and when the enemy left and it was safe they went back to their coastal villages. I find it interesting the way these ancient people used the local landscape to help them survive invading armies because it is usually more rugged terrain that is associated with military strategy. In this case they utilized the local terrain and it worked.

The evolution of people staying in the marshes was gradual. First it became a practice with successive invasions not to leave the marshes right away. Then they began to build small huts on stilts and stay longer. Some say were it not for Attila the Hun's invasion Venice might not have become established, but the Italians tired of hiding from the invaders determined perhaps this was their destiny: to build a city in the water that

had served them so well. Many decades later, they established permanent settlements in the lagoon, and by AD 638 the first settlement was built in Torcello. It was the seat of power. They also mined salt from the region during this time. In time sediment-filling from nearby rivers caused shallower water, and mosquitoes bred resulting in malaria. It was decided to move Venice's seat of power to a better location to where it is today.

The question is how did the Venetians build their homes in the marshes? This is the best part of the story of the technique they developed working with the local geology to build their city in the lagoon's marshy waters and muddy substrate. The lagoon's soft muddy deposits were not suited to building homes using the traditional means of laying down stones for the foundation. If they did, the stones would simply sink in the mud. The early Venetians had to figure out first how to build a foundation for their homes. They invented an ingenious way to create a foundation upon which to build their homes and eventually the entire city of Venice.

They took slender poles of alder trees and sharpened one end like a pencil. Standing each pole on end they sank it vertically into the underlying mud until the pole hit the clay and sand bottom that the Italians call "caranto" (Keahey 66). Caranto is the local soil that has been compacted so hard that it is almost lithified (rock like) due to its exposure to cold and arid climates over the past 11,000 years when sea level was lower. It is an over-consolidated silt-clay layer that separates the Pleistocene to Holocene (1.6 my – 10,000 years) (Critto, Carlon, and Marcomini 236). They continued sinking poles into the mud one next to the other until they filled all the space required for the outline of the structure.

This essentially formed the foundation for the structure (Keahey 66). It would be similar to inserting wooden match sticks in a block of clay vertically one next to the other until all the space was filled in. If the alder poles got too hard to sink they used a crude pile driver or drop hammer (Keahey 65). Over the centuries, they sank millions of these poles into the substrate. This wood surface was then covered with planks of oak and on top of this they laid slaps of Istrian marble (an impermeable stone) which would have been calculated to be well above the high-water line (Keahey 66). On top of this they placed the wood beams for the structure's frame followed by bricks along the exterior and faced the bricks with stucco.

As more and more of these structures sprang up in the lagoon they formed larger and larger clusters. The isolated islands of the lagoon grew towards each other connecting and forming the city of Venice. Meanwhile, the many streams pouring into the lagoon also became smaller as the Venetian dwellings were filling-in the water space that was occupied by the streams leaving narrow channels (fig. 5.26). This is how the streams became the canals of Venice (Keahey 67).

Let us reflect for a moment. I have just described that Venice is supported by wooden poles! It is true, even today those same poles laid centuries ago of 3-4 m (10-15 ft) lengths are still there. The reason they have survived is that compaction of the lagoonal sediments has squeezed out the oxygen so that the poles are in an anoxic (without oxygen) environment. This environment preserves the wood and actually hardened it to almost a petrified form (Keahey 68). I was stunned to learn about this building technique and that today Venice is still supported by ancient tree poles! How

amazing that the local culture embraced these lagoonal areas and built homes in what would seem like an impossible geologic setting. In fact, Venice flourished in this setting, rising to a City State of such great power that they dominated the region for the next 1000 years. Venetians became great seafarers trading with the Byzantine Empire and the Muslim world, and by the thirteenth century, it was the most prosperous city in Europe. Venice was raised in prominence, eventually gaining independence from Constantinople and becoming an empire of its own.

I said initially that Venice is sinking. It is true that global sea level rise caused by the melting of glaciers is adding to the city's water issues. In fact Venice is in very serious peril because there are three factors contributing to regular flooding episodes. The first is the fact that the sediment-laden Po Valley is subsiding due to its high load of sediment. Venice sits on the edge of the Po Valley thus Venice is also subsiding. This means 23 cm (9 in) total vertical lowering of Venice has occurred over the past 100 years. Of this total 12 cm (4.7") is due to land subsidence, which is broken down into natural subsidence 3cm (1.2 in) and anthropogenic (human induced) 9cm (3.5 in). The remaining 11 cm (4.3") is caused by something called eustacy or global seal level rise (Carbognin, Teatini, and Tosi 345).

As we know Venice is located in a sinking part of Italy's crust. This means the Adriatic Sea encroaches in the city with great regularity, particularly during precipitation events, flooding it in what are known locally as aqua alte (high waters). The citizens construct raised walkways the Italians call passarelle and people use these to travel around the city and often must wear rubber boots (fig. 5.24). It is not at all unusual to

have lobbies of hotels flooded and bellmen with their trousers raised to their knees walking about. This is life in Venice.

About one hundred years ago, St. Mark's Square was flooded only seven times a year generally following extremes in tide level as compared to today at over a hundred occurrences per year (Keahey 8). The instance of exceptional high waters 140 cm -194 cm (4.6 ft – 6.4 ft) occurred twelve times in the twentieth century. This may not seem

Fig. 5.24. "MOSE Project Aims to Part Venice Floods." National Public Radio. 7 Jan. 2008 Morning Edition. 5 Jan. 2009. <http://www.npr.org/templates/story/story.php?storyId=17855145>.

like much but for Venice, it is a dramatic evolution to its sinking history. Figure 5.25 shows St. Mark's Square during an aqua alta on December 2, 2008! Many of the buildings in the region are deteriorating as sea water reaches the bricks and begins to break them down. All basement windows are now cemented-in and no one lives in the

basement floor in Venice. Notice the deteriorating mortar on the brick in the left side of figure 5.26. Venice's population has dramatically declined from 184,000 in 1950 to 62,000 in 2004. It is simply too much trouble and costly to live in a constantly flooding city.

Several other factors contributing to Venice's sinking have been caused by humans over the past two hundred years. The Lagoon had seven openings to the sea, but

Fig. 5.25. "Venice Flood December 2, 2008." Rachel Donadio. The New York Times.com. 2 Dec. 2008. <http://www.nytimes.com/2008/12/03/world/europe/03venice.html?_r=2>.

those were closed and now only three exist that permit water exchange with the Adriatic Sea. Another human alteration is that deep channels were dug to create an industrial

harbor for large ships, and intertidal areas are now occupied by industrial sites. These anthropogenic changes have altered the hydrodynamics, accelerating erosion of the lagoon floor, silting up channels, and altering the flora and fauna (Brambati et al. 262). Humans have also increased subsidence dramatically by withdrawing too much water from the aquifers beginning in 1930 (Brambati et al. 262). It seems odd to think that water supports land, but ground-water does serve as a support for the land above it. Once

Fig. 5.26. "Canal in Venice." Personal photograph by author. 17 Jan. 2006.

removed there is a cavity, and you can imagine then Venice sinking without the ground-water for support (fig. 5.27). In addition to withdrawing water, methane gas was also extracted from underground and this added to subsidence. This is the story of why Venice is a city in peril having been attacked not only by natural phenomena but by human as well.

Everyone knows Venice is facing peril, but Venice has been embroiled for many years in laws, organizations and groups trying to save her. These parties sometimes have opposing opinions on how this should be done. All the while, the Italian government has not made fast decisions. Some think Venice has been there for seventeen centuries, why hurry? What is the best solution others ask? Despite all these delays, measures have been taken to remediate the incursion of the sea. Closure of artesian wells (for ground-

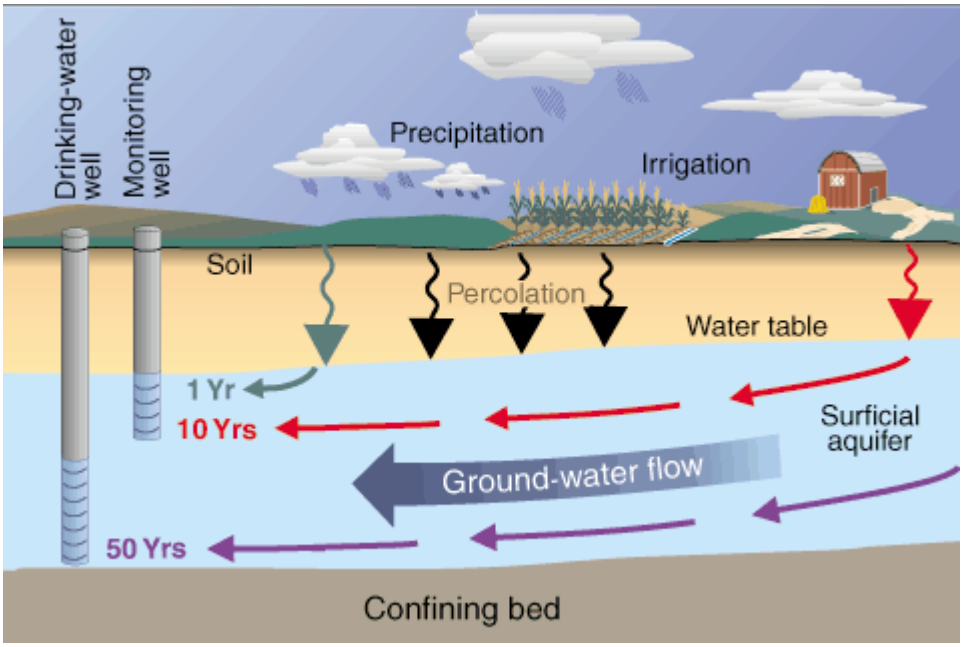


Fig. 5.27. "Ground-Water Diagram." Howard Perlman. USGS Water Science for Schools. 17 Nov. 2008, 8:52 EST. 10 May 2009 <www.usgs.gov>.

water) and the diversification of the water supply resulted in a quick reverse trend in subsidence due to ground-water removal by 1993 and is still the case (Brambati et al. 262). Methane is no longer extracted from the lagoon. Other efforts include constructed sea barriers (fig. 5.28).

The most ambitious project to protect Venice is called MOSE, the Italian word for Moses, and stands for Modulo Sperimentale Elettromeccanico (Experimental Electromechanical Module). Seventy eight gates divided into four rows are being installed on the sea bed at the three entrances into the lagoon: the Lido, the Malamocco and the Chioggia inlets. The gates are designed so they do not modify the water exchange between the sea and the lagoon to avoid damaging lagoon morphology. The

Fig. 5.28. "Mobile Sea Barrier at Malamocco Inlet in Venice Lagoon." National Public Radio. 7 Jan. 2008 Morning Edition. 5 Jan. 2009. <http://www.npr.org/templates/story/story.php?storyId=17855145>.

gates' metal structures would normally be filled with water at the sea bed. When a tide higher than 110 cm (43.3 in) is forecasted the gates would be emptied of water and would fill with compressed air which would allow them to rise until they emerge from the water and would temporarily isolate the lagoon from the sea, stopping the tidal flow.

Vessels would be allowed to pass and the gates are designed to be managed in a variety of ways depending on the winds, pressure, and level of the tide with differentiated or partial closure of each inlet. The total cost of the project is €4.2 billion (almost $6 billion). It is expected to be completed by 2012. MOSE is not a solution without problems and controversies. One of the environmentalists' greatest concerns has to do with cutting the lagoon off from the tides. The city has no plumbing system, but relies on the twelve hour tides to clean out the canals into which all waste is emptied from laundry to kitchen sink and toilets, all untreated and raw! The tides do their job of cleaning the city precisely every twelve hours by taking out the waste beyond the lagoon into the Adriatic and bringing in fresh seawater. Without the tides, nothing would clean the canals. For this reason, Italian law has been very strong in the protection of the canals.

Environmentalists are also concerned about the hydrogeological (the function of water and Earth) balance and delicate ecosystem of the lagoon. Another big concern is that the cost and maintenance is said to be much higher than alternative systems employed in other countries like the Netherlands and England. The world is watching and waiting to see if yet another human intervention to a natural setting will work this time to save Venice.

I have chosen a poem to end this section because I found it fascinating to realize that even 130 years ago people understood that Venice was in peril. It was written by Henry Wadsworth Longfellow in 1878 and is titled "Venice." Apart from the poem's tribute to Venice, I am impressed that early on there was an understanding of Venice's sinking problems.

Venice

White swan of cities, slumbering in thy nest
  So wonderfully built among the reeds
  Of the lagoon, that fences thee and feeds,
  As sayeth thy old historian and thy guest!
White water-lily, cradled and caressed
  By ocean streams, and from the silt and weeds
  Lifting thy golden filaments and seeds,
  Thy sun-illumined spires, thy crown and crest!
White phantom city, whose untrodden streets
  Are rivers, and whose pavements are the shifting
  Shadows of palaces and strips of sky;
I wait to see thee vanish like the fleets
  Seen in mirage, or towers of cloud uplifting
  In air their unsubstantial masonry.

Conclusion.

Italy is somewhat unique to have two mountain chains affecting its evolution. Comparing the Alps to the Apennines we saw that the majestic Alps are much higher and older than the much lower and younger Apennines. They are products of different Earth processes also. The Alps formed from continental-continental compression while the Apennines were raised by west to east compression. Both are beautiful mountains that people have inhabited for centuries. We went to Lake Como and studied the lake's evolution. The lake's origins have to do with a regional fault when the Southern Alps were undergoing extension. Geologic events of long ago and more recently the ice age have all left their mark on Lake Como. The lake is such a special place that the ancient people determined it was worthy of pilgrimages to sacred shrines they built in the mountains. They started this trend that spread beyond Italy.

We traveled to the Dolomite Mountains in the Southern Alps, which are characterized by flat-lying strata with craggy peaks on top. The dolomite, a derivative from limestone, was formed just when this region was still warm shallow seas before both the Alps and the Apennines. Nearby Bolzano gave us a chance to understand a little about the way humans have utilized copper through our story about Otzi the ice man. Although he was shot with an arrow and left to bleed to death, the residue in his hair told a story that he was most likely involved in copper smelting. Copper has been a big commodity in this region of the Alps and it is associated with dolomite from the local mountains. Interesting how early humans made that connection and figured out that dolomite cracked when it was burned so they burned the walls of the dolomite mines to break it up.

The Italians call Venice La Serenissima (the most serene one). Her formal name is The Most Serene Republic of Venice, Serenissima Repubblica di Venezia. It is precisely how you will feel when you arrive and realize you will have to leave your car outside the city because there are no traffic circles, no cars hurrying about, not even any motorinis, because transportation is by boat in Venice. It has an air of serenity and magically it envelops you as you try to take in the serenity. However, the city is sinking similar to other structures that are built on a muddy substrate. Venice is of monumental importance to Western civilization and there is a consensus to preserve it. Finally project MOSE may do just that. Seventy-eight underwater gates will be controlling intake of water during serious storm events. It will be costly to maintain, but is there an alternative?

