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Excerpt
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Part I

Evaporite Deposition and Flow

Part I examines the building blocks of salt tectonics. Chapter 1 opens the topic by summarizing the present and historical importance of evaporites and salt tectonics to humans, followed by an introduction to the most basic concepts of salt tectonics. Chapter 2 briefly reviews depositional systems of evaporites, ties these into secular changes in plate tectonics, and compares the origins of solar and hydrothermal salts. Chapter 3 explores mechanical aspects of salt flow: rock mechanics, microstructures, deformation mechanisms, strain rates, physics of salt flow, and modeling techniques.

Chapter 1 Introduction

1.1 Importance of Salt

A civilized life is impossible without salt.
Pliny the Elder, AD 77

Without salt we die. Yet this vital compound, sodium chloride, combines a lethal gas, chlorine, and an unstable metal, sodium, which reacts explosively with water. These two ions are bonded by electrostatic forces in a cubic closely packed lattice in which each ion is surrounded by six different ions at the vertices of an octahedron. Sodium chloride forms the mineral known as halite – the most common salt mineral, but only one of many (Section 2.1). Strictly speaking, **rock salt** is a crystalline aggregate of halite. However, pure halite sequences are rare, so in salt tectonics **salt** refers to any rock composed mostly of halite, and even more loosely to rocks composed mostly of other evaporites.

Sodium chloride is so common and cheap today that it is hard to imagine that until just a little more than a century ago, it was prized as "white gold" because it sustains life and preserves food. **Salt** was keenly searched for and was invested with supernatural powers because salt is vital for life. Salts are the only rocks regularly eaten by humans. Each of us contains about 250 g of salt, which must be topped up with a few grams each day and tightly regulated by our autonomous nervous system. Of the energy used in a typical resting adult, about 20 to 40 percent pumps ions across cell membranes to balance potassium, which is the main cation in cellular fluid, and sodium, which is the main cation in extracellular fluid. This concentration difference helps to transmit nerve impulses and to contract muscles, and in so doing keeps our heart beating. Sodium concentration in our kidneys regulates blood pressure and volume. Chloride as hydrochloric acid digests and absorbs many nutrients. Extreme sodium imbalance triggers a cascading range of symptoms that lead eventually to death or chronic diseases of the kidney, liver, and cardiovascular system.

Salt preserves food by osmotically drawing water out of living microorganisms, preventing them from reproducing and spoiling food. Soaking grain in brine protects it from the deadly fungal disease ergot. The ultimate in preservation care and ritual was mummification in ancient Egypt, which included packing bodies in trona. Salt also enhances natural flavors and suppresses bitterness, gives texture to processed foods, regulates fermentation, and strengthens gluten in bread.

Generally, hunter tribes, who ate plenty of salty meat, did not need to collect or trade salt, but agricultural tribes did, like wild herbivores that forage for salt licks or brine springs. The Greek historian Herodotus wrote of his journey across North Africa in *c.* 430 BC that "at the end of every ten days' [journey] there is a salt mine, with people dwelling round it, all of whom build their houses with blocks of the salt. No rain falls in these parts of Libya; if it were otherwise, the walls of these houses could not stand." The Egyptians made glass as early as 1370 BC by heating the evaporite trona (a complex form of sodium carbonate) and lime (calcium oxide) together. Salt has long been thought to protect against evil spirits in many cultures and religions. Pliny's *Historia Naturalis*, written in AD 77, claims that poisons could be moderated by taking a grain of salt. Salt sealed agreements in Judaism and Islam, blessed marriages and new homes in Christian culture, and purified people or places in Shintoism. Scores of verses in the Bible refer to salt, the earliest being the fate of Lot's wife, turned into a pillar of salt for her disobedience and fancifully preserved as a 12-m-high column left from dissolution on Mt. Sedom diapir overlooking the Dead Sea (Box 12.1). The Book of Judges and Hittite and Assyrian texts refer to conquerors sowing and plowing salt to make soil infertile around sacked cities in the ancient Middle East. By AD 100, Chinese salt workers at Sichuan were tapping subsurface brines using first pits and then bamboo tubes, conveying brine through bamboo plumbing to boiling pots fired by natural gas extracted from the same wells.

Because of its strategic value, salt was searched for and fought for as long ago as 6000 BC for possession of Yungcheng salt lake (China). Salt was internationally traded. Some ancient Roman workers and perhaps soldiers received a salarium in the form of salt. In Abyssinia (modern Ethiopia), pound-bars of rock salt (amoleh) from the Danakil Depression were local currency until the twentieth century. Salt was also a lucrative source of taxes and monopoly, especially in China and Poland. Rulers went to great lengths to protect their monopoly. The Great Hedge of India, which reached an astonishing length of 3,200 km and was manned by 12,000 people, was built to regulate and tax the salt trade. The Indian salt tax later declined

Box 1.1 – Salt Men of Austria and Iran

> . . . the skin a smoky brown color, yellow and hard like a codfish . . .
> *Salzburg Chronicle, AD 1666*

Bodies of Iron Age miners naturally mummified by the salt they were mining have been found at several sites in Austria and Iran. The leathery mummies were preserved by water loss from their tissues in the highly saline environments.

Dürnberg mine near Hallein in the Austrian Alps is on the border between Austria and Bavaria. The mine is one of the oldest in the world and has been worked for more than 4,000 years, with 65 km of tunnels originally excavated. In 1573 a mummified salt miner was discovered here. The Celtic miner wore trousers, a red plaid woolen jacket, leather shoes, and a conical felt hat. Mining equipment included a pickaxe, leather sacks, torches made of pine sticks, and a horn. The mummified body rotted on exposure and was buried. Three mummified bodies were found at the mine, which is now a museum.

