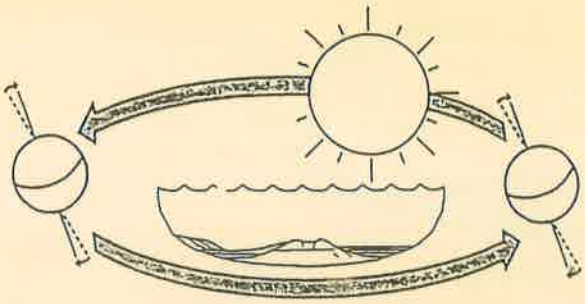
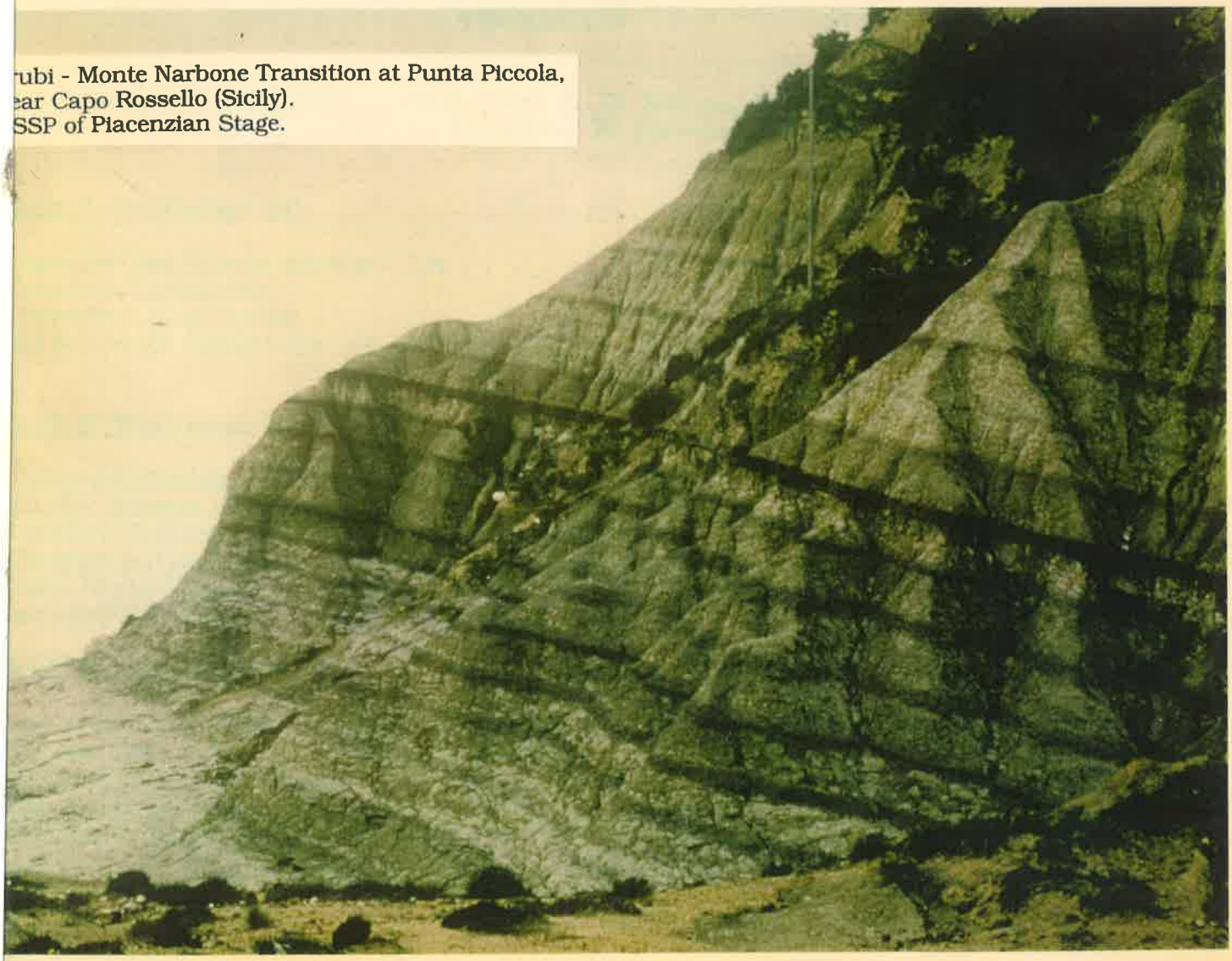
Neogene Mediterranean Paleoceanography