CHAPTER 6 - A SLICE OF SOUTHERN ITALY
From Naples to the Promontorio del Gargano
Naples, Mt. Vesuvius, Pompeii, Phlegraean Fields, The New Italian Dinosaur Species and The Promontorio del Gargano
The Regions of Campania and Puglia

Fig. 6.1. "Campania and Puglia." Modified from Wikipedia, The Free Encyclopedia. 15 May 2009, 5:33 UTC. Wikimedia Foundation, Inc. 18 May 2009. http://en.wikipedia.org/wiki/Campania>. Campania is yellow, Puglia is red, route is blue.

Southern Italy encompasses all the regions south of Lazio to the "toe" of the boot in Calabria. In this section, we will focus on a slice of Southern Italy from west to east that includes Naples to the Promontorio del Gargano in the regions of Campania and Puglia (pronounced poulia). Naples has a lot to offer in geologic and cultural interest

because it is dominated by volcanic activity. There are two active volcanic areas in Naples, Mt. Vesuvius and the Campi Flegrei (Phlegraean Fields) from the Greek meaning fields on fire. I will discuss the geologic history of Naples in the region of Campania. This densely populated port city is built on the pyroclastic flows of the Campi Flegrei and Mt. Vesuvius volcanoes. It makes for an interesting albeit scary discussion because both of these are active. Vesuvius last erupted in 1944. We will investigate Vesuvius by examining why it is there and what the prospects for future catastrophe might be. In terms of past Vesuvian catastrophic eruptions I will discuss a well-known historic event that occurred in AD 79 when the volcano erupted destroying the prosperous cities of Pompeii, Herculaneum, and Torre del Greco (Greek Towers) (Dobran, Neri, and Todesco 551). Scientists have established zones of hazard around Vesuvius, and I will address how a future eruption might impact the city's residents.

Continuing with our volcanoes theme we will examine the Campi Flegrei calderas and the town of Pozzuoli, which has experienced a special type of earthquake that causes gradual uplift or descent due to magma emptying from the underground. The Phlegraean Fields is a volcanic field of calderas accessible by foot comprised of fumaroles (an opening in the Earth's crust near a volcano that emits steam and gases) and boiling mud. These calderas are located in the densely populated areas of Naples! You can visit the Campi Flegrei and walk among the gas-spewing calderas. Imagine this feature in the midst of a big city! Both Vesuvius and Campi Flegrei are a testament to the region's close relationship with the Tyrrhenian Sea's opening and the region's interactions between the African and European Plates plus the interactions of many other micro

plates.

I will discuss the geologic/cultural relationship to the volcanoes including Naples' underground city. In Roman times the Phlegraean Fields were thought to be the home of the God Vulcan. Our next stop will be the city of Pietraroia only a short distance northeast of Naples to see the fossil remains of a new species of dinosaur recently discovered in Italy. For the last part of our trip, I think it will be different to take you to the eastern Adriatic coast of Italy to see the Promontorio del Gargano (Gargano Promontory). It is the small portion of land in southeastern Italy that protrudes into the Adriatic. To me it looks rather like the spur on the Italian boot. In most cases, you will not find the Promontorio listed as a prime place to visit in Italy, but I think most guides focus on the more touristy places leaving out treasures like this.

You will see the famous white cliffs called faraglioni off the coast, and in these towering rocks, you will be able to read the story of the region's evolution. I assure you, you will not be disappointed. You will be enchanted by the Promontorio's dramatic beauty, private coves, and because it is home to Italy's only remaining forest (Foresta Umbra). Ancient oak and beech forests similar to the Foresta Umbra once covered much of Eastern Europe. We will also get to walk on the Tethys Oceans' continental slope here on the Promontorio del Gargano, an ocean no longer in existence.

Naples – Earth Established The Volcanoes, The Greeks Established A New City:

Let us consider our mission in Naples to discover the geologic roots of this great city founded by the Greeks in 800 BC. Its Greek name is Neapolis and it means new city. Permit me to admit here that I am a little proud of my own Greek heritage and its

profound influence on Naples as well as in the greater region of southern Italy. I will address Naples' geologic history and Earth's processes involved in its development. Millions of years before the Greeks arrived the Bay of Naples was already there. Let us start with the foundation upon which the city of Naples was built.

The greater area that Naples is situated on is called the Campanian Plain. It is a structural depression (extensional basin) of Plio-Quaternary age (5 my – 1.6 my) located between the Tyrrhenian Sea and the Southern Apennine Mountains. It is associated with the opening of the Tyrrhenian Sea (Bianco et al. 200). Figure 6.2 shows the Campanian Plain and you can see it is devoid of mountains other than Vesuvius and the Campi Flegrei volcanoes. The Campanian Plain's offshore extension is the Bay of Naples (Milia and Torrente 194). Figure 6.2 shows Naples built adjacent to the Campi Flegrei. The

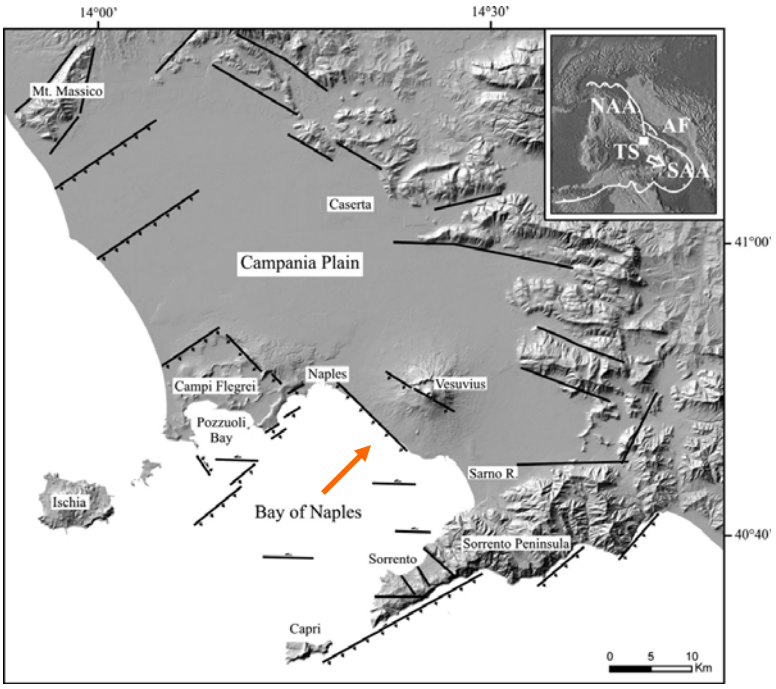


Fig. 6.2. "Structural Map of Campanian Margin." Modified from Milia and Torrente 193.

Bay of Naples is structurally what geologists call a half graben and it is connected to a rifted continental margin (extension) associated with the opening of the Tyrrhenian Sea (Milia and Torrente 194).

What is a half graben? Grabens are associated with normal faults. When tensional stresses pull on Earth's crust they produce normal faults. Differential movement on these faults can yield uplifted-blocks called horsts and down-dropped

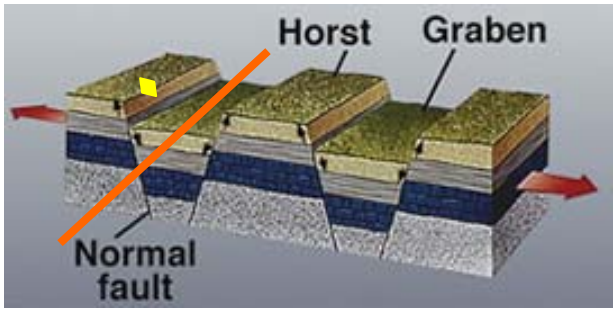


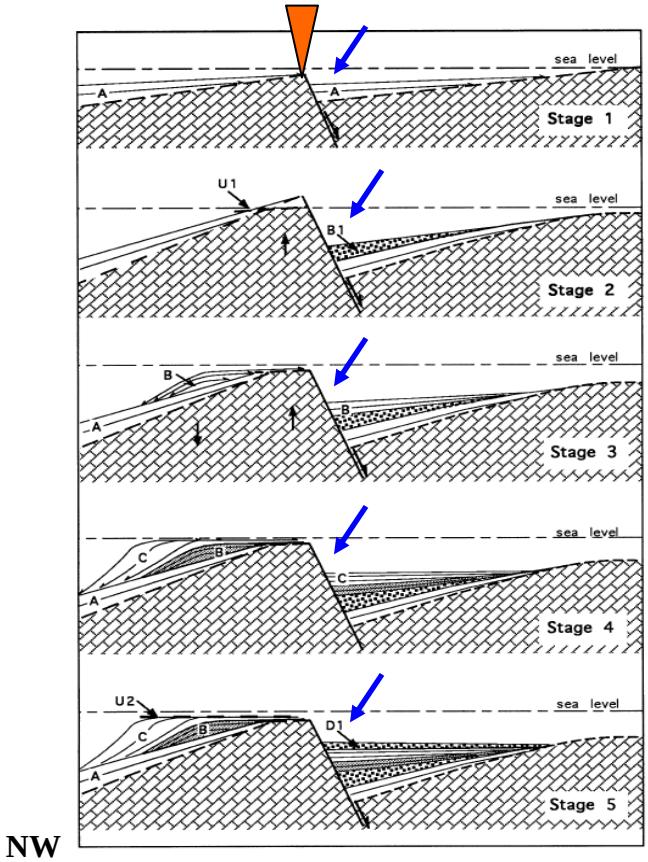
Fig. 6.3. "Graben." Modified from Wikipedia, The Free Encyclopedia. 6 Dec. 2008, 13:29. Wikimedia Foundation, Inc. 9 Feb. 2009. <http://en.wikipedia.org/wiki/Graben>. Orange line cuts a graben into two half-grabens. Yellow diamond is the hypothetical location of Naples showing the relationship of the city to the half-graben.

blocks called grabens (fig. 6.3). The orange line in figure 6.3 hypothetically divides the graben into a half graben like the one in the Bay of Naples. The orange arrow in figure 6.2 points to a normal fault, which is indicated as a line with hatch marks. The normal fault is the boundary of a half graben. The Neapolitan half graben formed at the rear of the Apennine Mountain front at the same time as the counter-clockwise rotation of the Italian Peninsula (Milia and Torrente 302).

Extension attributed to the Tyrrhenian Sea's opening during the Tortonian to Pliocene age (10 my – 5 my) formed a series of NS and NNW-SSE trending normal

faults. As extension continued during the Pliocene until the present (5 my – present) new faults became active in slightly different orientations (NW-SE, NE-SW and E-W). In other words, older extension faults became inactive and in later times new faults were formed that are currently active. Figure 6.2 indicates the normal faults as black lines with teeth.

These faults have controlled the morphology of the Bay of Naples. Extensional basins occur almost all along the eastern margin of the Tyrrhenian Sea. I have discussed this occurring in Northern Italy near Pisa, and further south near Rome in the region of



NW SE

Fig. 6.4. Two-dimensional Cartoon of the Five-Stage Tectono-Stratigraphic Evolution of the Bay of Naples." Modified from Milia and Torrente 302.

the Roman volcanoes. The geometry of the Bay of Naples is comprised of the two surface outcrops of the horst forming the boundary to the north which is the Campi Flegrei caldera, and the islands of Procida and Ischia (fig. 6.4). The boundary to the south includes the Sorrento Peninsula and the Island of Capri (Bruno, Rapolla, and Di Fiore 195).

Let us look at more details of the morphology and development of Naples Bay. Figure 6.4 shows and illustration of the development over time of Naples Bay in cross section. It is like looking at a vertical slice of Naples and the Bay. Stage one through stage five represents time intervals and the morphologic evolution over time of the basin in the Bay of Naples. Stage one would be when the half graben first formed. Notice that sea level at stage one is at the same level as Naples. Naples is approximately indicated by the orange triangle. You can see the horst on which it lies. Stages two through five show the basin getting deeper as more and more sediments come off the coast filling it. The way this works is sediment erodes from the horst, which is the uplifted high relief feature, then winds up down into the graben usually carried by water from rivers and streams or as ignimbrite volcanic flows in this case.

We have just learned the geometry of the Bay of Naples and that there are sediments offshore. In fact, Naples Bay (the half graben) is filled with 3000 m (9843 ft) sequences of sediments and volcanics from the Meso-Cenozoic about 35 my (Milia and Torente 302). This represents a huge package of sediments. Sediments include at least six ignimbrite deposits including the famous one from Vesuvius in AD 79. Recall from

the geologic primer in chapter one that ignimbrite (welded tuff) is the same as the volcanic rock tuff that comes from highly explosive volcanic eruptions. Naples Bay has

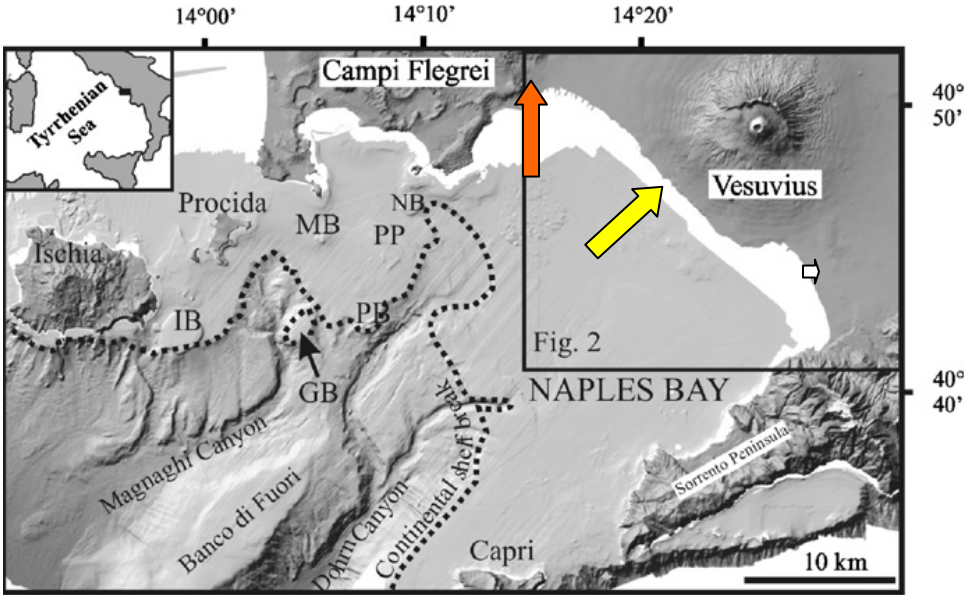


Fig. 6.5. "Physiographic Map of Naples Displaying the Continental Shelf and Two Canyons Across the Slope." Modified from Milia, Raspini and Torrente 59. Orange arrow indicates Naples, yellow arrow indicates shoreline.

a large continental shelf (the area between the shoreline and continental slope where the sea floor slopes gently in a seaward direction) (fig. 6.5). The shelf width is 20 km (12.4 mi) at its widest (Milia, Raspini, and Torrente 59). The yellow arrow indicates the shoreline. Figures 6.4 and 6.5 show the massive sediments offshore and you can see they extend well beyond the Bay. Alfonsa Milia and others have identified a submarine fan-shaped pyroclastic body that they interpret to be the submarine counterpart of the onshore pyroclastic deposits from the Vesuvian eruption of AD 79 (839). It lies at a depth from 10-140 m (32 – 459 ft) (Milia et al. 839). It is thought that the interplay between the three-dimensional geometry of the fault blocks and relative sea level formed the

continental shelf, continental slope, and deep basin of Naples Bay (Milia and Torrente 302).