A more recent discovery of Iron Age miners was made in Chehrabad salt mine, Iran, which is 1 km south of Hamzehlu village and 75 km northwest of Zanjan city. The Douzlakh (Azeri for "place of salt") salt deposit consists of as much as 99.5 percent halite where the mummies were preserved and forms part of a gypsum-rich lacustrine evaporite sequence of Miocene age, overlain by red and green marl. These evaporites are clearly diapiric farther northwest in the Iljac basin and may be slightly diapiric at the salt mine.

In 1993, a bulldozer excavating this otherwise unremarkable salt deposit unearthed the mummified upper body of a white-bearded miner (Figure 1.1). He wore a gold earring, a leather boot encasing a lower left leg, and a pair of textile shorts. He carried three iron knives, a silver needle, a sling, a leather rope, a grindstone, and a walnut. In 2004 another naturally preserved mummy was discovered, followed by two more bodies the next year, including a 16-year-old boy. Six have now been discovered: four of them were taken to the Zanjan Archeology Museum and one to the National Museum of Iran in Tehran. The sixth body, which was excavated in 2006, has been left encased in rock salt until preservation techniques are improved. Hair, flesh, and bone are all preserved except where locally degraded by ingress of water. Even internal organs are intact, along with six types of human and animal paleoparasites in soil samples. In 2008 the Iranian government canceled the mining permit and declared the site to be an archeological research center. The site has been investigated by an international team of scientists since 2006.

Figure 1.1. The head of Salt Man 1 excavated in 1993 from the Douzlakh salt at Chehrabad salt mine, Iran. This Iron Age miner died around 2,400 years ago and is displayed at the National Museum of Iran in Tehran.

The Chehrabad mummies have been distorted and crushed by burial. A likely cause would be the collapse of the gallery they were mining, an inference supported by the fractured skull and broken back in two miners. Mining was by iron pickaxes using a system of pillars and rooms, without wooden supports. Carbon dating of mummified miners 3 to 5 suggests they died between 405 BC and 350 BC (Achaemenid era), possibly during a single catastrophe such as an earthquake; the oldest and most reliable date is 410 BC to 385 BC. The other two mummies have been carbon dated to the Sassanian era (AD 224–651).

Key references: Aali *et al.* (2012); Kurlansky (2002); Pollard *et al.* (2008).

to trivial levels but was symbolically defied in 1930 when Mohandas Gandhi picked up sea salt from a Gujarat beach after leading thousands on a march of nearly 400 km.

Industrialized production has made salt plentiful. The world produced about 260 million tons of salt in 2008, extracted as brine or rock. Brine is extracted from formation water. Where rainfall is low and evaporation rates are high, sea water or saline lake water evaporates in successive solar evaporation ponds until salt crystallizes on the pond floor to a thickness of 10 to 25 cm. The final few ponds are harvested after they dry. Solution mining injects water through wells into rock salt, usually buried between 150 and 1,500 m deep. Salt dissolves to form a cavern from which brine is piped to an onsite evaporating plant to yield dry salt, or to a plant for chemical production. Almost all salt sold as food in the United States is produced by vacuum evaporation of brine. Rock salt is mined as a solid, typically in deep underground mines. Shafts are sunk to a particular mine level, and rooms as large as 60 m

Box 1.2 – Kopalnia Soli Wieliczka, Poland

Within the metropolitan area of Kraków, Miocene salt accumulated in a flysch setting of the Carpathian foredeep and has been duplicated by thrusting. Wieliczka salt was probably exploited in mid-Neolithic times (3500 BC), but records date from AD 1044, when Benedictine monks tapped saline springs and wells. Rock salt was discovered in 1288, and until 1890, millions of tons of salt were chipped by hand to excavate mine workings having a total length of more than 350 km on seven operational levels, including about 2,000 chambers. Gallery roofs were supported by salt pillars and neat stacks of logs, which fueled fires triggered by leaking methane. Gas pockets in gallery ceilings were courageously ignited by crawling miners carrying torches burning on the end of long poles. Three thousand maps of the salt mines dating back to 1638 have survived. Three chapels are carved into abandoned galleries. The most magnificent, the chapel of St. Kinga, has salt statues and furniture carved from rock salt and is illuminated by chandeliers supporting chains of salt crystals (Figure 1.2). Salt chambers are also used as a health resort and hospital for respiratory patients to breathe humid but salty air. The mine yields 230,000 tons of salt a year from saline seeps but runs at a loss because the main purpose of mining is to keep underground flooding at bay, which used to occur every century. Without constant stemming of leaks and infilling of mined-out chambers, salt pillars would dissolve and chambers would eventually collapse beneath Kraków. The Wieliczka Salt Mine is now a UNESCO World Heritage Site.

Key reference: Brudnik *et al.* 2010.

Figure 1.2. The magnificent chapel of St. Kinga, carved out of thrusted Miocene evaporites below Kraków, Poland. Photo courtesy of Alan Dutton.

long, 18 m wide, and 12 m high are excavated by drilling and blasting or mechanized cutting.