Cycles Events Sea Levels



ubi - Monte Narbone Transition at Punta Piccola,
ear Capo Rossello (Sicily).
SSP of Piacenzian Stage.

Excursion Guide Book

Palermo - Caltanissetta - Agrigento - Erice

24 - 27 September 1997

Conference Convenors:
M.B. Cita (University of Milano)
J.A. McKenzie (ETH. Zürich)

ocieta' Geologica Italiana

ESCO Secretariat,
Zurich-Switzerland

Neogene Mediterranean Paleoceanography

Erice, Sicily *28-30 September, 1997*

Societa' Geologica Italiana

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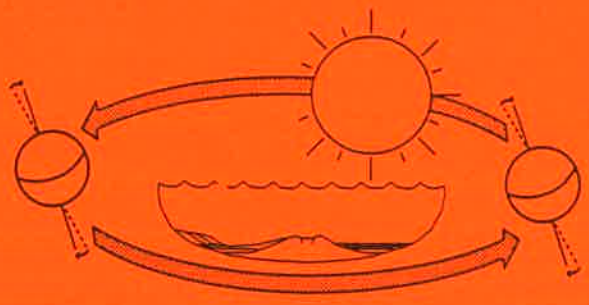

Cycles *Events* *Sea Levels*

PRE-CONFERENCE EXCURSION PROGRAM

EXCURSION LEADERS: **M.B. Cita, E. Di Stefano, M. Grasso, S. Lugli, C. Schreiber, R. Sprovieri, F. Vitale.**

DAY 1 (September 24)

Departure from Palermo airport at 4 P.M.
Transfer to Caltanissetta.
Overnight at Hotel Ventura
(SS 640, 93100 Caltanissetta - tel. +39-934-553780; fax: +39-934-553785).

DAY 2 (September 25)

Visit to pre-Messinian and Messinian outcrops along the margins of the Caltanissetta Basin (Landro, Alimena, Contrada Gaspa).
Transfer to Gibliscemi (late Miocene cyclic sedimentation).
Overnight in Agrigento at Hotel Akrabello (two nights).
(Parco Angeli-Villaggio Mosé, 92100 Agrigento - tel.: +39-922-606277; fax: +39-922-606186; e-mail: ATHENA@MEDIATEL.IT)

DAY 3 (September 26)

Visit to the classical Pliocene sections of Capo Rossello, Punta Piccola, Punta Grande (Pliocene cyclic sedimentation; Piacenzian GSSP).
Visit to the Realmonte salt mine.
Stop at Valle dei Templi.
Overnight in Agrigento.

DAY 4 (September 27)

Visit to the Eraclea Minoa Section
(Gessi superiori and "Lago Mare"; Messinian/Zanclean boundary; cyclicity in the Trubi).
Plio-Pleistocene sequence stratigraphy in the Belice Valley south of Partanna.
Transfer to Erice, Centro Ettore Majorana, in the late afternoon.

The Realmonte salt deposit (Agrigento, Sicily): geology and exploitation

STEFANO LUGLI

Dipartimento di Scienze della Terra, Università di Modena, Largo S. Eufemia 19, 41100 Modena, Italy.

The mining tradition of Sicily, from sulfur to salt

The complex mining history of Sicily begins with the exploitation of sulfur that probably started since the II century (Cedrini, 1993). Sulfur was used by Greeks and Romans in ceremony, for medical purposes and to prepare incendiary weapons. With the beginning of the development of the sulfuric acid industry (middle of the XVIII century) sulfur became a very important resource, and the island contained the main world-known deposits. For this reason Sicily established a relatively monopolistic production till the end of 1800's when sulfuric acid was produced on industrial scale from pyrite as well as sulfur. At that time more than 700 sulfur mines were active in Sicily and about 38.000 workers were employed (Acciarito, 1989). During the XX century the Sicilian production underwent a further long-term crisis partly due to the discovery of efficient exploitation methods of the huge North American sulfur deposits (Terranova 1966).