The foundation rocks of Naples from the most recent to the oldest are a series of eruptions from the calderas of the Campi Flegrei volcanic fields and Vesuvius (ignimbrites and ash flows). The ignimbrite deposits date to the origin of the region's volcanoes starting during the Quaternary (about 1.64 my). Recent studies report at least six ignimbrite eruptions during the last 270,000 years (De Vivo et al. in Milia and Torrente 193). The first major eruption was that of the Campanian ignimbrite, a huge ash flow deposit that covered the entire Campanian margin about 39,000 years ago (De Vivo et al. in Milia and Torrente 193). This was followed by the second large-volume ignimbrite called the Neapolitan Tuff that came from the Campi Flegrei 15,000 years ago (Deino et al. in Milia and Torrente 193). The others were not as large as these two. These ignimbrite deposits have also been discovered offshore in the Bay of Naples. Many sequences of ignimbrite and ash volcanic flows are followed by a series of older carbonate successions of Mesozoic to Cenozoic age rocks. The Neapolitan volcanoes erupted ignimbrite similar to the volcanoes around Rome and in the Tuscan region (Auger et al. 1510).

The Cultural Connection to Naples' Geology. Now that we know the evolution and the foundation rocks of Naples and the Bay of Naples, let us turn out attention to the cultural relationship between the people and the city's geologic roots. The very volcanoes that produced the rocks shaped the terrain but the Neapolitans integrated these rocks into the most important areas of their lives. One of the places that will give us a

sense of the city's early connection with its geology is Naples' underground city. It is amazing to think that under this busy city is another city. There are literally millions of cubic meters of cave space covering most of the underground in Naples. You will want to take the underground tour offered mostly by archeology students. The entrance to the Napoli Sotterranea (Naples Underground) is located on Piazza San Getano 68. It is a little obscure in a section of narrow streets in the heart of the old city of Naples. The web site is: http://www.napolisotterranea.org/.

Various people built the underground over the centuries including the Greeks, the Romans and the Bourbons. The "sottosuolo" or city beneath a city has been mapped, catalogued and documented by the "Centro Speleologico Meridionale," the Southern Speleological Society of Italy. There are hundreds of grottos and caves. We know that the foundation of Naples is volcanic ash and ignimbrite deposits. The reason the tunnels under Naples were dug is because the yellow tufo is a great building material and easy to dig. If the rock beneath the city were granite (considerably harder), for example this would not have been possible. Mining it beneath the city also made it a convenient source of building material. Recall from chapter three this was also done in Orvieto for similar reasons. In Naples tufo was mined using access and removal shafts called "occhio di monte" or (eye of the mountain). The shafts beneath the city were half-oval shaped with the bottom flat.

After the building material was removed some of the tunnels were converted to water reservoirs using water diverted from the main aqueducts. In other cases they were converted into rainwater cisterns and into trash disposal sites. Here as in Orvieto and in

Rome they served as air raid shelters during WWII. If you take the underground tour in Naples you will see some of the graffiti from WWII Neapolitans who hid there. Some of the tunnels have been used to construct the city's rail way and subway tunnels. Several years ago the police discovered that portions of the city's underground were being used by the "Stolder Clan," who set up a drug laboratory in one of the underground caves. It was connected to various escape tunnels directly to the mob boss's house!

One of the more interesting cultural uses of the underground in Naples was as catacombs. These were places to bury the dead and places of worship. The catacombs in Naples are called the Catacombs of San Gennaro, the patron saint of Naples. They were the longest in use and have the best preserved frescoes in southern Italy. It is worthwhile to visit them (fig. 6.6). They are located in the northern part of the city near the Capodimonte (top of the hill) and accessed through the courtyard of the Basilica dell' Incoronata Madre del Buon Consiglio a Capodimonte (the Basilica of the Crowned Mother of the Good Counsel at the Top of the Hill). These burial places go back to the third to fourth centuries AD though it is thought they were used by earlier Christians. St. Agrippino, the third century bishop of Naples, is buried there.

Why bury the dead in elaborately carved tunnels? It is thought that catacombs started as simple quarries. The Romans burned their dead to ashes so they did not bury people in the catacombs, but it is thought that occasionally they threw the bodies of slaves and executed criminals into the quarries. Some think the Jews began the practice of burying in the underground. In time, Christians began to bury their dead in the underground and during persecution, it became a place to worship safely. Most of the

catacombs were built in the first five centuries AD. The catacombs of St. Gennaro contain extensive early Christian mosaics and frescoes from the second century. Over the centuries, many myths have developed in Naples about people's souls and the catacombs.

The Greeks not only established the city of Naples, they colonized Southern Italy. Sicily, Campania and Apuglia have been known as Magna Gracea (Greater Greece). The Greeks left their Hellenic traditions and culture in these regions of Italy. Some Greek

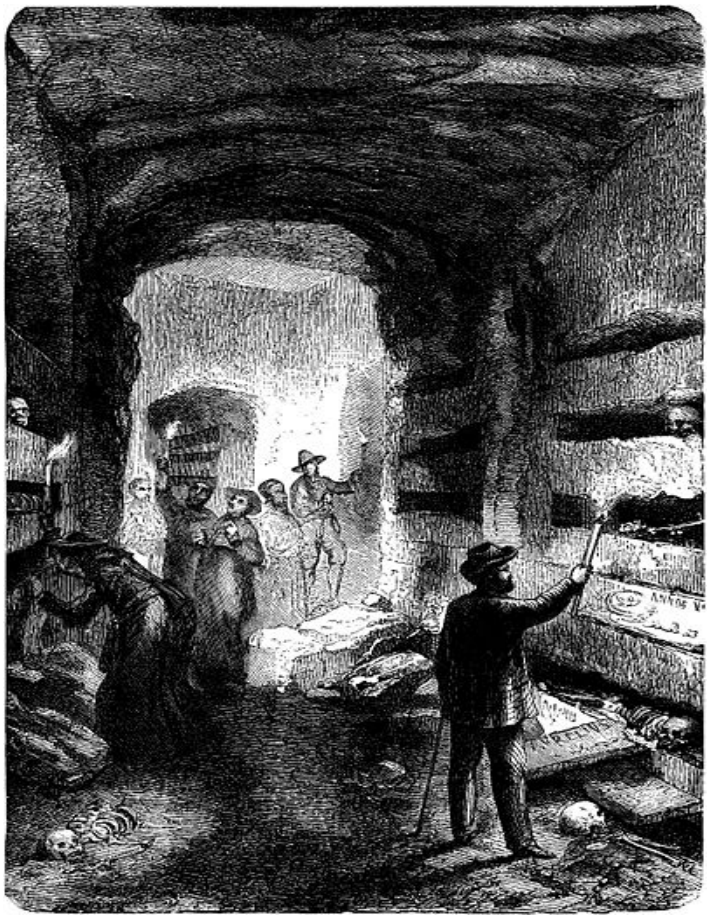


Fig. 6.6. "Catacombs of San Gennaro." Wikipedia, The Free Encyclopedia. 18 Mar. 2008, 12:18. Wikimedia Foundation, Inc. 13 Feb. 2009. <http://en.wikipedia.org/wiki/File:The-Catacombs-of-Naples.jpg>.

temples are well preserved in Southern Italy. One of the best preserved is the temple at Paestum dedicated to Hera (fig. 6.7). It was built by the Greek colonists around 550 BC. Hera was both the wife and older sister of Zeus and the goddess of marriage and childbirth. She was worshiped in this temple. There are two altars and it is thought it the temple could have been dedicated to Poseidon, the God of the Sea. In either case it is hard to find better preserved temples in Greece! The temple is made of limestone with some sandstone details. The sandstone was used where it was desired to have a soft stone in order to carve moldings (MacKendrick 230).

Fig. 6.7. "Second Temple of Hera, Paestum Italy." Personal photograph by author. 29 Sept. 2008.

The Greek cultural influence is quite strong and even today there are Greek-speaking towns in Southern Italy. Salento, known as Grecia Salentina, consists of nine towns in the region of Puglia (at the heel of the boot). The Greek spoken is a dialect called Griko but it preserves enough of the modern Greek that a Greek-speaking person

would easily understand. The local people are Catholic not Greek Orthodox but they continue to preserve the language. I hope to visit this region that my ancestors have so strongly influenced and to see if I will understand them. It will be a strange feeling speaking Greek in an Italian town, but this makes the point of the strong cultural ties that exist even today.

Mt. Vesuvius - The Angry Volcano.

Now let us take a drive east from Naples to the top of Mt. Vesuvius. It will take us about an hour to get there from the downtown are of the city. Once on the volcano we will park and walk for another thirty minutes along the soft cinder deposits on the rim of the caldera. We will look into the volcano and see areas where gases are coming out of vents. From atop the now quiet volcano we will be able to see the city of Naples stretching out in all directions. We might even consider the volcano's devastating power as we look at the multiple volcanic flows along its flanks. They appear in various shades of black to gray and are clearly distinguishable. This is Europe's most dangerous, most studied and best documented volcano. Let us consider the volcano's origins and evolution while we are driving there.

The volcano commonly known as Vesuvius is actually called Somma-Vesuvius. This is because it is comprised of an older volcano called Somma that was dissected by a caldera now known as Vesuvius (Cioni, Santacroce, and Sbrana 208). Figure 6.8 shows the cone inside the caldera. On the front right of the image you can see the road the leads up to the cone. Figure 6.9 shows the rim of the cone that we will walk on. The older

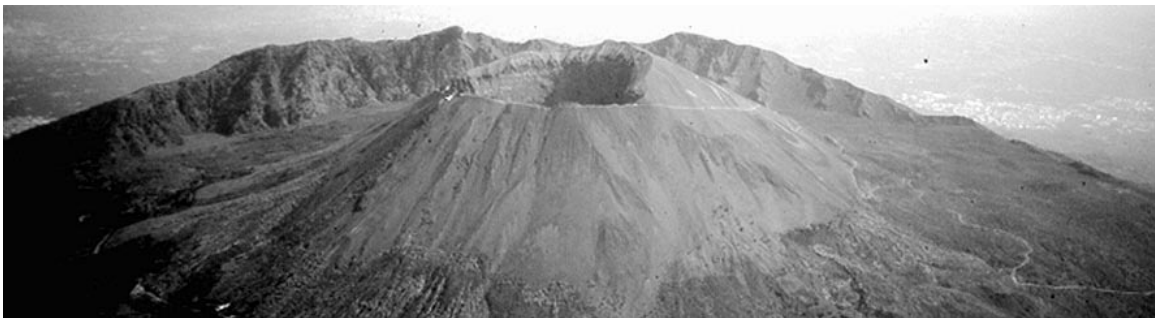


Fig. 6.8. “The Vesuvius Cone and Caldera Viewed From South Southwest.” Cioni, Santacroce and Sbrana 208.

strato-volcano (Somma) has collapsed repeatedly, the recent cone has not. That could happen during the next eruption depending on what type it is. The volcano’s geologic history tells us that it has had violent eruptive episodes that began 300,000-500,000 years ago (Bianco et al. 200). Vesuvius is 1281 m tall (4203 ft). Figure 6.10 shows the eruptive history, rock types, and geomorphology of the volcano including the Plinian type eruptions that I will be describing.

It is one thing to go to Naples and see Vesuvius; it is yet another to understand why it is there. Geologists understand these things and it gives us a unique perspective of what has occurred in this region to bring about the volcano. I hope the explanation of the volcano’s history will bring you a more satisfying appreciation of Vesuvius. Why is the volcano there in the first place, which Earth processes during Italy’s evolution produced it, and when?

Fig. 6.9. “Vesuvius’ Cone.” Colorviagi.com. 18 May 2009. <http://www.colorviaggi.com/data/vesuvio-half-day/2007-04-16.7911347184/image>.

Somma-Vesuvius developed during the Quaternary (1.64 my) along the western margin of the Campanian Plain. Volcanism was mainly a response to extension (the stretching of Earth’s crust that produces basins and volcanoes) related to the Tyrrhenian Sea’s opening. We have seen this scenario all along the western coast of Italy by now. The volcano is built at the intersection of NW-SE and NE-SW trending oblique-slip faults in a more or less perpendicular orientation NW-SE and NE-SW as well as normal faults that trend E-W (Cioni, Santacroce and Sbrana 208). Figure 6.10 indicates by the dashed dark lines the various orientations of the faults beneath the volcano. Movement of the SE sector of faults is moving E relative to the NW sector (Scandone and Giacomelli 192)! The exclamation here is warranted to appreciate the fact that not only is the volcano sitting on these faults but the faults are moving in different directions. Greatly simplifying these cracks in the crust beneath Vesuvius, just think of them

collectively as shaped like this X with each line segment (representing a fault) moving in different directions.

The stress fields of the faults also affect the greater Campanian Plain but they are not totally understood. All these faults are located in an area known as the Tyrrhenian 41st parallel, which has a system of strike-slip faults in the region (Bianco et al. 201). It is thought that both local and regional stresses are affecting the rate of the volcano's magma supply, the distribution of the eruptive fractures, and the vertical gravity-controlled movements due to loading of the magma inside the volcano (Bianco et al. 199).