The salt industry cites 14,000 modern uses of salt (Kostick, 2011). The largest use of dry salt is to prevent ice from forming on roads. Most brine is sent to the enormous chloralkali industry to make mostly chlorine and sodium hydroxide, but also sodium chlorite and sodium chlorate, metallic sodium, and hydrogen. Chlorine, in turn, is used for disinfectant and bleach, vinyl chloride and polyvinyl chloride, pesticides, flat-panel televisions, solar panels, and so on. Sodium hydroxide is used to process pulp and make cellulose chemicals.

One chloride in particular is more prized than sodium chloride. The salt flats of Salar de Uyuni, Bolivia, are the world's largest modern salt body. They contain the world's largest reserves of the alkali metal lithium, although Chile is the world's largest producer of lithium chemicals. Because of its high electrochemical potential and low atomic mass, lithium is used as an anode in rechargeable lithium-ion batteries and disposable lithium batteries and newer technologies being groomed for electrically powered vehicles.

Salt caverns, either left over from mining or purpose built, are used as storage vessels, which provide high rates of injection and withdrawal. These purpose-built caverns are as much as 100 to 200 m wide and 600 to 1,000 m tall. Since the 1980s, the number of storage sites in salt caverns in the United States has grown rapidly, mostly in salt diapirs in the Gulf Coast area. Strategic reserves of crude oil are stored in four salt diapirs here, amounting to about 1020×10^5 m^3 of oil (all storage data from Thoms and Gehle 2000, although these quantities fluctuate daily). Also stored in salt caverns are light hydrocarbons (850×10^5 m^3 in the USA, followed by 66×10^5 m^3 in Canada) and natural gas (5527×10^5 m^3 in Canada, followed by 3420×10^5 m^3 in the USA and 1430×10^5 m^3 in Poland).

Salt caverns have also been extensively studied as geologic repositories of radioactive wastes ranging from low-level hospital wastes to high-level wastes from reprocessing nuclear reactors' fuel and spent fuel rods, which need sequestering for hundreds of thousands of years. Transuranic waste, contaminated mostly by plutonium, is stored in bedded salt at the Waste Isolation Pilot Plant in the Chihuahuan Desert of New Mexico. Other pilot plants, in Gorleben and Asse diapirs in Germany, temporarily store low-level and intermediate-level nuclear wastes, with controversial plans to store high-level nuclear wastes permanently.

Salt caverns have also been considered for observatories in which salt filters out unwanted particles, in order to study extremely rare nuclear reactions like ultrahigh-energy neutrino scattering and dark-matter interactions (for example, Saltdome Shower Array).

1.2 Importance of Salt Tectonics

Salt tectonics refers to deformation involving bodies of salt consisting of halite or other evaporite minerals (Hudec and Jackson 2007). "Tectonics" usually applies only to large-scale deformation at all scales, but the lower length scale of salt tectonics has never been specified because such a limit would be impractically restricting. Salt tectonics can involve extension, shortening, or wrenching on a regional scale. Salt tectonics also includes **halokinesis**, which is deformation driven purely by gravity (loss of gravitational potential energy) without significant lateral tectonic forces. Whether in the form of vast buried mountain ranges, towering plugs, canopies the size of the United Kingdom, or salt glaciers oozing over land or seafloor, the salt bodies molded by salt tectonics are some of the most complex, variable, and awe-inspiring structures in geology. These superlatives do not end at the salt contact, for salt tectonics also facilitates unusual degrees of deformation of the encasing rock or overburden. Divergent continental margins containing salt tend to have much more updip extension and downdip shortening than margins without salt. Moreover, salt-detached fold belts are typically much wider than their nonsalt equivalents. Also, sedimentary facies patterns in salt basins are commonly fundamentally different from those in basins that lack salt.

These differences stem from the fact that evaporites have mechanical properties different from those of most clastic and carbonate rocks. Salt acts as a geologic lubricant. Under typical geologic strain rates, salt flows like a viscous fluid in the subsurface and at the surface (Section 3.2.3). Fluids have negligible yield strength, so salt bodies and layers are much more easily deformed than are other rocks. On the other hand, on an engineering time scale, salt is an elastic solid capable of supporting large underground caverns for decades. Salt's geologic weakness is the Rosetta Stone of salt tectonics – the principle that makes all other observations comprehensible.

A second key aspect of salt is that as a crystalline rock it is relatively incompressible. Because pure rock salt has an approximate density of 2,040 kg/m^3, it is less dense than most carbonates and moderately to fully compacted siliciclastic rocks. Salt buried beneath denser overburden is therefore buoyant and gravitationally unstable and is liable to rise unless restrained. Buoyant salt could begin rising beneath an uncompacted shelf-carbonate overburden, but it typically requires burial beneath at least 650 m (and more typically 1,500 m) of siliciclastic overburden before the deepest sediments compact to densities equivalent to that of rock salt. Burial of at least 1,600 m (and more typically 3,000 m) is required before the average density of the entire siliciclastic overburden exceeds that of salt, which is necessary for a salt diapir to reach the surface by buoyancy alone.

The uniqueness of salt tectonics is thus firmly rooted in rock mechanics. Salt's rheology and incompressibility make it inherently unstable under a wide variety of conditions. As a result, basins having salt tend to deform much more easily than basins lacking salt, with significant effects on basin tectonics and stratigraphy.

Salt tectonics receives little attention in most structural geology texts for several reasons. (1) High-quality, accessible salt exposures are rare. (2) Most teachers in academia lack large seismic datasets. (3) Most professors of structural geology or tectonics have not had first-hand experience in salt tectonics and, until now, there were no comprehensive textbooks on the subject. However, salt tectonics is of major interest to many practicing geologists, as indicated by the burgeoning of salt-tectonic articles in the professional literature. Of the 7,760 publications on salt tectonics as of 2014, about 64 percent were published after 1990 (Web of Science database).