It was only with the decadence of the Sicilian sulfur mining system that energies were drawn to the search for new minerals: halite and potash salts were the candidates (Acciarito, 1989; Mezzadri, 1990).

Halite was known to be present in the subsurface of Central and Southern Sicily by small outcrops and salt springs. The native inhabitants of Sicily before the Greek colonization (VIII-III b.C.), the Sicels (Sicani), were locally quarrying halite that was used for alimentary purposes also during the Middle Age (Mezzadri, 1990). Potash salts were discovered and mined at the beginning of the 1900 in small outcrops in the area of Villapriolo (Enna). Until 1913 a small hydrodissolution-recrystallization plant was also operating to extract magnesium sulfates from the underground of Bompensiere (Caltanissetta) and the production was shipped

to England (Mezzadri, 1990). Halite and potash minerals were then completely ignored, while efforts and energies were devoted to sulfur survey and exploitation.

An extensive survey for salts that could replace the dying sulfur mining industry started in 1952. In a few years several boreholes were drilled and 36 buried halite deposits were discovered, among them 13 also contain potash salts. Many mines were opened and just in one decade the Sicilian mining production switched from sulfur to halite and potash salts (Acciarito, 1989; Mezzadri, 1990).

Today, as a consequence of a complex series of political and economical causes, the potash salt exploitation is no longer active and only three salt mines are open: Realmonte, Racalmuto, both for road de-icing and industrial halite, and Petralia for alimentary and industrial halite.

The Realmonte mine: characteristics and exploitation

The Realmonte mine is the most recent salt mine of Sicily, it was opened in 1968. Originally only halite (NaCl) was mined but soon two exploitable kainite ($K_4Mg_4Cl_4(SO_4)_4 \cdot 11H_2O$) layers were reached and the mine was the first to have the possibility to switch exploitation between potash and halite following the variable needs of the market. The southern boundaries of the deposit are still not completely recognized and the estimated reserves exceed 30 years (Adamo, 1993). The kainite exploitation is not active since 1990 and presently only halite is mined.

The mine is accessible throughout a 1100 m-long truck gallery with a slope gradient of 13,5% and a section of 36 m^2. The gallery entrance is at an altitude of 65 m and extends down to -105 m.

The exploitation system is that of rooms and pillars which become larger with depth. The rooms are 23m-large, 7.5 m-high and are separated by layers 7.5 m-thick. Exploitation was made at levels -15, -30 and -105 and is now active in the western part of the mine, at level -165, where also the layers separating vertically adjacent rooms are exploited and the final rooms are 30 m-high.

The mine has an underground grinding plant which is fed by a transportation belt with a capacity of 600 T/h situated along a 1830 m-long gallery. The production capability exceeds

4000 T/day, whereas the total halite production is presently about 400.000 T/year. The employed workers are now 30, whereas 120 were needed when kainite was mined (Adamo, 1993).

When kainite exploitation was active the enrichment and conversion processes to produce K_2SO_4 for high-quality fertilizers was made at the Campofranco plant. Halite for road de-icing and industrial purposes is sent by trucks to the Porto Empedocle harbor located at a distance of 4 Km from the mine where it is shipped to several localities, including in recent years some North European countries (Denmark, Belgium, United Kingdom and Norway) and even North America (Boston).