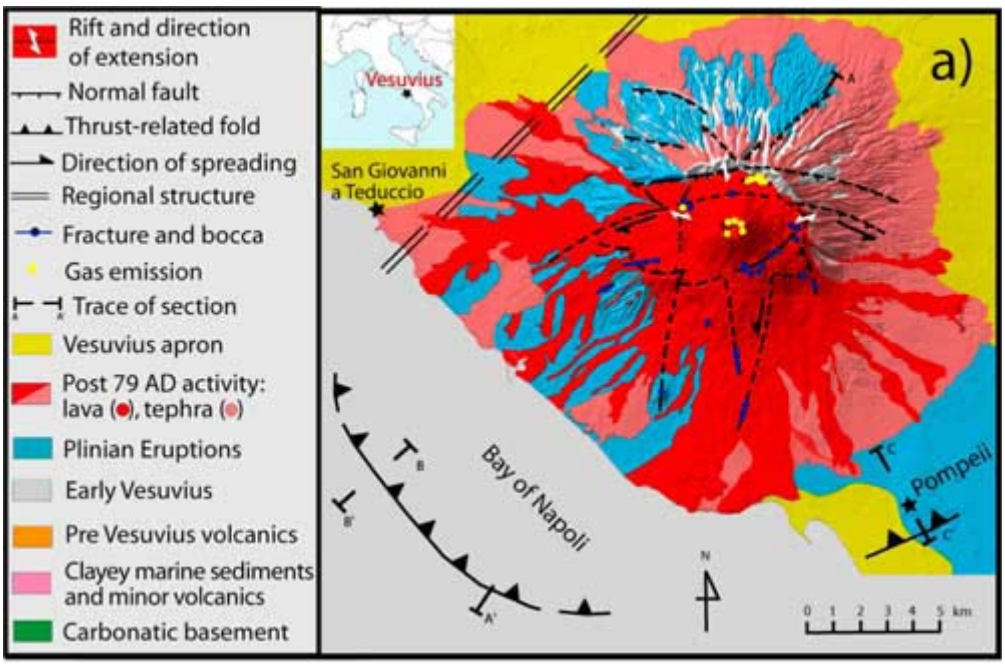


Fig. 6.10. "Geology and Structure of Vesuvius." From Borgia, A., P. Tizzani, G. Solaro, M. Manzo, F. Casu, G. Luongo, A. Pepe, P. Berardino, G. Fornaro, E. Sansosti, G.P. Ricciardi, N. Fusi, G. Di Donna and R. Lanari. "Volcanic Spreading of Vesuvius, a New Paradigm for Interpreting its Volcanic Activity." Geophysical Research Letters 32 (2005): 2.

The term “Plinian” was first used to describe highly explosive cloud type eruptions as witnessed and documented by Pliny the Younger in AD 79 (fig. 6.11). Plinian eruptions are explosive turbulent streams of fragmented magma and gases released at a high velocity from the vent and extending high into the stratosphere. It is characteristic of Plinian eruptions to have large amounts of tephra (pyroclastic eruption) and tall eruption columns. Following the Plinian eruptions, Vesuvius produces what geologists call phreatomagmatic explosions, meaning explosions that extrude both magmatic gasses and steam caused by the contact between magma and groundwater. The eruptions can be short or long. The longer eruptions can go on for months and produce clouds of volcanic

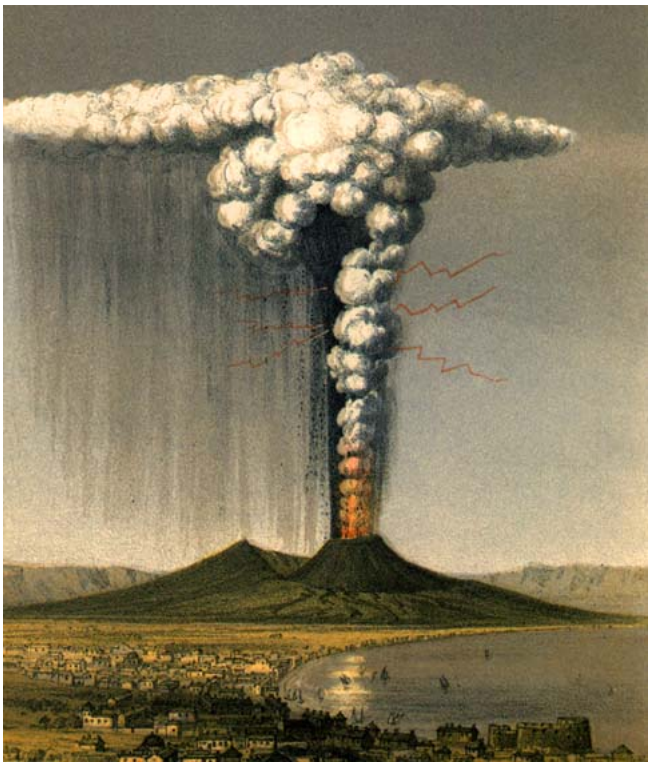


Fig. 6.11. “Vesuvius a Rendition in 1822 of What the 79 AD Eruption May Have Looked Like.” Wikipedia, The Free Encyclopedia. 6 April 2009, 23:57 UTC. Wikimedia Foundation, Inc. 19 May 2009. <http://en.wikipedia.org/wiki/File:Vesuvius1822scrope.jpg>.

ash sometimes with pyroclastic flows.

The reason for the volcano's violent (Plinian) eruptions is attributed to two things. First, with each Plinian eruption that collapses the caldera, there is destabilization in the volcano's shallow magma chamber followed by decompression in the water/magma fluids that are hosted in the surrounding rocks. Second, this destabilization process fractures the thick Mesozoic carbonate basement rocks beneath the volcano that are host for the aquifers and in turn causes additional destabilization and a more violent eruption (Cioni, Santacroce, and Sbrana 207). An interesting study by Cioni, Stantacroce, and Sbrana reconstructed Vesuviu's caldera after each Plinian eruption over the past 20,000 years. Figure 6.12 depicts eruptions 18,000, 8000, 3400 ago and AD 79 (A-F). The right side of the figure shows a bird's eye view of the volcano and a line bisecting the volcano positioned in the same place at each time interval. This line represents a cross section that is shown on the right side beneath the caldera image. The caldera rim is depicted as a circle on the left side of each sketch. Notice the caldera changes shape and size slightly from eruption to eruption suggesting the volume of the eruption may have changed.

Vesuvian eruptions are not all Plinian style. The last eruption of 1944 was not a Plinian type. It was characterized by explosions both small and large with lava flows within the rim of the caldera and outflows. The explosions destroyed 88 planes in a B-25 bomber group (volcanic ash clogs air plane engines) as WWII raged on plus the towns of San Sebastiano al Vesuvio, Massa di Somma, Ottaviano, and part of San Giorgio a Cremano. The volcano is also known for having Strombolian type eruptions. This type

eruption is named after another Italian volcano, the island of Stromboli, which is part of the Aeolian chain in the Tyrrhenian Sea not far from Naples.

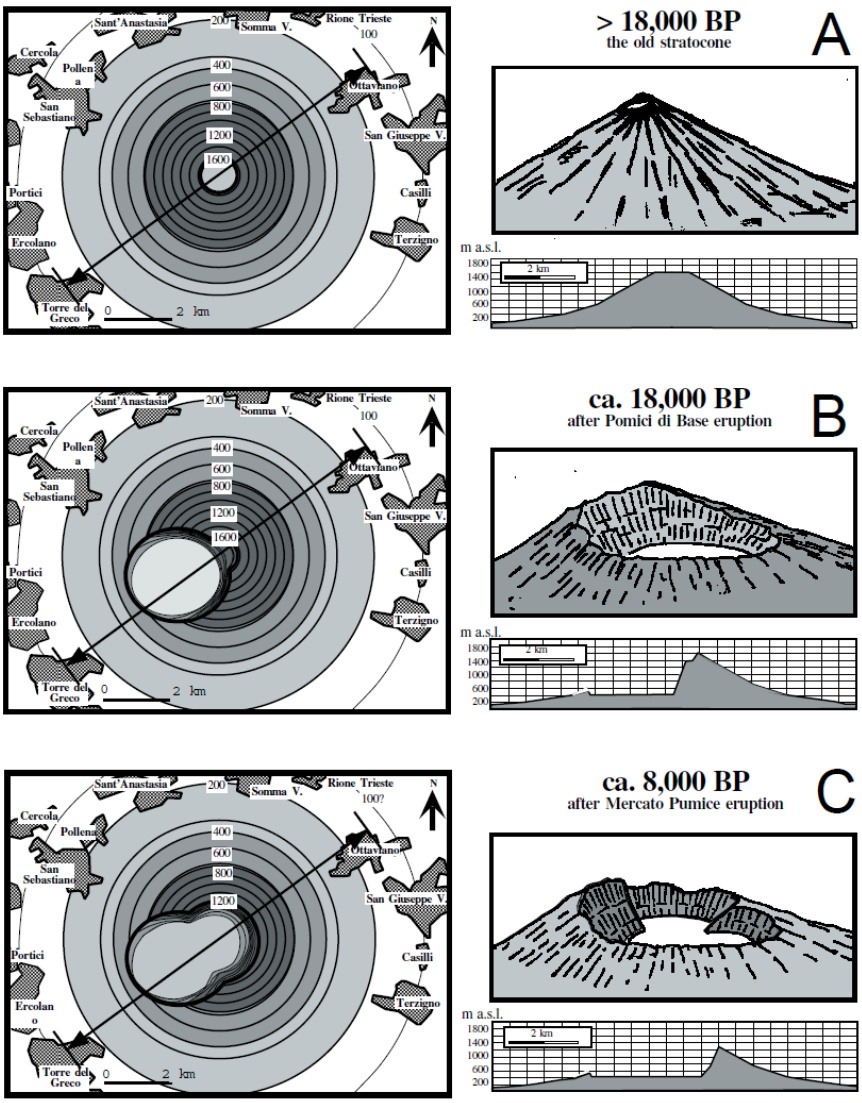


Fig. 6.12. “Reconstruction of the Morphologic Evolution of Somma-Vesuvius Caldera, the Ideal Reconstructed Topography, a Sketch of the Volcano (view from west) and the Morphologic Cross Section.” Cioni, Santacroce, and Sbrana 218 - 219.

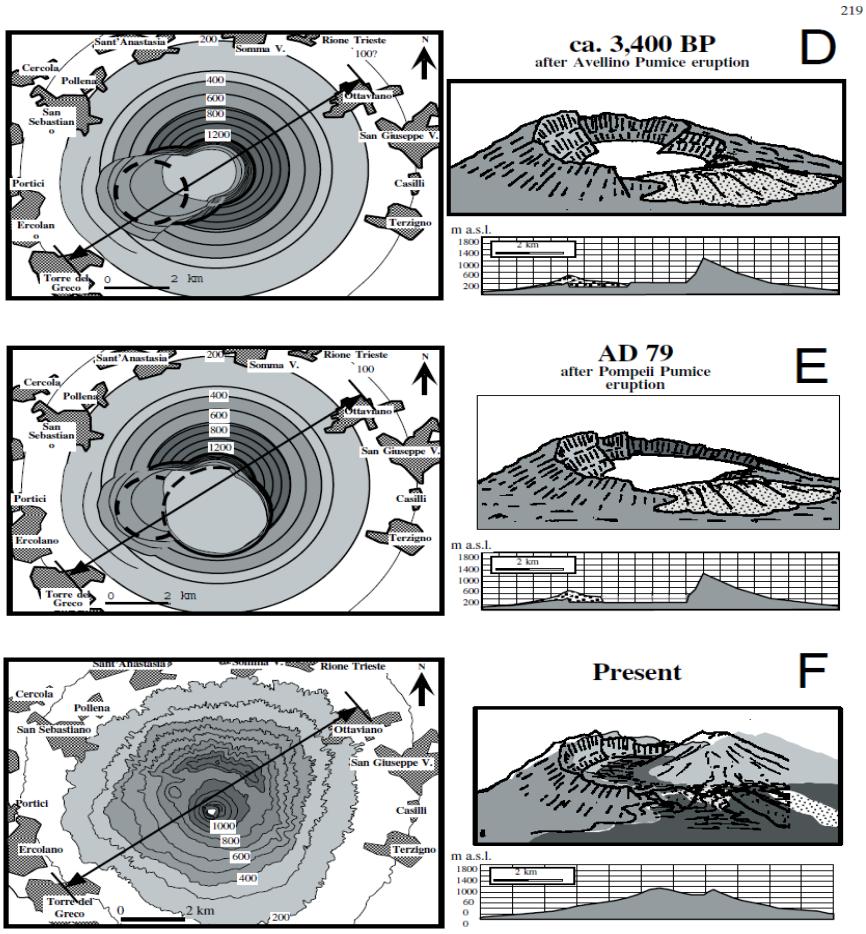


Fig. 6.12. Continued.

Strombolian eruptions are characterized by ejections of incandescent cinder, lapilli (small bits of tephra) airborne material, and lava bombs (small and large size molten rock) that can be ejected many kilometers from the vent. I like to make the analogy about Vesuvian eruptions to the volcano having a temper and the degree of an eruption depends how angry the volcano gets. If the Volcano is only irritated it may have

an effusive eruption like the one in 1944. At other times the volcano is more than irritated but not angry so it will have the Strombolian eruption. But when the volcano is angry that is when it is the most destructive with a Plinian type eruption like the one it had in AD 79. I call them the three personalities of Vesuvius.

The State of the Art of Forecasting Volcanic Eruptions. You might be wondering what the future holds for Vesuvius and if scientists can predict the next eruption. This is a good place to explain the science of predicting a volcano's activity. Volcanologists do not predict eruptions but sometimes they may be able to forecast an eruption. There is a distinction of terms here. To predict means to say with specificity when a volcano will erupt and the magnitude of the eruption. Volcanologists cannot do that. However, using some observation tools they may be able to say what they think may happen based on the past activity of a volcano.

One of the tools for forecasting a volcano's activities is by monitoring various aspects of a volcano's behavior. Several analogies can be drawn here between people and volcanoes. A doctor takes a patient's vital signs (blood pressure and heart rate) in order to predict if the patient will get heart disease. Doctors are trained to look for certain changes that will tell them the possibility of heart disease. In a similar way volcanologists monitor aspects of a volcano to forecast its behavior. For example we know volcanic eruptions are preceded by increased magma pressures leading to inflation (swelling up) as magma moves upward on a volcano's edifice and causes ground deformation. Monitoring this process using various techniques including measurements of the tilt of a volcano's sides can provide useful information to forecast eruptions.

However, just as each person is unique and may not respond exactly the same way to heart disease, volcanoes are also unique and may not respond in the way we think they will. For example a volcano may not show inflation because activity may be localized at depth with no visible changes on the surface.

Another indicator of volcanic activity may be the release of volcanic gasses and ground movement (seismic activity). Volcanologists know that as magma makes its way upward it may release gasses, and there are instruments on some volcanoes that measure SO_2 (sulfur dioxide) and CO_2 (carbon dioxide). In addition, magma moving upward is usually accompanied by increased seismic activity, and volcanologists can monitor this with seismometers. The integrated approach of all three tools, ground deformation, gas, and seismic activity are key for making educated guesses about a volcano's activity.