The prime interest in salt tectonics comes from the oil industry because many of the world's great hydrocarbon provinces are in salt basins (for example, Gulf of Mexico, Persian Gulf, North Sea, Lower Congo basin, Campos basin, and Precaspian basin). Salt affects virtually all aspects of a hydrocarbon system (Chapter 15). Salt flow creates structural traps, influences reservoir distribution, and can seal hydrocarbon migration. Salt is a powerful conductor of heat, elevating thermal maturity of rocks above salt structures and slowing maturity below or adjacent to salt bodies. The geometry of salt canopies must be correctly interpreted before seismic data can reliably image deeper exploration targets below salt. Understanding salt tectonics is thus critical to effective exploration for oil and gas in many parts of the globe. Hot brines can also transport dissolved metals, so evaporites can focus, trap, or precipitate metal deposits. Finally, evaporites provide economic resources of potash for fertilizers, sodium salts, gypsum for building purposes, sulfur, borates, nitrates, and zeolites.

Box 1.3 – Spindletop Salt Diapir Launches the Petroleum Era

The modern petroleum era began in the cow pasture of Spindletop Hill, just south of Beaumont, Texas. The low mound above Spindletop salt diapir had no sign of oil seeps, but sulfurous soil and seeping gas hinted at hydrocarbons below. Patillo Higgins, a self-taught prospector, joined forces with Capt. Anthony Lucas, a naturalized Austrian mining engineer who had gained more practical knowledge of salt domes than anyone in America. After seven years of dry holes, Lucas started drilling a well at Spindletop in October 1900 using a rotary rig and drilling mud from a settling pond churned up by cattle to hold the soft encasing sediments in place. After drilling had reached a depth of 347 m into the diapir's cap rock on the morning of January 10, 1901, mud and oil erupted and blew off the top of the wooden derrick, hurling the iron drill pipe high into the air, followed by eruptions of mud, then gas, then rocks, then oil (Figure 1.3). From the 45-m gusher a greasy mist of oil drifted downwind. Dikes were hastily built to check the spreading lake of oil. After nine days the gusher was smothered with a heavy sled. A second well also gushed two months later, followed by four more oil gushers within a month, then 138 producing wells on the diapir at the end of the year. Spindletop showed how one part of one salt dome could yield hitherto unimaginable quantities of oil. As the Spindletop field briefly outproduced the rest of the world combined and the Texas oil boom exploded, the price of oil plummeted to 2 cents a barrel, the lowest price in history. The United States replaced Russia as the largest oil producer and drilling technology leapt forward.

Key reference: Owen 1964.

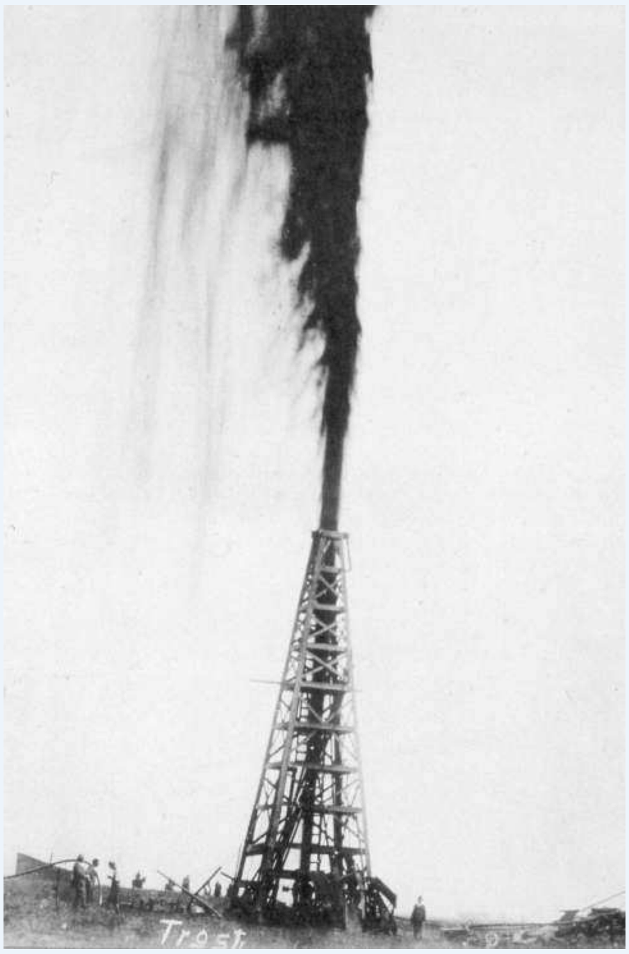

Figure 1.3. The Spindletop gusher in full flood. The 1901 discovery launched the modern Age of Petroleum.

Even beyond salt's importance to resources, however, advances in salt tectonics shed light on a wide range of scientific problems. For example, advances in the understanding of diapiric processes are influencing work in extraterrestrial geology and shale tectonics. Because salt's mechanical weakness makes it a sensitive strain gauge, the growth histories of salt structures have contributed to ideas of divergent-margin evolution and even orogeny (Talbot 1992).

Salt's unique deformational style, widespread occurrence, and massive deformational overprint on some divergent margins make salt tectonics an important component of the analysis of sedimentary basins.