The Mediterranean and the Sicilian salt deposits

The Realmonte salt deposit is part of the Messinian "Gessoso-Solfifera" evaporite Formation present in the Caltanissetta basin of Central Sicily. The Sicilian succession is considered to be one of the most significant product of the "salinity crisis" that involved the Mediterranean area because it appears to be similar to the evaporite deposits discovered beneath the deep Mediterranean depressions (Fig. 1). Even though only a few topmost samples were recovered from the deep Mediterranean depressions (Hsü et al., 1973; Khün and Hsü, 1978), the similarities are clear on a broad scale, as suggested by seismic data (Montadert et al., 1978; Kastens and Mascle, 1990; Robertson et al., 1990): most of the deposits can be divided into two mainly sulfatic units, the Lower and the Upper Evaporites, separated by a tectonic interregional unconformity. In most areas of the Mediterranean the halite deposits apparently are present only in the Lower Evaporites.

Several halite bodies are present at the subsurface of the Caltanissetta Basin (Fig. 2), they have been interpreted variously to:

a) lie on top of the Lower Evaporites (Decima and Wezel, 1971 1973);

b) represent the lateral equivalent of the Lower Evaporites (Catalano and D'Argenio, 1982; Rouchy, 1982; Garcia-Veigas et al., 1995);

c) predate the deposition of the abyssal plains halite (Butler et al. 1995).

Some of the Caltanissetta basin salt deposits contain potash layers mainly represented by kainite ($K_4Mg_4Cl_4(SO_4)_4 \cdot 11H_2O$), whereas only a few contain carnallite ($KMgCl_3 \cdot 6H_2O$),

bishofite ($MgCl_2 \cdot 6H_2O$) and sylvite (KCl) and only one contains kieserite ($MgSO_4 \cdot H_2O$) and langbeinite ($K_2Mg_2(SO_4)_3$) (Decima and Wezel, 1971).

Geology of the Realmonte salt deposit

Stratigraphy

Four main depositional units (from A to D) were recognized in the area of the Realmonte mine (Agrigento), where the salt reaches a total thickness of 400-600 m. From the bottom to the top these depositional units are (Decima and Wezel, 1971 and 1973; Decima, 1978; Fig. 3):

- basal anhydrite and marly mudstone breccia up to 2 m thick;
- A unit: halite with anhydrite nodules and laminae passing upward to massive halite up to 50 m thick;
- B unit: halite with polyhalite ($Ca_2K_2Mg(SO_4)_4 \cdot 2H_2O$) and anhydrite laminae, also containing six main kainite layers up to 12 m thick; locally the kainite zone is replaced by a 10-30 m-thick halite-anhydrite-mudstone dissolution breccia; the total thickness is about 100 m;
- C unit: halite-clay couplets 10-20 cm thick with minor amounts of polyhalite and anhydrite, the total thickness is 70-80 m;
- D unit: anhydritic mudstone (15-20 m thick) passing to an anhydrite laminite sequence followed by halite intercalated with anhydrite laminae; the total thickness is 60 m.

The geology of the deposit appears complicated by intense folding (Fig. 4). In the northernmost and in part of the southernmost zone of the mine the folded kainite beds of unit B are truncated and overlain by the Upper Evaporites. For this reason the folding of the salt deposit apparently predates the deposition of the Upper Evaporite Unit, suggesting also that its base represents a dissolution surface at the top of the folded beds.

On the basis of the microfauna (planctic foraminifers) and microflora (nannoplancton, dinocysts, pollen grains) contents of the intercalated clay layers, Bertini et al., (in press) propose tropical to subtropical prevailing thermic condition for the deposition of the halite and estimate its deposition in about 30-40 kyrs.

Sedimentology, petrography and geochemistry

New sedimentologic and petrographic data on the Realmonte salt deposit (Lugli and Lowenstein, in preparation) indicate that the A and B units are mainly composed by well sorted cumulates of halite plate with minor amount of cumulitic kainite (Fig. 5). These salt layers show no evidence of bottom overgrowth, current structures, dissolution and/or truncation surfaces. These particular characteristics indicate that evaporite precipitation took place in a stratified water body, a feature that suggests the existence of a relatively deep basin. Only the topmost part of the B unit shows a progressive appearance of large halite rafts and localized dissolution features, characteristics that, together with the presence of thick kainite beds, testify for a marked upward shallowing of the basin. Kainite is present in fine- to coarse-grained (Berry and Ribacchi, 1976; Garcia-Veigas et al., 1995) cumulate rocks (Lugli and Lowenstein, in preparation).