Although great progress has been made over the past several decades by studying previous volcanic eruptions, in most cases a volcano's strong eruption is only a short episode of its history. The fact is that most of the time the volcano remains in a quiescent state and therefore provides little information to forecast its future activity. Nevertheless, more is being done and newer techniques of monitoring are allowing scientists to get closer to the day when they can accurately forecast the activity of a volcano with enough lead time to allow for the evacuation of people in harm's way. But we are not there yet.

So what about Vesuvius? What kind of monitoring is taking place and what kind of eruption do volcanologists think will happen next? The historical record of Vesuvius is uncommonly long (since AD 79), and this helps volcanologists to understand this

volcano better than others. Located at 600 m (1968 ft) the Vesuvius Observatory (Osservatorio Vesuviano) is dedicated to research in the geological structure and improved monitoring of the volcano. Ongoing studies on the internal functions of the volcano provide valuable information that may be applicable to future activity, but of course no one can tell for sure what the volcano will do next. The volcano has both a shallow and a deeper magma reservoir. Marianelli, Metrich, and Sbrana found that during the 1944 eruption it emptied a shallow chamber (fig. 6.13) (48). It is recognized that during the Plinian type eruptions the volcano empties the shallow reservoirs of magma (Santacroce, Cristofolini and La Volpe 230).

Another study has looked at certain precursors to Vesuvian eruptions. For example there have been long reposes preceding violent explosive eruptions. It is thought that renewal of activity since the1944 eruption had been preceded by unrest lasting years to weeks. This may be because the volcano's rising magma must reconnect to the shallow reservoir that is probably 4 – 6 km (2.5 – 6.7 mi) deep (Scandone and Giacomelli 199). The study concludes that the seismic activity since 1944 is similar to that which preceded violent eruptions following the last period of permanent activity and that the seismic swarms (many earthquakes occurring close together in time and space) are caused by magma coming up into reservoirs at the same depth as those that fed Sub-Plinian eruptions (Scandone and Giacomelli 199). This represents another piece of valuable information about Vesuvian activity to better understand the volcano but does not mean the volcano will have another Plinian eruption in the immediate future. Things are more complicated than this.

Other studies of Vesuvius' pyroclastic flow hazards concluded that if the volcano has a large to medium type eruption (similar to the one that destroyed Pompeii) it could produce complete destruction in the 7 km (4.3 mi) radius around the volcano in fifteen minutes or less (Dobran, Feri, and Todesco 551). If the volcano has a small scale eruption it will probably be contained by the summit caldera Monte Somma. This study is based on mathematical modeling and vent conditions established by modeling magma ascent

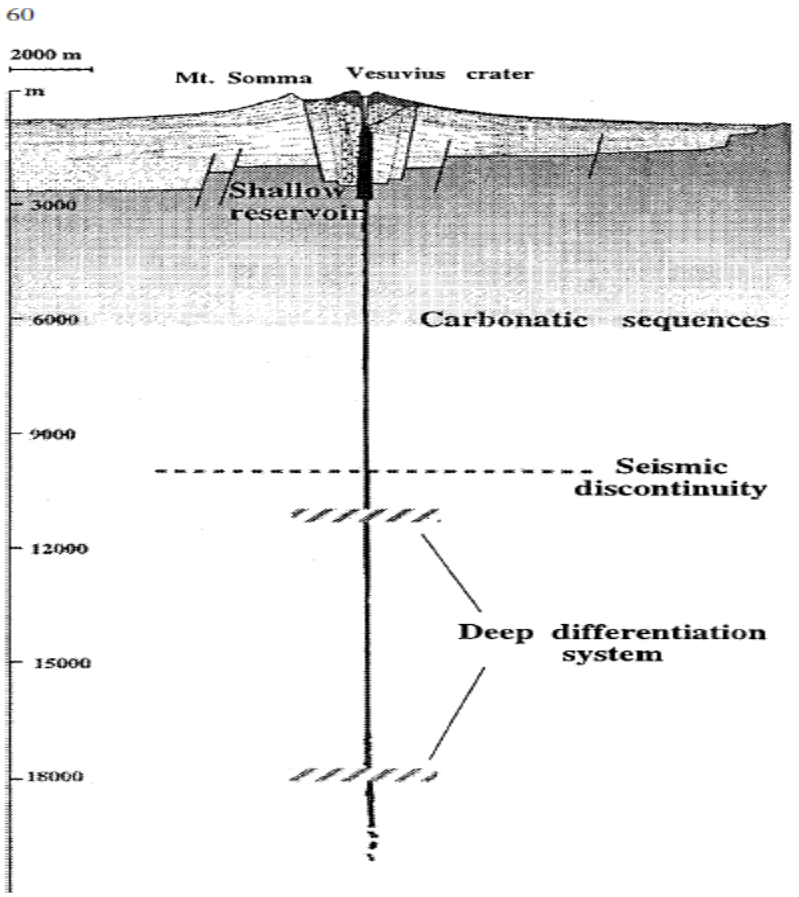


Fig. 13 Sketch of the feeding system of the 1944 eruption. Depth of the seismic discontinuity from Zollo et al. (1996)

Fig. 6.13. "Sketch of the Feeding System of the 1944 Eruption." Marianelli, Metrich, and Sbrana 60.

along the conduit using three different scales of eruption. In another study a mathematical model was set up to predict long term forecasting of Vesuvius' next eruption. The model is based on the principle that a complex system if perturbed will become organized again. Using data from the last 300 years of Vesuvius' activity, the study concluded that the volcano will have a Sub-Plinian eruption estimated to occur around AD 2030. Sub-Plinian implies not as large as the one that buried Pompeii. The idea of a less explosive next eruption is also supported by a recent article in National Geographic Magazine. Brian Handwerk reports a study of Vesuvian lavas led by Bruno Scaillet that suggests Vesuvius' magma reservoir has been migrating upward for the past 20,000 years, which could mean the volcano is less likely to erupt explosively (Handwerk 1).

These three studies agree that the next eruption will not be the magnitude of the one that devastated Pompeii. However, as I previously stated no one can predict exactly when the next eruption will occur and what type it will be. Scientists will likely get detailed eruption information immediately before and during the early stages of the eruption given the present level of forecasting capability. It is my hope that the science of forecasting volcanic eruptions will reach the level of sophistication where scientists can forecast a volcanic eruption with a high degree of accuracy and enough lead time to evacuate people before Vesuvius' next eruption.

Emergency Preparedness Plan for the Residents Within Vesuvius' Reach. The evaluation of Vesuvius' volcanic hazard has been at the forefront of most research during the past twenty years (Barberi et al. 247). As a result, in 1995 the Department of

Civil Protection approved an emergency preparedness plan that is currently in place which assumes a Sub-Plinian event. The plan outlines three zones of color; the Red Zone closest to the volcano extends about 236^2 km (90^2 mi) and includes 550,000 people (fig. 6.14) (Barberi et al. 248). This area will be exposed to pyroclastic flows and lahars (volcanic mudflows). Lahars can be deadly because of their energy and speed. They can flow several meters per second for many kilometers causing devastating destruction along their path. Outside the red area is the Yellow Zone that would be exposed to pyroclastic fallout and could affect another150,000 to 200,000 people. This estimate is based on the basis of field measurement from past Sub-Plinian eruptions (Barberi et al. 247). The Yellow Zone is large, but it is thought that only a limited part of it (about 10%-20%) is expected to be affected by ash fallout, depending on the sustained height of the eruption column and the prevailing wind directions (Barberi et al. 247). Next to the Yellow Zone is the Blue Zone that could be affected by large floods.

The emergency plan states that under this Sub-Plinian scenario the Red Zone (half a million people) will have to be evacuated *before* the onset of an eruption because there will not be sufficient time to evacuate them once the eruption begins (Barberi et al. 248). The plan estimates there will be seven days necessary to safely evacuate the Red Zone based on current infrastructure meaning roads etc. This means that the alarm will have to be activated before the eruption begins based on evaluation of eruption precursors (Barberi et al. 249). However, we do not have the capability of forecasting volcanic eruptions with this type of lead time. Therefore, this suggests that a false alarm is very

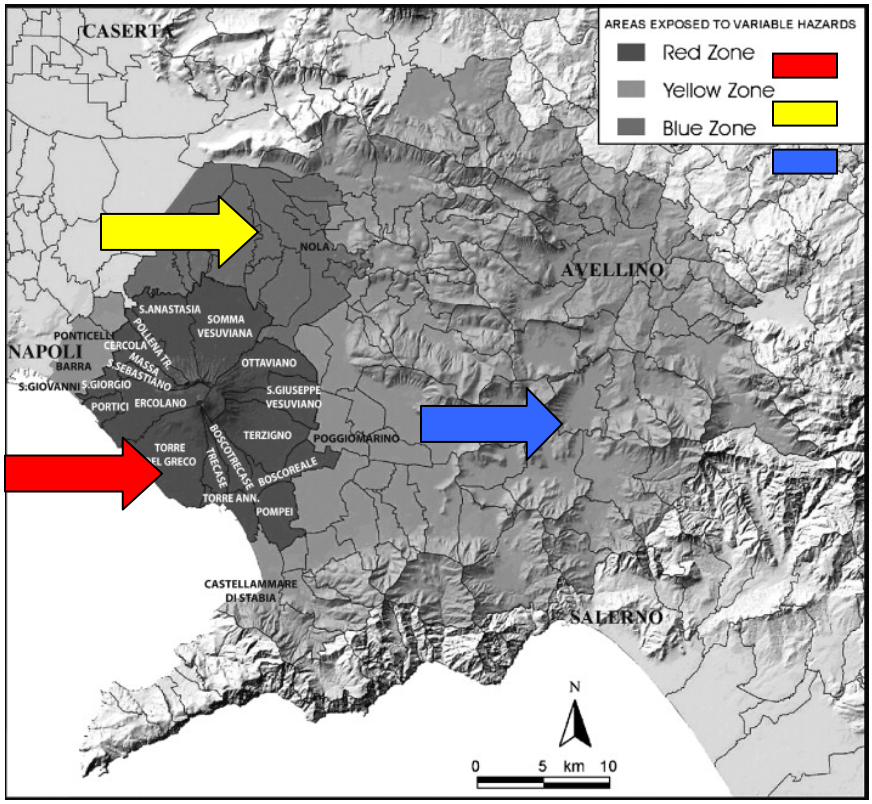


Fig. 6.14. "Hazard Zonation at the Base of the Present Vesuvius Emergency Plan." Modified from Barberi et al. 247. The color coded arrows indicate the red, yellow and blue zones.

likely. Imagine evacuating half a million people over a highly congested area for nothing! Having traveled the narrow streets of Naples I can say this could be a very difficult situation at best.

Based on a survey conducted by Barberi et al. of 2655 people surveyed, (which represents a 73.3% response rate), the Neapolitans who live in the area of the volcano's path seem to have a realistic view of the hazard and risk (244). They know an eruption is likely, they know it will have serious consequences, and they are worried. At the same

time they listed several other security-related issues as more likely than Vesuvius. The survey results indicated a widespread lack of knowledge about the emergency plan and a lack of confidence in the public officials responsible for carrying it out. The population at risk wants to be more educated about the danger and wants to participate in public discussions with scientists and public officials. This study concluded that a major education effort is absolutely needed to improve everyone's capability of facing such a volcanic emergency (Barberi et al. 247). It is my hope that the Italian government will undertake the necessary steps to educate the public and or provide the means and necessary infrastructure for people to be safely removed from harm's way when the next eruption does occur.

Religious Beliefs in Shaping Vesuvian Volcanic Risk. Italy's Roman Catholic tradition has influenced Italians in terms of how they perceive volcanoes, eruptions and other natural hazards. In a recent study addressing these issues covering the past 150 years it was argued that eruptions of both Vesuvius and Etna (on the island of Sicily) have been received with religious responses by the population. Cultural beliefs in Italy prevail that the Virgin Mary and Saints can intercede and change the outcome of disasters like volcanic eruptions. This is based on more modern beliefs that God's wrath may be appeased through human actions of repentance, changed conduct etc. In Southern Italy this conduct is often associated with ritualistic events like processions.

The tradition of processions has been occurring for centuries during eruptions of both Vesuvius and Etna. Processions are when people follow some type of religious

statue, image, relics, or other item considered holy through the streets. In Naples, this has been a long tradition going back to AD 305 when St. Januarius (S. Gennaro), the patron Saint of Naples, was martyred that year (Chester, Duncan, and Dibben 219). When Vesuvius erupted in AD 472 people for the first time prayed to Gennaro, and the citizens appealed to the skull and two vials of Gennaro's blood through various processions. It has been noted in a table of eruptions and religious response by Chester, Duncan and Dibben that severe panic is rarely mentioned in accounts of eruption responses to eruptions by Vesuvius and Mt. Etna (222). The authors found that during eruptions responses of intercessions (like processions) were occurring at the same time as more practical measures being put into place such as evacuations (222).

During the 1906 Vesuvian eruption a British diplomat expressed disgust at the fact the rather than running away from harm the most people did was to carry images of saints. He interpreted this calm reaction to be the pitiful exhibitions of superstition and ignorance (Chester, Duncan, and Dibben 221). The Diplomat said the women's behavior was a mixture of vanity and hysteria while the behavior of the men was ignorance.

I disagree with this assessment that disregards some important points. Should the people of the congested red zone region react with hysteria rather than calm during the next eruption many more will be killed just due to the high concentration of people and the limited access out of the city. The emergency preparedness plan to evacuate people from Naples would be more effective without citizen panic. I agree with the American scientist Perret who interpreted the people's reaction in a less biased way. He said "The

behavior (sic) of these stricken folk was admirable and a greater patience, resignation and 'savoir faire' could hardly have been expected of any race" (Chester, Duncan, and Dibben 221). Savoir faire describes the Neapolitans' response to the 1906 eruption very well. What more appropriate reaction to a situation could there be than calm and orderly conduct when faced with an emergency of such proportions?

Pompeii: the City Rained by Fire.

Pompeii was a prosperous and lively city in AD 79. Situated just at the south side of Vesuvius along the Gulf of Naples the town was a favorite for vacationing Romans who owned holiday villas there. Completely buried by volcanic ash from the eruption of

Fig. 6.15. "Pompeii." Wikipedia, The Free Encyclopedia. 20 May 2009, 18:06 UTC. Wikimedia Foundation, Inc. 14 Feb. 2009. <http://upload.wikimedia.org/wikipedia/commons/thumb/e/ed/LastdayofPompeii.jpg/300px-LastdayofPompeii.jpg>.