1.3 Discovery of Diapirism

A diapir is a mass of salt that has flowed in a ductile manner and has discordant contacts with the enclosing overburden of rock or sediment. Three ancestral lines influenced the study of salt diapirs. Centuries past, some salt diapirs were found and held because of their geostrategic value. A prime example is Hormoz Island, a fortified diapir whose defenses fell repeatedly over the centuries to Arab, Portuguese, and Anglo-Persian attackers. The island controlled the Hormoz Strait of the Persian Gulf, which was one vertex of the monsoon-driven triangle of sea trade connecting India, Africa, and the Middle East.

A second ancestral line was European, which focused on irregular salt bodies in fold-and-thrust belts, revealed mostly in outcrop and mines. The first scientifically described diapir, which is in Algeria (Box 1.4), is affiliated with this line because the diapir is in a fold belt and was described in French literature. The basic properties of a diapir were first described in Romania by Pošepný (1871) (Figure 1.4). His sketch shows (1) increasing conformity of evaporite layers toward the diapiric contact, (2) marked discordance of flanking strata against the contact, (3) onlap of deep strata against the contact, and (4) an overturned collar around the crest of the diapir. Only much later was the word *diapir* coined in the Carpathian fold belt farther east in Romania (Mrazec 1907) from the Greek verb διαπερνώ (*diaperno*),

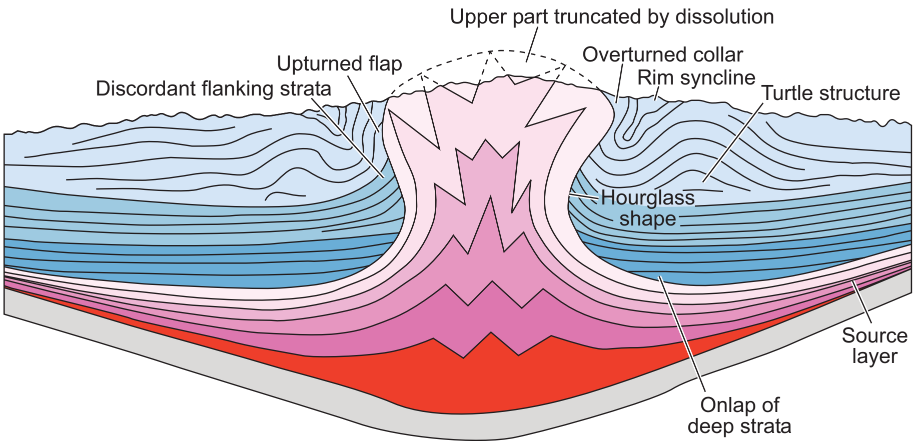

Figure 1.4. Pošepný's (1871) schematic cross section of a Romanian salt diapir captured many of the fundamental qualities of diapirism both inside and outside the salt body.

meaning to pierce, penetrate, or perforate; this word is related to *porosity* via the same root πόρος (*poros*), meaning a void, opening, or passage. The first to use the term *salt tectonics* seems to have been Stille (1925), who saw it filling a gap between his mobile "normal tectonics" and the highly mobile "tectonics of vulcanism."

The third ancestral line was American, which focused on pluglike salt bodies encased in strata on a flat coastal plain. The Five Islands salt domes in the coastal swamps of Louisiana were recognized as "dome-shaped folds" above salt surprisingly early, considering that no evaporites were exposed (Harris and Veatch 1899).

Box 1.4 – Diapirs Surface in the Intellectual Realm

> All this bizarre, fantastic, rugged topography makes the Rocher de Sel a magnificent spectacle for the traveler who arrives tired by the monotony of the flat plain of Zahrez.
> *Ville, 1859, p. 408.*

The Ran el Melah (Rocher de Sel de Djelfa) (N34.835°, E3.094°) is one of several salt diapirs exposed in Algeria's Atlas Mountains (Figure 1.5), but it has the distinction of being the first in the world to form the subject of a scientific paper – and a substantial paper at that. It is easy to envision the frisson of excitement that M. Ville, a French mining engineer, felt on approaching this 80-m-high hill he was to survey for its mineral resources. Karstic processes of dissolution have riddled it with ravines and closely packed sinkholes and swallow holes, all covered by a thick pale mantle of residual gypsum soil, resembling a monstrous head of cauliflower. The steep walls of the myriad holes expose crystalline rock salt. Streams of brine encrusted with reprecipitated salt drain northwest into the Oued Melah. The hill is studded with exotic insoluble clasts, which are strewn over the northern plain as the probable remnants of a dissolved salt glacier. Ville's map and cross sections (Figure 1.6) portray the diapir's upturned-to-overturned collar of mid-Tertiary strata, the intricate karstic topography, and Cretaceous inclusions acting as capstones protecting the underlying salt and gypsum from dissolution.

Key reference: Ville 1859.

Figure 1.5. The first salt diapir described in the geologic literature (Ville, 1859), Ran el Melah (Rocher de Sel de Djelfa), in the Algerian Atlas Mountains. The panorama shows the northeast contact of the 80-m-high plug of Triassic salt. Photo by Martin Jackson.