The overlying C unit is characterized by the deposition of cumulates of halite skeletal hoppers showing further vertical overgrowth that occurred at the bottom of the basin (chevron; Fig. 6). These salt layers also show a number of dissolution features, such as pipes and irregular truncation of the upper surfaces of crystal terminations (Fig. 6), indicating precipitation from a non-stratified, relatively shallow water body. The relatively large difference showed by the paleotemperatures of the brine from which the halite crystals precipitated (22° to 32°C; Lugli and Lowenstein, 1997) supports such mode of formation. On the basis of its low-bromine content this unit has been interpreted to be deposited as consequence of recycling of previous halite by meteoric and continental waters (Decima, 1978). Garcia-Veigas et al. (1995) demonstrated that the low-bromine content of the salt could not be sufficient to indicate a precipitation of recycled halite from continental water. This because the analysis carried out on fluid inclusions within halite showed a high-sulfate and a significant potassium and magnesium content of the mother brine, indicating that the recycling fluids have a composition similar to seawater.

The boundary between units B and C carry the signature of the drawdown and desiccation of the evaporite basin by the occurrence of buckled, upturned and subaerially modified salt layers and by the presence of deep contraction polygons (Lugli and Schreiber, 1997; Lugli et al., in review; Fig. 7).

The giant polygons: evidence of the desiccation of the basin

Spectacular vertical fissures cut through the topmost part of unit B at its boundary with unit C in many parts of the mine (in the NW zone at a depth of-128 m and in the NE zone at -90 m, -75 m and in the underground garage area at -28 m; Fig. 7). The fissures are spaced at intervals of up to 5 m apart and extend down for a maximum visible depth of 6 m; their maximum width is generally less than 5 cm. In one case it has been possible to recognize two successive sets of fissures that initiate from different salt layers (Fig. 8). An irregular green clay layer up to 0.5 m-thick commonly seals the B layer and lies directly on top of the fissures which are filled by red clay. The topmost salt beds of unit B affected by the fissures are commonly upturned (Fig. 7), and are truncated by the succeeding flat-lying halite beds of unit C. The upturned layers are cut by closely spaced vertical pipes a few centimeters across filled by clear halite cement and red mud (Fig. 8). This piped zone extends down up to a depth of 4 m.

The described features have been interpreted as the product of the development of two distinct successive and superimposed polygonal patterns on subaerially exposed salt layers (Lugli et al., in review):

A) cumulate halite was precipitated in a stratified water body (Fig. 9, stage A);

B) the evaporite basin began to experience drawdown (Fig. 9, stage B).

C) the basin dried out and the exposed halite layers were buckled, broke into polygonal crusts and formed tepee structures as a consequence of a net expansion of the salt layers by precipitation of new halite within the pore spaces; this process is made possible by the evaporative pumping of concentrated brines from the underlying groundwater table (Fig. 9, stage C);

D) the polygons were then affected by meteoric dissolution that cut vertical dissolution pipes (like the modern ones visible at Death Valley, California; Li et al. 1996; Fig. 9, stage D);

E) the "salt saucers" and the associated dissolution pipe zone were further cut by a new network of large polygons outlined by fissures at least 6 m deep, in which red colored silt collected, blown by the wind or carried by small phases of surface flooding (Fig. 9, stage E).

The opening of the new polygons could have been induced by the volumetric changes induced by annual temperature variations (Tucker, 1981);

F) the exposure of the salt basin was definitely interrupted by a flood that partly dissolved the upturned salt layers and deposited a green clay layer of variable thickness (Fig. 9, stage F);

G) after the reflooding of the basin, a new phase of shallow water evaporite deposition was established and the halite-clay couplet of unit C sealed the truncated and cracked halite layers (Fig. 9, stage G).