Vesuvius in AD 79 it is a well preserved display of city architecture and many other details of Roman every day life and society. The city was accidentally discovered as partof other excavations near the area in 1748. Besides the many well-preserved buildings there are well-preserved frescoes that have given us a detailed description of life during the first century. It is thought that there were about 20,000 inhabitants in Pompeii during the eruption.

Today you can walk the streets of Pompeii and it is like stepping back in time to AD 79 (fig. 6.16). You will see what kind of shops there were in Pompeii, the place of government, the villas, the many bakeries, and the wine stores similar to today's bars where you could stop for a drink. Pompeii had many restaurants called thermopolium

Fig. 16. "A Street Today in Pompeii." Wikipedia, The Free Encyclopedia. 18 June 2006. Wikimedia Foundation, Inc. 11 Feb. 2009. <http://en.wikipedia.org/wiki/Pompeii>.

where hot food and drink were served. There are preserved public lavatories in the Forum and twenty five brothels throughout the city. The buildings are located exactly where they were two millennia ago.

The first historic eruption of Vesuvius was a Plinian type and it occurred on August 24-25 of AD 79. It buried both Pompeii and Herculaneum (Hercolano) under 18 m (60 feet) of ash and pumice and froze life at that moment in Pompeii (fig. 6.15). The volcano's eruption was preceded by a very powerful earthquake in AD 62, thought to have been 7.5 magnitude, and several earthquakes in the preceding week just prior to the eruption. Being used to earthquakes the Romans thought nothing of it. In an ironic coincidence, the eruption of August 24-25 occurred the day after Vulcanalia, the festival of the Roman god of fire.

The eruption occurred in two phases: first the Plinian phase that lasted about eighteen hours and rained about 2.8 m (9 ft) of pumice on Pompeii. This was followed by a pyroclastic flow called a nuee ardente, French for "glowing cloud." The term is used for a fast moving cloud of hot gas and ash collectively known as tephra travelling at speeds of 700 km/hr (450 mi/hr) and at temperatures of about 1000º C (1,832º F). Nuee ardentes are so hot they glow red in the dark. As one might imagine the residents of Pompeii stood no chance against these elements.

The only surviving reliable eyewitness account of the eruption was recorded by Pliny the Younger, only seventeen years old at the time. He observed it from Misenum, which is across the Bay of Naples about 35 km (22 mi) from the volcano. His uncle

Pliny the Elder in command of the Roman fleet at Misenum, tried to rescue some people but died upon returning to the beach probably due to a heart attack or stroke. Others have speculated it was from inhalation of poisonous sulfuric gases, but it is unlikely due to the fact that his companions were not affected. This is what Pliny the Younger said during the first day of the eruption according to Giacomelli et al.:

> It resembled a pine {Mediterranean pine} more than any other tree. Like a very high tree, the cloud went high and expanded in different branches. I believe, because it was first driven by a sudden gust of air then, with its diminution or because of the weight, the cloud expanded laterally, sometimes white, sometimes dark and stained by the sustained sand and ash. (235)

It is thought that what Pliny the Younger is describing is the volcano's eruption column, now estimated to have been about 32 km (20 mi) high. On the second day Pliny the Younger observed the development of pyroclastic flows. Recall these are the clouds of superheated gas, ash and rock. This is how he described them according to Giacomelli et al.:

> From the other side, black and horrible clouds, broken by sinuous shapes and flaming winds, were opening with long tongues of fire…After a little while descended onto the land, opened the sea, covered Capri and prevented the sight of Misenun…(235)

From studies of the volcanic rocks we now know that most of this material was probably between 240° C (464° F) and 340º C (644° F) (Cioni, et al. 1). This suggests

that the ash cloud had a temperature of 850º C (1560° F) when it came out of the volcano and cooled to below 350° C (662° F) by the time it reached the city (Barberi et al. [1981] in Cioni, et al. 12). Pliney also stated that several tremors were felt at the time of the eruption that were followed by a very violent shaking of the ground. He said the sea was sucked away during the ground shaking and forced back, in what we know today to be a tsunami. He described thick ash falling and blocking the sun until the day became night.

These descriptions are powerful reminders of the volcano's might and of the plight of many people. It is not known how many were killed by the eruption; however, 1150 bodies and or casts (impressions in ash deposits) have been recovered. Archeologists made casts of the human molds by pouring clay into them (figs. 6.17-19). This is thought to represent but a small sample of the number of actual deaths. Most of the casualties during the first phase of the eruption are thought to have been caused by roof collapses.

During the second phase people were killed by the volcano's kinetic energy of the flow causing trauma (burns) or by burning ash in the atmosphere (Giacomelli et al. 235). The casts on exhibit in Pompeii create a moving effect as they bring the Pompeians back to "life" for us at the moment of their death. With arms raised and mouths open, one can almost feel the horror as the rain of fire engulfed the population (figs. 6.17-19). You can see many casts like these in the Archaeological Museum of Naples and in Pompeii itself. Pompeii has been designated a UNESCO World Heritage Site and is probably the most popular tourist attraction in Italy with over 2.5 million visitors in 2007.

Fig. 6.17. “Garden of Fugitives in Pompeii.” Kamran. Usefilm.com. 13 Mar. 2006. Photo Publishing Group 2005. 11 Feb. 2009. <https://www.usefilm.com/image/1069452.html>.

Fig. 6.18. “The Agony of Death in Pompeii.” BlogAndGo. 3 Sept. 2005. 11 Feb. 2009. <http://www.blogandgo.co.uk/A55A21/BlogAndGo.nsf/frmAbout?ReadForm>.

Phlegraean Fields – Not Another Volcano in Naples!

By now, you must be thinking there is quite a volcanic hazard in Naples. However, Vesuvius is not the only active volcano in Naples. There is another caldera in fact upon whose deposits Naples is built. It is called the Phlegraean Fields or Campi Flegrei, both names will be used (Auger et al. 1510). The Phlegraean Fields includes the volcanic island of Ischia, Vivara, Monte di Procida and a number of submerged volcanoes beneath the gulf of Naples (fig. 6.19) (De Astis, Pappalardo, and Piochi 622). These volcanoes that are not visible are called Formiche di Vivara, La Catena, Banco di

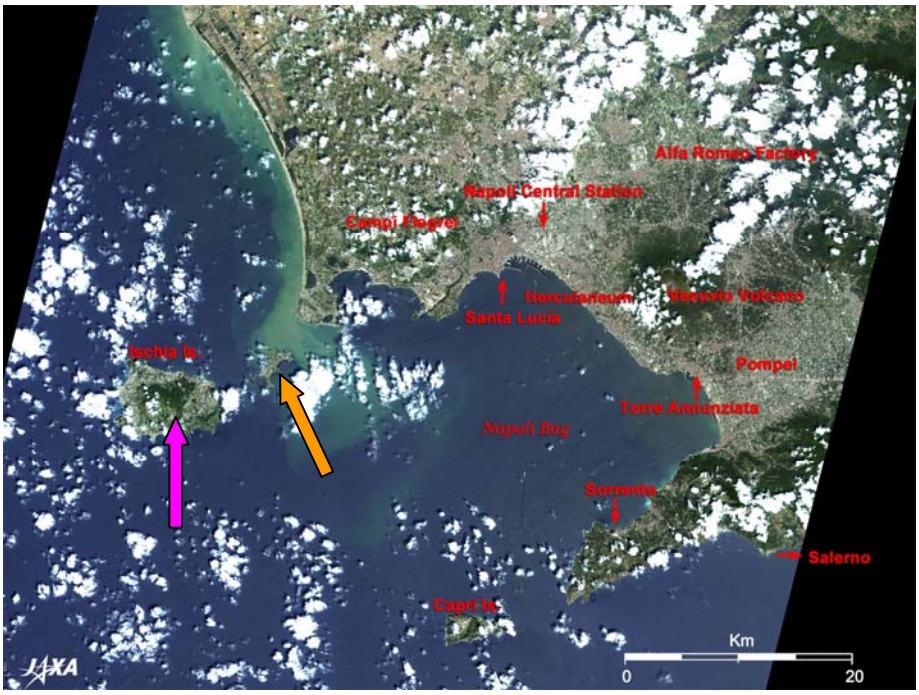


Fig. 6.19. "Satellite Image of Naples and Vicinity." Modified from Japan Aerospace Exploration Agency. 27 June 2008, 1001 UTC. Advanced Land-Observing Satellite. 24 May 2009. <http://www.eorc.jaxa.jp/en/imgdata/topics/2008/img/tp080206_01e.jpg>. Orange arrow points to Procida, pink arrow points to Ischia.

Nisida and Banco di Pentapalummo. The pink arrow in figure 6.19 points to Ischia, the orange arrow points to Procida. Vivara is so small and close to Procida it does not show in this image. Campi Flegrei is yet another large volcanic collapsed caldera in Italy of Quaternary age. It is about 36,000 years old, a little older than Vesuvius (Rosi et al. 541). Figure 6.20 shows the series of pyroclastic cones within the greater caldera. They appear as collapsed circular features. You can actually see the volcanic flows from the Campi Flegrei and Naples built right on top of them (indicated by the yellow arrow).

The Phlegraean Fields Volcanic District is one more set of volcanoes resulting from crustal extension associated with the opening of the Tyrrhenian Sea. We can see a

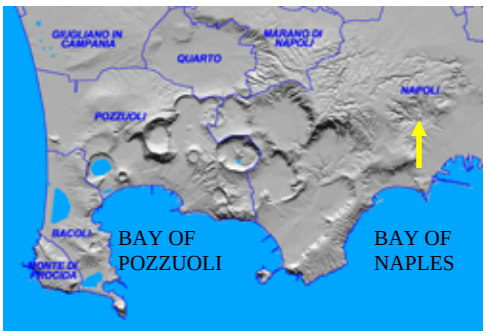


Fig. 6.20. "Phlegraean Fields Digital Elevation Image." Modified from Protezione Civile Nazionale.15 Feb. 2009. <www.protezionecivile.it>. Yellow arrow indicates Naples.

pattern of volcanoes all along the west coast of Italy. The volcanoes in southern Italy and the others to the north are distributed along the main line of extensional faults in Italy (fig. 6.21) (De Astis, Pappalardo, and Piochi 622). In other words we can see volcanism along the NE-SW fractures in a systematic fashion from Tuscany to Campania since

extension of the Tyrrhenian has been occurring all along Italy's western margin. It has been suggested that it is the NE-SW fractures that are responsible for controlling the ascent of the magma in the Phlegraean Fields (De Astis, Pappalardo, and Piochi 624). It makes sense geologically because the magmas erupted from the alignment of volcanic vents show similar isotopic and chemical properties, suggesting they are coming from the same source (De Astis, Pappalardo, and Piochi 638).

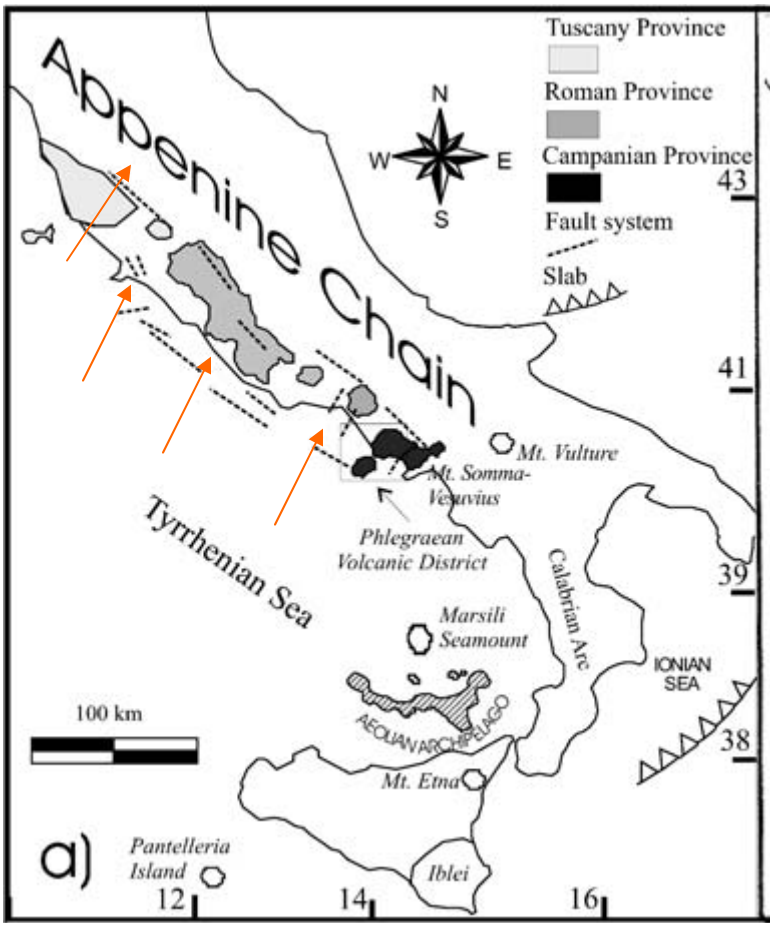


Fig. 6.21. "Distribution of Volcanic Activity and Main Tectonic Lineament, in Italy." Modified from De Astis, Pappalardo and Piochi 623. Orange arrows indicate normal faults and showing three volcanic provinces along Italy's western coast.

Figure 6.22 is an image of Monte Nuovo (New Mountain) along Pozzuoli Bay. It is Europe's newest mountain in the Phlegraean Fields. This image shows the physiographic expression of the mountain and several of the other calderas now filled with water. Figure 6.23 is an image inside the caldera showing sulfur rising from vents. The Phlegraean Fields history of eruptions as recorded in the rocks tells us that it was the site of an eruption of unprecedented world proportions that occurred 36,000 years ago (during the late Quaternary). This was the eruption of the Campanian Ignimbrite that violently erupted as pumice and ash and covered a vast area of southern Italy (Rosi et al. 542). It is estimated the same eruption covered an area over of 7000^2 km (2703^2 mi) (Rosi et al. 542).

Fig. 6.22. "Monte Nuovo, Naples Italy." Modified from Donnalbina7. 15 Feb. 2009. <http://www.donnalbina7.it/immagini/foto-colore-free/campi-flegrei/monte-nuovo/nuovo-e-averno.jpg>. 40°50'00.05"N and 14°04'59.79"E.

Fig. 6.23. "Campi Flegrei." Wikipedia, The Free Encyclopedia. 24 July 2005, 19:45 UTC. Wikimedia Foundation, Inc. 15 Feb. 2009. <http://en.wikipedia.org/wiki/File:Campi_Flegrei.JPGa>.