Box 1.4 – (*cont.*)

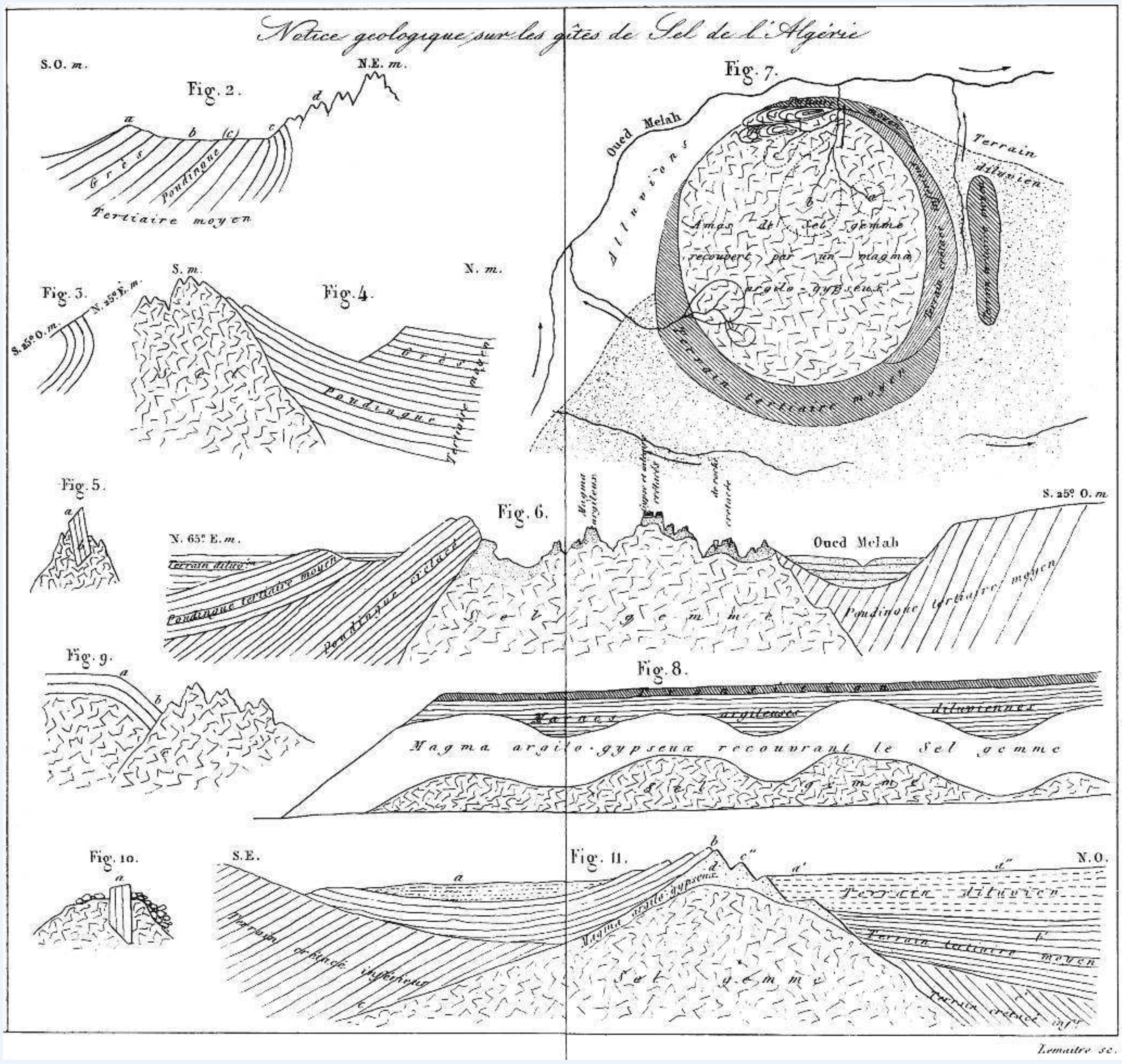

Figure 1.6. The bizarre structure and geomorphology of Ran el Melah diapir, Algeria, as first recorded by a mining engineer, who was surveying for sources of salt for French garrisons. Plate III of Ville (1859).

These different settings inevitably led to different schools of thought for the origin of salt structures (Jackson 1995).

1.4 Basic Concepts in Salt Tectonics

Salt tectonics has a large terminology (see the Glossary), but in this section we introduce enough basic concepts to provide background knowledge for later chapters.

1.4.1 Types of Salt Structures

In the broadest sense, salt structures vary in size from subgrain scale to basin scale. However, for most practitioners of salt tectonics, **salt structure** denotes a salt body large enough to be visible on reflection seismic data but smaller than an entire salt basin. This macroscopic scale of deformed salt is introduced in this section, and elaborated on in Chapters 4 to 7.