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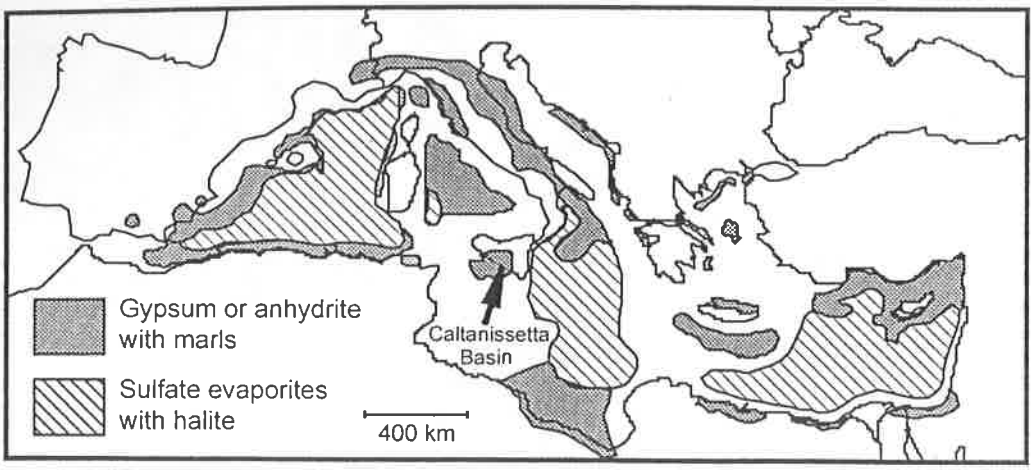

Figure 1 - Occurrence of the Messinian evaporites in the Mediterranean area (after Rouchy, 1982).