Figure 6.24 shows the evolution of the eruption in five stages of volcanic events. The first phase (a) was the Plinian fallout characterized by a high column and raining volcanic ash; (b) is the pyroclastic flow stage leading to ignimbrite and volcanic breccias (igneous material cemented together); (c) more pyroclastic flow; (d) more breccia, dominant magmatic explosion and collapse of caldera; and (e) more caldera collapse and emission of pumice and ash flows from various vents within the caldera (Rosi et al. 553). The Campi Flegrei erupted of the Neapolitan Yellow Tuff about 15,000 years ago, and since then there have been numerous recurring explosive and effusive (less explosive) eruptions (Santacroce et al. 231). The last eruption was the one in AD 1538 that produced Monte Nuovo (Civetta et al. 415).

The Campi Flegrei is an area of intense volcanic activity where the ground exemplifies strong deformation at least since Roman times (Civetta et al. 415). This is to say the ground is uplifted slowly and then lowered again in periodic episodes involving seismic activity. In geologic terms, this is called bradyseism. A dramatic example of this is in the town of Pozzuoli that lies in the center of the Campi Flegrei along the sea. The Temple of Serapium or ancient market place located in Pozzuoli is shown with several columns. In figure 6.25, you can see dark rings around the columns. These rings are holes made by lithodomes (sea mollusks living in coastal areas between high and low tide areas). The rings indicate how far the temple columns were submerged into the sea during these brandisism episodes. Today the Temple of Serapium is not under the sea. From 1969-72 and 1982-84 the inhabitants of Pozzuoli experienced the Earth's surface

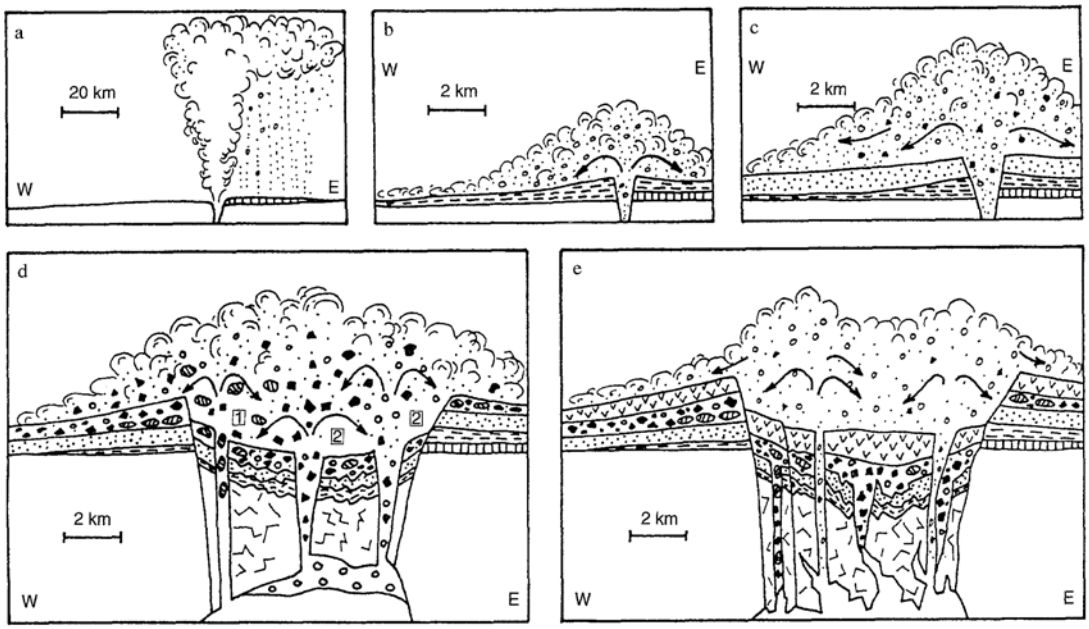


Fig. 6.24. "Eruptive Stages and Vent Evolution During the Campanian Ignimbrite Eruption." Rosi, et al. 553.

rising 3.5 m (11.5 ft) within a few months (Voltattorni et al.180)!

Geologists believe that these periods of ground unrest are a result of complex interactions between the magma chamber and hydrothermal fluid circulation all going on below the surface (Todesco et al. 532). The ground's up and down movement is as though it is taking breaths in and out. It is like the up and down movements of breathing. When the ground "breathes out" there is collapse and the area gets submerged and when it "breathes in" there is uplift. There is great volcanic risk at Campi Flegrei just as at Vesuvius nearby because Campi Flegrei is volcanically active and located in a highly

Fig. 6.25. "Nicola e Pina. Temple of Jupiter Serapis, Pozzuoli, Naples." Panoramico Contest. 29 Oct. 2007. 15 Feb. 2009. <http://static.panoramio.com/photos/original/5617227.jpg>.

urbanized area. An emergency plan is also in place here. The area of highest risk (Red Zone) would affect 350,000. As with Vesuvius the warning must go out before the eruption, but once again current volcano forecasting cannot be made but a few hours in advance of an eruption (Santacroce et al. 232).

The Campi Flegrei area has been the site of cultural and strategic importance since ancient times. It was known to the ancient Greeks who had colonized nearby in Cumae, which was the first Greek colony in Italy. In nearby Bacoli, the Romans had their military academy headquarters, and the Appian Way passed through this area. The most ancient hot springs complex built for the richest Romans is located at Baiae, a district in Bacoli. Hot springs are areas where geothermal heat will heat ground water above body temperature that is comfortable for soaking. They occur all over the world. Many people in Italy believe hot springs have healing properties, and people often will soak in them just as the Romans did. In some volcanic areas the water is superheated or boiling, and people have been burned to death by going in them.

Pietraroia Home to Italy's New Dinosaur Species – Say Hello to Ciro.

It is time to leave the volcanoes of Naples and head eastward to the town of Pietraroia (means "red stone" in Spanish), a village in the province of Benevento, to meet Ciro. Ciro is the first and only dinosaur discovered in Italy. We are going to Pietraroia for one reason only and that is to see the place where a new species of dinosaur was discovered in Italy! The exclamation is justified because Italy is a most unusual place to find dinosaurs. This is because the rocks of Italy during the Mesozoic (the time of the

dinosaurs) were made in marine settings but Ciro did not live in the sea. Italy's many vertebrates are from a marine environment. The name Ciro, a typical Neapolitan name, was given to the little dinosaur by the-editor-in-chief of the Italian magazine, Oggi, (Today) that published a story about the discovery.

Let us now journey back to the Middle Cretaceous (about 110 my) and see what it was like at the time of Ciro. During this time recall that most of Italy was submerged by the Tethys Ocean and was broken up into various carbonate platforms. Some of the areas were above sea level and for this reason there would have been transitional environments with plants and animals. The climate during the Jurassic in this region was tropical with lush forests and vegetation. This was the environment in which our friend *Scipionyx*

Fig. 6.26. "Tidal Flats." American Geological Institute, Bruce Molnia. 2009. 24 May 2009. <http://www.earthscienceworld.org/images/search/lightbox2.html?ID=hpe3ql>.

samniticus known as Ciro walked around. The coastal tidal flats environment in which the dinosaur was found was the perfect area to preserve the little dinosaur. We might imagine a similar environment today in (fig. 6.26).

As Ciro and other dinosaurs walked around they left footprints in the mud or maybe they even died there and became preserved over the millions of years that ensued. What is extraordinary in this case is that Ciro's soft tissue has been preserved (fossilized). There are only a handful of specimens around the world that have been found with soft tissue preserved. Hard parts such as bones preserve easily but it is rare to find soft tissue preserved because burial conditions have to be extremely specialized for this to occur. Other parts of the anatomy never before seen on any dinosaur in the world are also preserved. The most important is that there are several internal organs are perfectly preserved and three dimensional (Dal Sasso 81).

We can speculate how Ciro died. Maybe the little dinosaur was caught in a sudden violent storm (Dal Sasso 94). Perhaps the wind and tide dragged the body into the shallow water of the lagoon, to be drowned and then covered with sediment. Figure 6.27 is a close up of the muddy substrate exposed when the tide is out. This is the type of environment where Ciro would have fallen and gotten buried. Very rapid burial and exceptional circumstances in the burial area forming a sort of microenvironment also had to occur for the dinosaur to begin fossilizing within a few days. Quick mineralization

Fig. 6.27. "Close-up of Muddy Tidal Flat." American Geological Institute, 2009. 16 Feb. 2009. <http://photo.agiweb.org/utils/showimage.php?ID=hna4kg>. Scale: smallest air holes are about the size of a dime.

preserved the skin and outer tissues. Some thousands of years later the little dinosaur was completely replaced by minerals before the sediments were compacted and became limestone on the bottom of the Tethys, forming the rock in which Ciro was nicely enveloped. Then within the last 40 million years, the Apennines rose and so did Ciro, well-preserved within the limestones and uplifted with the mountains to what would be called the Matese Massif 960 m (3200 ft.) above sea level in Pietraroia, waiting to finally be discovered (fig. 6.28). Ciro was a very young dinosaur, perhaps a few weeks old, but the gender cannot be determined (Dal Sasso 96). The entire specimen was only 38 by 26 cm (14 in by 10 in) (Dal Sasso 203). Ciro would have weighed about half a kilo (17 oz) and might have grown to about 25-30 kilos (55-66 lbs) as an adult and reached not more than 1.5 m (4.9 ft) in length (Dal Sasso 71).

The discovery of this famous Italian dinosaur did not happen by a renowned paleontologist but by a novice who loved fossil hunting. His name is Giovanni Todesco, a footwear technician from the city of Verona in Northern Italy (Dal Sasso 55). He had a passion for fossil hunting, and he took advantage of opportunities to do it whenever they

presented themselves. On a business trip to Avellino in 1981 he decided to go on a fossil hunting excursion during the weekend. He headed for Pietraroia, which was only about 55 km (34 mi) from Naples. The area Giovanni visited was well known and studied since 1798 for its numerous fish fossils so it was a big surprise that a dinosaur would be found there (Dal Sasso 203). Giovanni headed for a nearby dump that had been a limestone quarry for building material. There as he was removing slabs of stratified rock he noticed what looked like bone fragments but realized there was a skeleton of a small animal that did not look like a fish. The fossil was almost complete; the only missing parts were part of the tail. Anatomically every part was there indicating that at the time of death the little dinosaur was not transported nor did it suffer from predation (Dal Sasso 66).

Giovanni took the fossil home and tried to clean it but not realizing the significance of the specimen, he stored it in a drawer for eleven years. In 1992 he decided to ask a paleontologist from Milan, Giorgio Teruzzi to examine it (Dal Sasso 57). Upon inspecting the specimen through the microscope and realizing what he had, Giorgio overcome by emotion declared "I am the first Italian paleontologist to see the first Italian dinosaur" (Dal Sasso 57). Several years of restoration and preparation ensued to prepare the specimen and conduct extensive studies to be sure Ciro belonged to an unknown species. The findings were published in Nature, which featured it as a cover article. This news caused quite a stir around the world (Dal Sasso 64).

The name the dinosaur was given, *Scipionyx samniticus*, had to come from a historical perspective in keeping with Italian culture. Thus, the first part of his name

“Scipio” comes from the scholar Schipione Breislack who was the first to describe the fossils of the Pietraroia region. It also honors the Roman general Scipio Africanus who defeated Hannibal. The other part of his name “onyx” means claw in Greek, and since

Fig. 6.28. “Ciro In the Rock the Dinosaur was Found.” La Republica.it. 26 Mar. 1998. 26 Mar. 2009. <www.geologi.it/pietraroja/images/ciro-vivo.jpg>.

the little dinosaur had large curved claws the name *Scipionyx* seemed appropriate (fig. 6.29) (Dal Sasso 64). Figure 6.30 is a reproduction of what Ciro might have looked like. If you would like to meet Ciro, who has been waiting some forty million years to meet you, stop by the Natural History Museum in Milan where the little dinosaur is displayed.

Fig. 6.29. “Ciro’s Nail.” Dal Sasso 75.

Fig. 6.30. “Reproduction of Ciro.” La Republica.it. 26 Mar. 1998.
26 Mar. 2009. <www.geologi.it/pietraroja/images/ciro-vivo.jpg.>.

The Promontorio del Gargano - Let us Walk on the Wild Side of the Tethys Sea.

Now let us leave Ciro but we can stay in the same geologic time period (110 my)

that the little dinosaur lived. We will look at other rocks of the same age which were deposited in the Tethys Sea that was separating the European and African continents. As promised we can actually walk on the ancient Tethys. We are going to the east coast of Italy to do this. It is exciting to think that we will actually see the sediments of an ancient oceanic margin preserved in the rocks, and we will walk on them imagining ourselves back to the time of the Mesozoic.

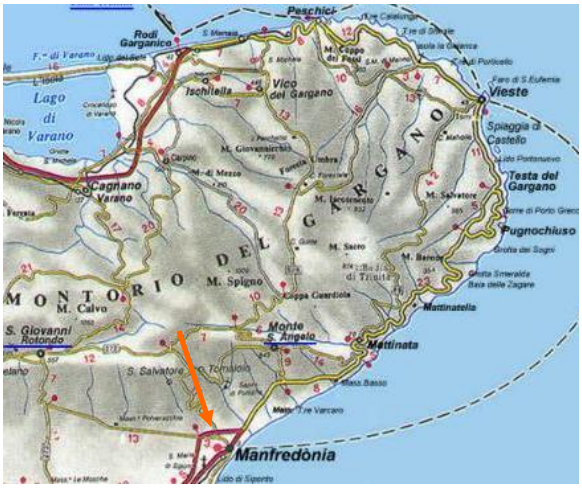


Fig. 6.31. "Promontorio del Gargano." Modified from Italy Travel Guide.Com. 8 Feb. 2009. <http://www.italytravelsguide.com/gargano-peninsula.php>.

The place we are going is called the Promontorio del Gargano, and it is not well known in travel literature. It is the area on the southeast coast of Italy that juts into the Adriatic. To get there we will leave Ciro's mountain, the Matese massif, and travel to Benevento by route S 372, then take S 90b and S 90 both heading northward to Foggia. From Foggia, we will pick up S 89 east to Manfredonia to reach the southern most point

on the Promontorio del Gargano (fig. 6.31). Although you can see similar rocks in other parts of Italy I think few places are as scenic.

I have written several times about the Tethys Sea that closed between Africa/Adria and Europe to form the Alps, and its association to the evolution of the Apennines. At the Promontorio we will see the massive limestone carbonate deposits that came from the ocean floor of the Tethys many meters below the water but which have since risen dramatically above the sea. The Promontorio del Gargano extends eastward into the Adriatic as a structural uplifted block which on a regional scale is a gentle anticlinal structure (Brankman and Aydin 809). The Gargano represents sediments that were laid down during the Mesozoic and early Tertiary (250 – 60 my) when the Tethys Sea was opening. The sediments represent a distinct area of the Tethys Sea, the transitional margin between Adria's coast and continental slope and the Tethys Sea's deeper water. Geologists call these rocks platform-to-basin transition, and it is a very exciting area because this is the only area that they are exposed on land to be studied. Geologists from all over the world come to this classic setting to study them. An analogous setting today might be if Florida's continental shelf offshore was exposed for five and a half miles to the deep water and we could see it.