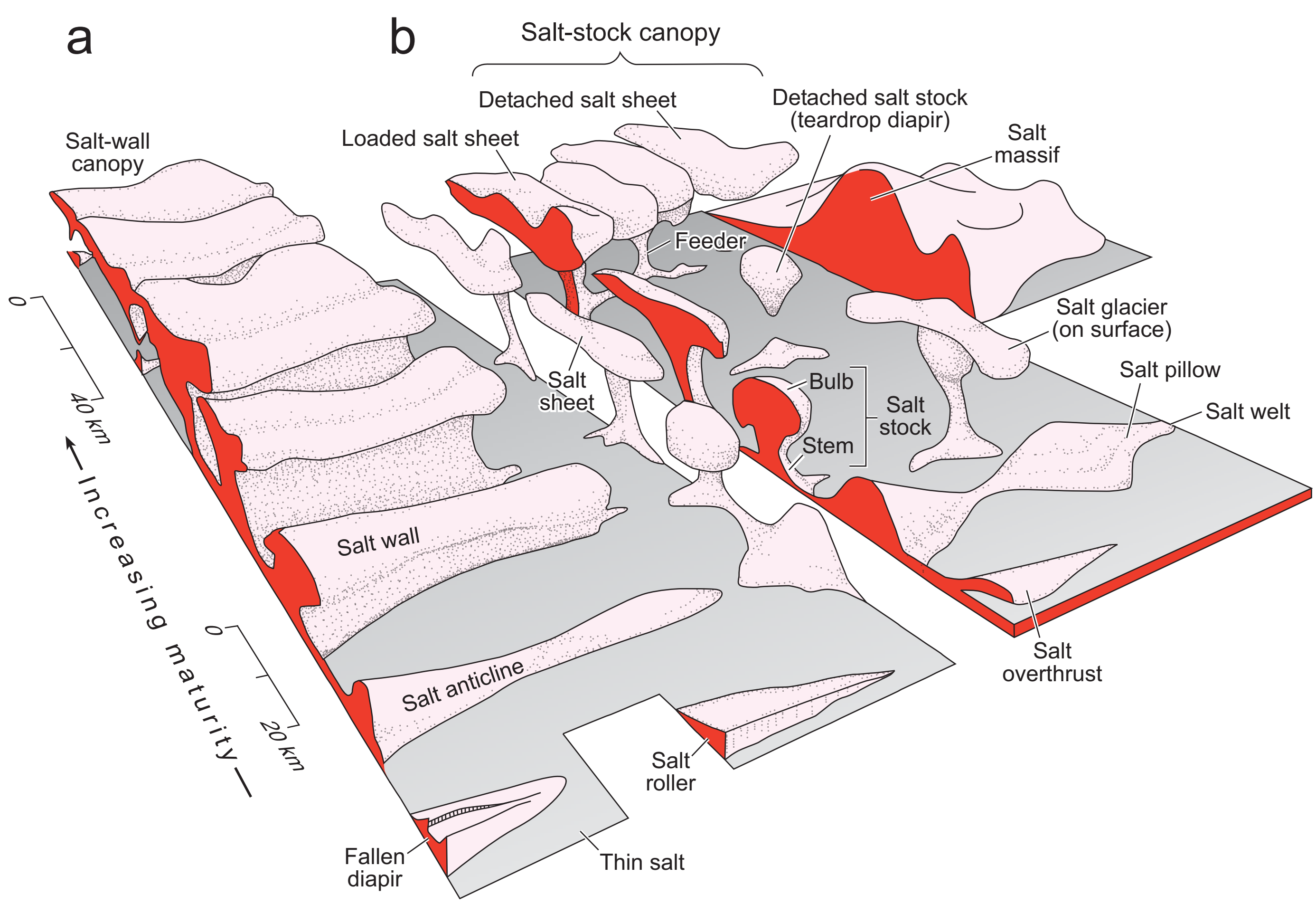

Figure 1.7. Names of salt structures are derived from cross-sectional shape and map geometry. After Jackson and Talbot (1986).

A salt structure can be described purely by specifying the shape of the salt body itself. Some salt bodies, such as salt anticlines, salt walls, salt rollers, and salt overthrusts, are elongated in map view (Figure 1.7). Others, such as salt pillows and salt stocks, have more equant planforms. Some stocks narrow upwards; others widen upwards from a deep **stem** to a shallow, swollen **bulb**. Still others, such as salt sheets, salt canopies, and **salt massifs**, are irregular.

These diverse salt geometries hint at different origins and evolutions of salt bodies. For example, equant salt structures tend to form by halokinesis, but elongated structures commonly form by regional extension or shortening. But these are only generalizations. The surrounding overburden yields more genetic insights than the salt body alone, which explains why some salt structures have different names even though their shapes in Figure 1.7 overlap.

1.4.2 Overburden Geometry as a Record of Salt Tectonics

The growth history of a salt structure is far more clearly read from surrounding sediments than from the salt body itself. The surrounding sediments provide, first, a tectonostratigraphic context for salt (Figure 1.8). An **autochthonous salt** layer rests on its original foundation: stratigraphically older **presalt** strata or **basement**. This original salt is the **source layer** (also known informally by some as the mother salt). **Suprasalt** strata above the source layer are **overburden**. In contrast, **allochthonous salt** has moved from its place of origin and overlies younger **subsalt** strata (Chapter 6). Allochthonous salt may or may not be connected to autochthonous salt by a **salt feeder**. The cover is the entire sedimentary–volcanic pile, including autochthonous and allochthonous salt. All these components above and below the salt and the salt itself make up a **salt system**.

The geometric relationship between overburden strata and salt bodies is profoundly important for interpreting salt tectonics in four respects: thickness relations, contact relations, age relations, and regional relations.

Thickness relations are lateral variations in overburden thickness above a salt structure. These are primary thickness changes in overburden deposited above moving salt (Figure 1.9). When **salt deflation** occurs (thinning by internal flow), the top of the salt subsides and with it the overburden, which creates space for more sediments. The result is an isopach thick above the subsided salt. If the intervening