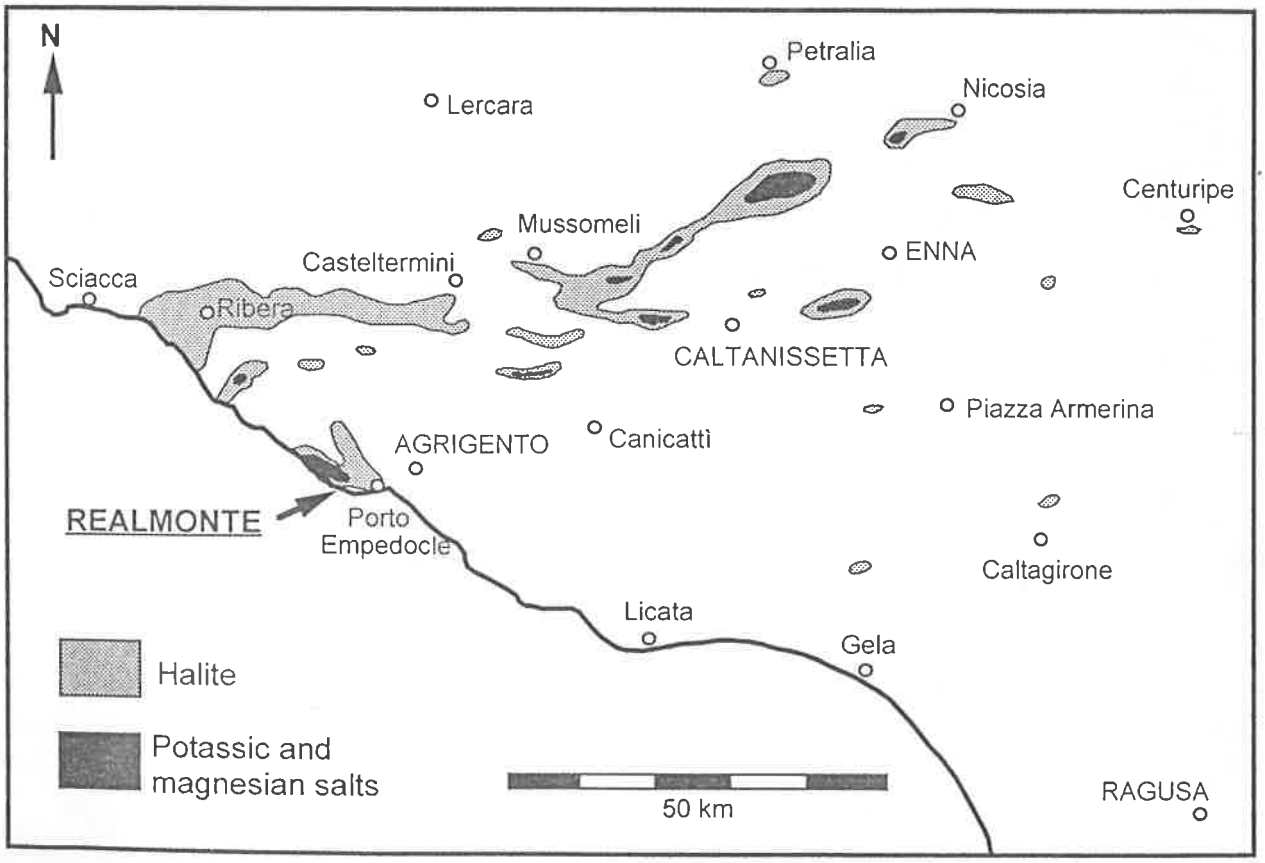

Figure 2 - Map outlining the occurrence of Messinian evaporites in the Caltanissetta basin, Sicily (after Decima and Wezel, 1971).