The Gargano Peninsula represents an uplifted structural block. It is the most uplifted part of the Adriatic plate, and it is part of the foreland basin of the Apennines, which is submerged beneath the Adriatic (Mastronuzzi and Sanso 593). By uplift we mean that this entire block of rocks has literally been lifted out of the Sea. In fact during the Holocene (the last 10,000 years) there is evidence that indicates the average uplift rate

is 1.5 mm yr^{-1} (Mastronuzzi and Sanso 593). Figure 6.32 is a paleogeographic reconstruction of the Gargano Promontory during the Jurassic-Cretaceous time (Luciani, Cobianchi, and Fabbri 293). Notice the outline of present day Italy in figure 6.32. The solid area of figure 6.32 represents the basin deposits while the striped area represents platform deposits. The question arises why is this area so uplifted that we can even see these sediments along the Gargano's cliffs as towers?

Fig. 6.32. "Paleogeographic Position of the Gargano Promontory in Southern Italy During Jurassic-Cretaceous." Luciani et al. 240.

The story about Gargano's uplift is attributed to all the faults located on the Gargano Peninsula. The Promontorio del Gargano has two main fault systems that are E-W oriented strike-slip faults and NW-SE oriented reverse faults, and another more complex orientation called oblique reverse faults. Figure 6.33 indicates all the faults as black lines. The faults are controlling the uplift of the entire Gargano Peninsula (Brankman and Aydin 807). They intersect or terminate at intersections. Extensive movement has occurred along these faults as evidenced by how high the sediments are

today. Since late Cretaceous (about 74 my) extensional faulting has caused the area to be totally submerged beneath the Adriatic Sea. The Promontorio del Gargano was not connected to the Italian Peninsula, it was an island off the coast (Borgomano 1586). A little before that time (about 90 my) the area was exposed perhaps due to compression (Borgomano 1586). As recent as the Late Miocene age (12 – 4 my) the area was once again separated from the mainland as an island. I hope you get the sense that the Promontorio has undergone a lot of up and down movement.

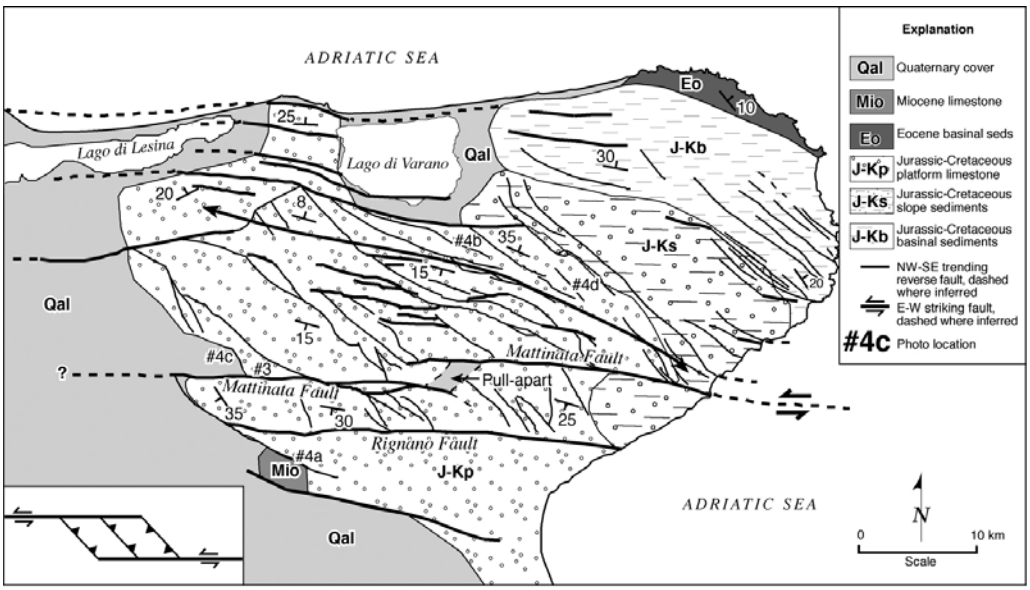


Fig. 6.33. "Fault Map of the Gargano Promontory Southern Italy." Brankman and Aydin 808.

The Apennine Mountain front is pushing eastward and the Gargano Peninsula is in the way of the Apennine's foreland basin that plunges beneath the Adriatic Sea. To make matters even more complicated, across the Adriatic in what is Bosnia and Herzegovina there is another set of mountains called the Denarides. They are west verging (facing) and their foreland basin is also the Adriatic plate. Thus there are two

mountain chains, the Apennines facing east exerting pressure and pushing down in their foreland basin along the Adriatic's west margin and the Denarides doing the same thing along the eastern side of the Adriatic Sea. All these crustal movements have also played a role in the Gargano Promontory's up and down movements.

Fig. 6.34. "Limestone Towers (Faraglioni)." Flickr A Yahoo Company. 2009. 26 May 2009. <http://www.flickr.com/>.

We came here to walk on the carbonate rocks of the ancient Tethys Ocean's oceanic margin. You will be walking on them in many parts of the Gargano Peninsula and you can see them exposed as towers (faraglioni) along the Gargano's coastline (fig. 6.34). While travelling on Monte Gargano (Gargano Mountain), which is the backbone of the Gargano Peninsula, you will have ample places to take pictures from the high vantage point of the road that circumnavigates around the promontorio (fig. 6.35). In certain areas you can cross the interior via other roads and experience the only remnants

of the ancient European forest that once dominated the region. As a side note if you like to camp, this is the area of Italy to do it. The Gargano Peninsula has many well appointed camp grounds. Some campgrounds overlook the sea from a high vantage point, providing a wonderful vista and a different way to experience Italy.

Fig. 6.35. "Promontorio del Gargano Limestone." Flickr A Yahoo Company. 2009. 16 Feb. 2009. <http://flickr.com/photos/hmcm/2089897329/>.

As you stand high above the coastline, entertain the thought that the ground you stand on was once beneath the ocean, and at times raised as a separate island not connected to Italy through the action of faults. Through time Earth's processes have elevated it and lowered it several times. For our pleasure at the present time the Promontorio del Gargano is exposed, raised, and provides us with dramatic views of the Adriatic.

The Effects of Tectonic Movement on Animals and Culture. It is important to realize that tectonic up and down movement has had an impact not only on the land but also on the animals. During one of the episodes when the Gargano Peninsula was an island isolated from the Italian mainland a highly specialized form of vertebrates evolved. These species were only found on the Gargano Peninsula. They are called endemic species. Sometimes endemic species grow to large proportions, and at other times, they grow to be more miniature versions of animals we are familiar with. From evidence of fossils found on the Promontorio del Gargano the endemic species grew larger than normal. This is known as gigantism. Gigantism is a biological term that means the size

Fig. 6.36. "Island Gigantism - Giant Haas Eagle Attacking Moa in New Zealand." Wikipedia, The Free Encyclopedia. 21 May 2009, 4:44 UTC. Wikimedia Foundation, Inc. 24, May 2009. <http://en.wikipedia.org/wiki/Island_gigantism>.

of the animals increases dramatically over generations. Figure 6.36 shows an oversized eagle attacking Moas on a different island, New Zealand.

When the Promontorio del Gargano was an island during the Miocene and Early Pliocene age (23 -5 my) a three-horned animal known as a prongdeer *Hoplitomeryx matthei* once roamed (fig. 6.37). It was a deer-like animal with protruding canines. One theory is that there may have been different morphotypes of this animal on each island of

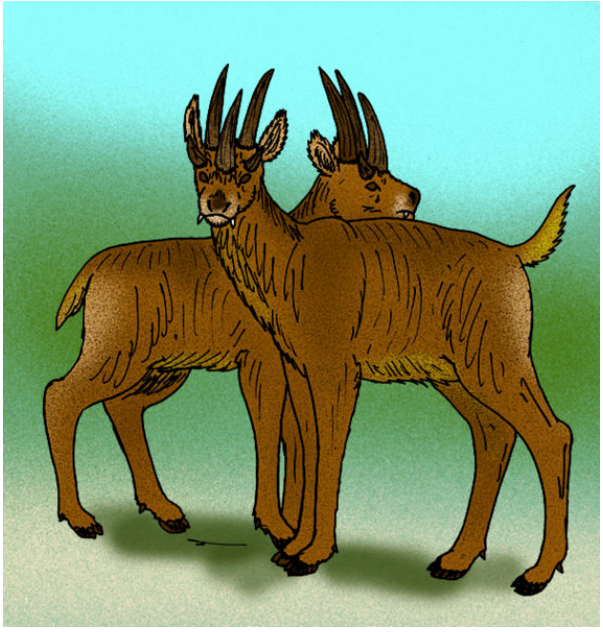


Fig. 6.37. "*Hoplitomeryx matthei*." Wikipedia, The Free Encyclopedia. 27 Sept. 2007. Wikimedia Foundation, Inc. 25 May 2009. <http://en.wikipedia.org/wiki/File:Hoplitomeryx_matthei.jpg>.

the archipelago. There are several other species, and they were found only on the Gargano Peninsula. Today there is also the "garganica" a species of goat that originated on the Promontorio del Gargano. The goats are particularly suited to living in difficult rocky habitats.

One of the interesting cultural customs of the Promontorio del Gargano is the use of karst caves by humans. Recall that limestone dissolves with weak acid to form underground caves. Monte Gargano has a lot of karst caves. In one of these caves the oldest shrine in Western Europe is built. It is called the Sanctuary of Monte Sant-Angelo (Sanctuary of St. Angel) (fig. 6.38). The shrine was built as a result of the Archangel Michael appearing four times to different people. The first time Archangel Michael appeared he requested that the dedication shrine be built at the site of a karst cave, a

Fig. 6.38. "Sanctuary of Monte Saint Angelo." Wikipedia, The Free Encyclopedia. 11 May 2009, 9:05 UTC. Wikimedia Foundation, Inc. 25 May 2009. <http://en.wikipedia.org/wiki/Monte_Gargano>.

grotto which was used to worship the Non-Christian religion called Mithras. The Archangel said the cave was sacred to him. Tradition says the Archangel instructed that the rock be opened wide, and the sins of men can be forgiven. He also instructed that the grotto be dedicated to be a Christian church.

In AD 493 the Archangel appeared to the local bishop and told him that he himself had consecrated the grotto. The last time the Archangel appeared was AD 1656

during a pestilence in Gargano while the Archbishop was praying to the Archangel Michael to intervene and save the people. This time the Archangel Michael told the archbishop that he should bless the stones of the grotto, engraving them with the sign of the cross and the letters MA (Michael Archangel). The Archangel said whoever kept these stones devout would be immune from the plague. Legend says as soon as the bishop followed these orders the town was delivered from disease.

I find it interesting that a cave was targeted to be converted to a Christian church by a prominent member of the Christian faith, Archangel Michael. The Archangel could have asked for a real church to be built. Rather he requested that the pagan cave be converted. Perhaps there is more wisdom here than meets the eye. I wonder it this was not only an attempt to establish a Christian church, but also an attempt to do away with a pagan place of worship. I also found interesting the reference to the notion that a rock opening (the grotto) would be a place to forgive men's sins. Perhaps this notion goes back to sin being housed in the underworld of Hades someplace below Earth's surface.

Eventually the cave became a place to bury the dead, and the church of St. Michael was built on top (fig. 6.38). During the centuries Monte St. Angelo has been a place of pilgrimage including St. Francis of Assisi who felt unworthy to enter the grotto. St Francis it is said paused and kissed the stone at the entrance of the grotto and carved a sign of the cross in the form of a "T".

Conclusion.

Like other parts of the western coast of Italy, Southern Italy has several active volcanoes. We found them in Naples. It seems the Tyrrhenian Sea has been creating

havoc forming all these volcanoes during its opening. But this is what happens when oceans open. It was both interesting and frightening to learn about Mt. Vesuvius' potential for destruction. The density of population in Naples means many people could be exposed to the dangers of the volcano. Although there is an emergency preparedness plan to evacuate people we do not have forecasting methods that can predict an eruption with enough lead time from the onset of the eruption to carry out the emergency plan in a Plinian eruption scenario. In addition, the infrastructure will also complicate evacuation plans.

One thing the city of Naples has in its favor during the next eruption is the tradition of calm supplication to God while at the same time executing evacuation plans. This should facilitate getting more people out, but clearly, it is a very difficult situation to have a high density of people in the path of a very active volcano yet this situation is not unique to Italy. In many parts of Earth, people live on in close proximity to active volcanoes. Once again, the issue of building in areas of geologic hazard arises. Most geologic events happen a lot slower than a human life span, and I believe for this reason people do not relate to the potential hazard. After a geologic hazard such as an earthquake, people's need to rebuild in the same place seems to outweigh their understanding for the potential hazard. Part of this I believe has to do with people's reluctance to leave an area they consider their home.

Following the threat of Vesuvius, we visited another set of volcanoes in Naples, the Campi Flegrei. The special seismic activity called bradyseism has caused the ground to move up and down over a short period. Imagining living in a region that undergoes

eleven feet of up and down motion in just a few months seems surreal. If we contrast this to the east coast of Italy, we can see ground movement there as well but that is where the similarities stop. On the west coast of Italy, there is a very different geologic setting to cause the movement than the geologic setting at the Promontorio del Gargano and the processes are very different (volcanism on the east, tectonic uplift in the west). However, it is important to realize that although the geologic settings and processes operating are vastly different in these two places only about 300 km (186 mi) apart, some of the result (uplift) is the same. Earth's processes can produce similar results and only through careful study of an area can we understand the geology. This can be helpful in determining safer places to live that may in turn save lives.

AFTERWORD

We have finished out journey of Italian geology. I became motivated to do this project because I felt that Italy's geologic story has not been told to the average person. Italy has been described as a laboratory for geologic discovery because it offers so much diversity in geologic settings, structures and wonder. In Italy, we often find unexpected geologic phenomena that like a mysterious stranger add to the country's allure. There is a great deal of enrichment that can be derived by understanding the country's geologic past. I thought the best way to tell that story is through the connection of the cultural elements to the geology. My hope in presenting this connection is that it will open up new dimensions for you into the history of Italy. I am confident that understanding of the earth process and geological background will enhance your appreciation of both the land and the culture of Italy.

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