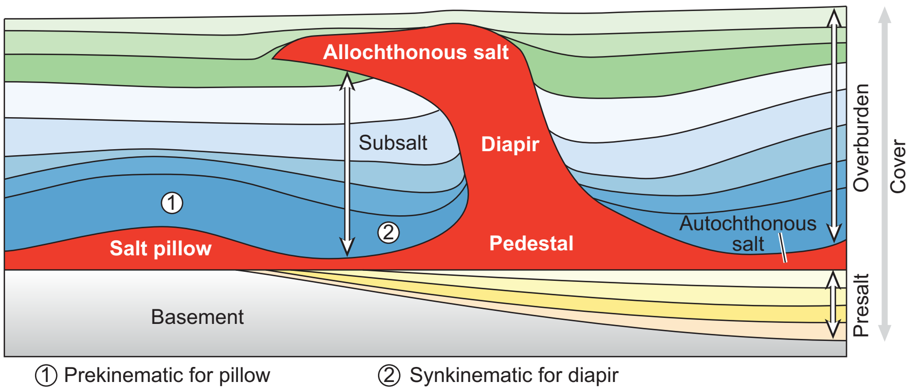

Figure 1.8. Basic tectonostratigraphic elements of a salt system. The lowermost overburden layer maintains constant thickness above the salt pillow, making it prekinematic with respect to the onset of salt flow in that structure. The same layer thins against the diapir flank and is thus synkinematic for that structure.

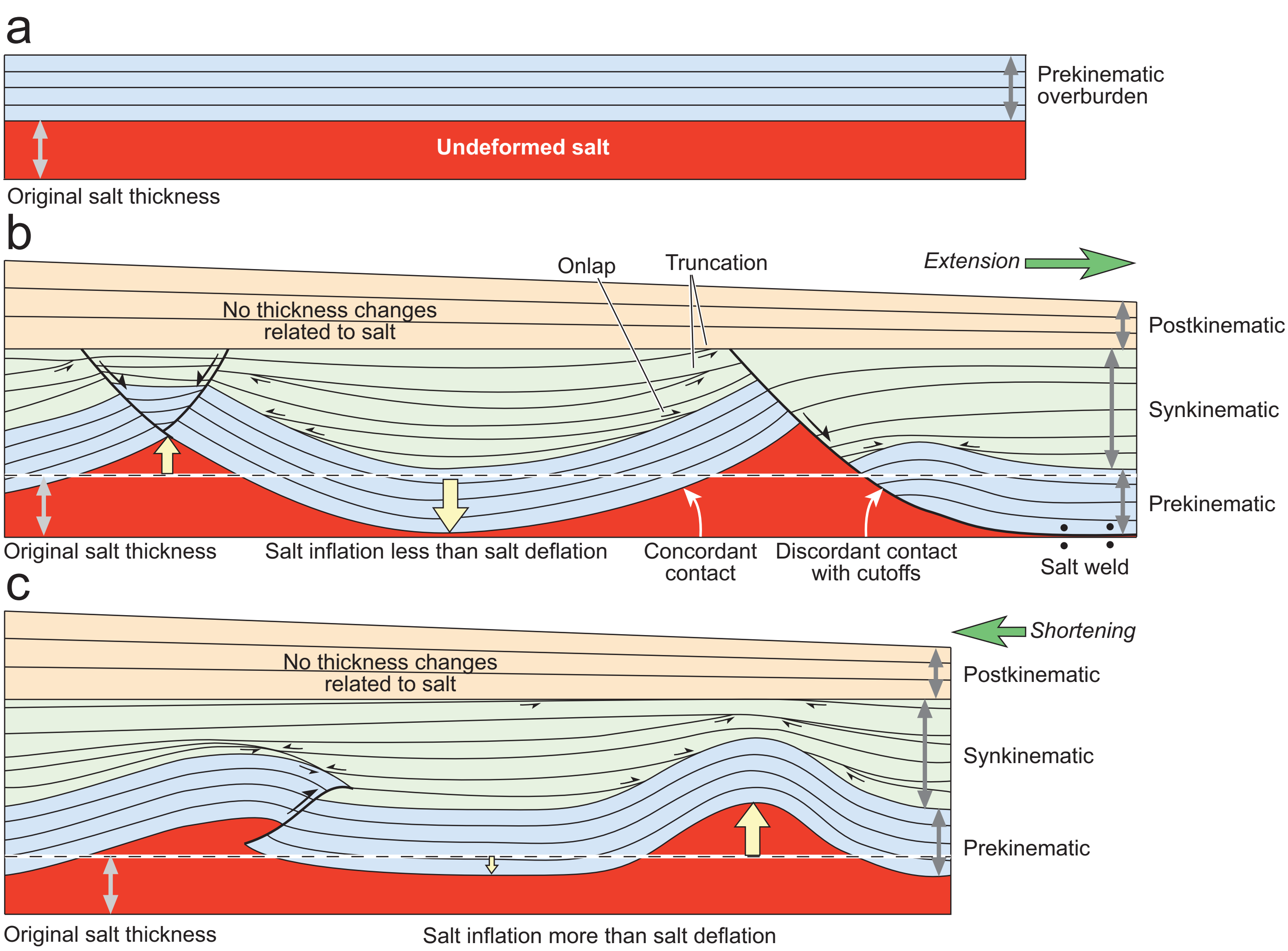

Figure 1.9. Tectonostratigraphic signature of (a) a prekinematic salt-based sequence deformed by (b) regional extension and (c) regional shortening. The cross section delineates the prekinematic, synkinematic, and postkinematic intervals and areas where the salt has inflated and deflated during deformation. After Jackson and Talbot (1991).

autochthonous salt is completely or almost completely removed by internal flow or dissolution, this creates a primary salt weld. Other types of salt weld exist, and all are described at length in Chapter 9. The same internal flow that deflates salt also transports salt elsewhere. The salt either escapes to the surface and dissolves or flows elsewhere in the subsurface and causes **salt inflation**, feeding the growth of another salt structure. The inflating salt structure is overlain by an isopach thin