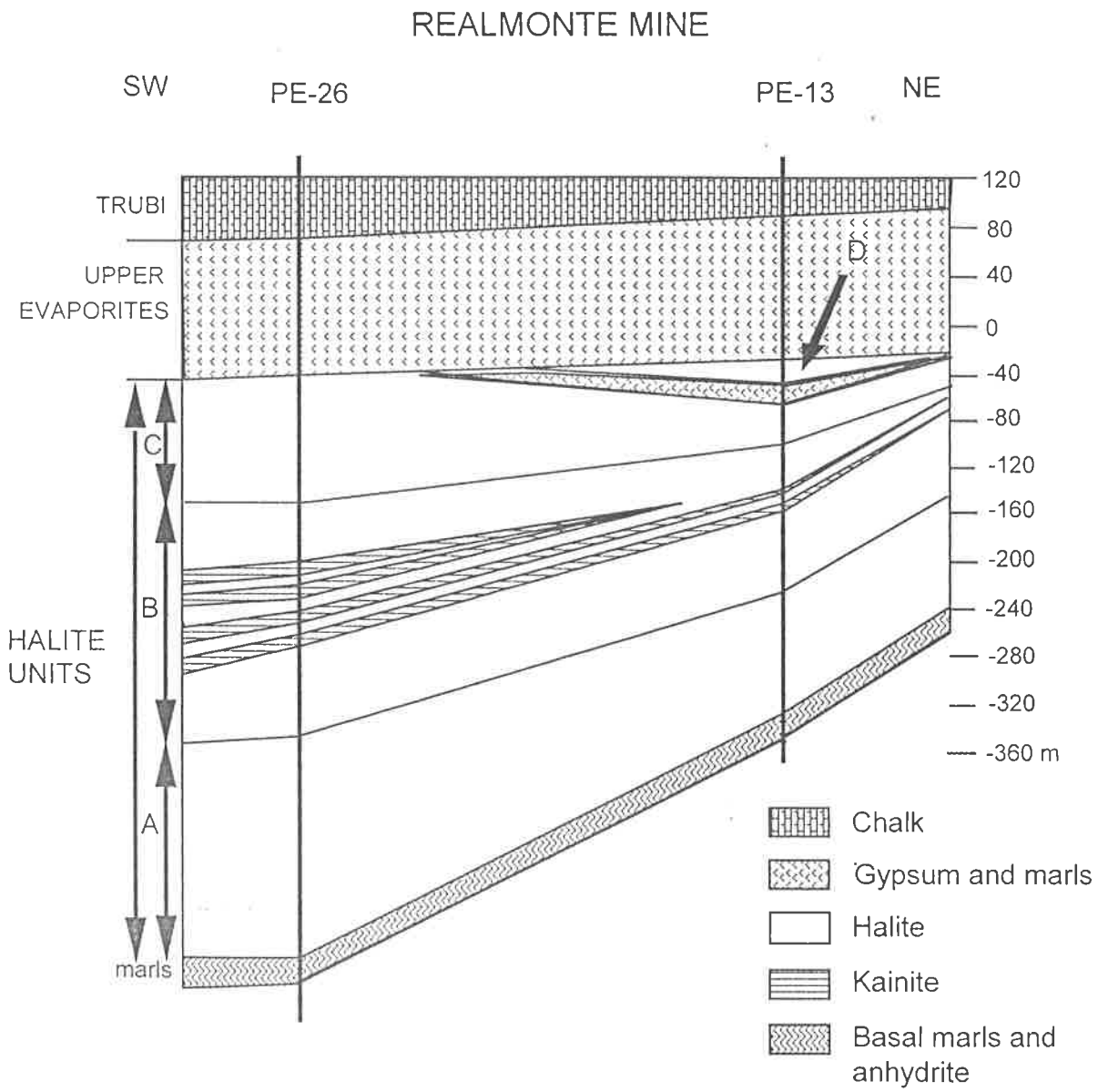

Figure 3 - Stratigraphic column of the Realmonte salt deposits. Modified after Garcia-Veigas et al. (1995) and originated from an ITALKALI internal document; in Lugli et al., in review).

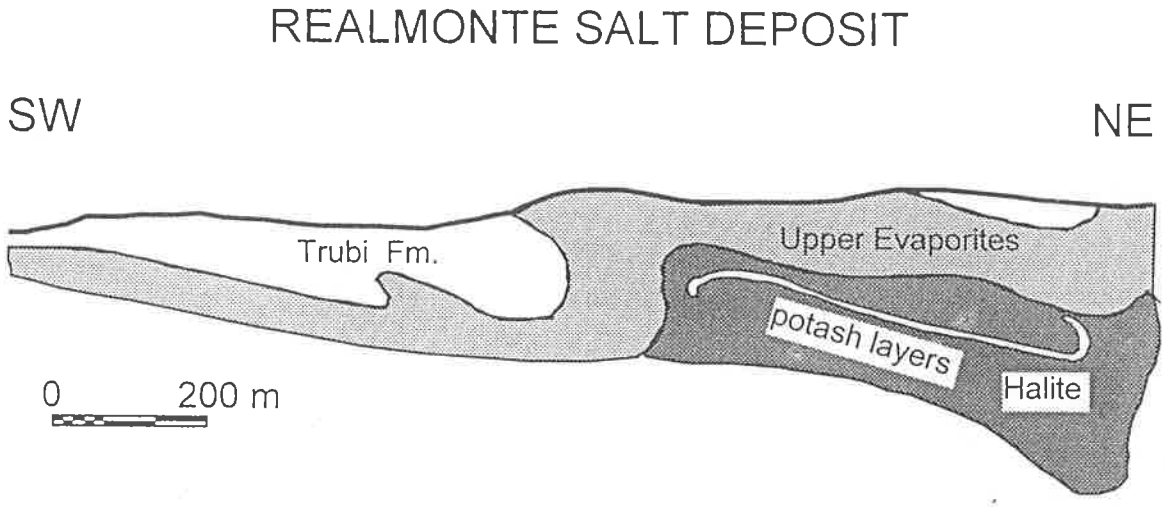

Figure 4 - Cross-section of the Realmonte salt deposit (modified from the "Carta Geomineraria," F. 636 Agrigento, Servizio Geologico Italiano, 1972; in Lugli et al., in review).

Figure 5 - Photomicrograph of a cumulate rock made of halite plate crystals. Note graded bedding. A raft made of three coalescent pyramidal crystals is visible at the top. Realmonte Mine, salt unit B; plane light. Raft is 5 mm-large.

Figure 6 - Photomicrograph of a cumulate rock made of halite skeletal crystals showing further vertical overgrowth (chevron) that occurred at the bottom of the basin (at center and lower part). The halite crystal terminations of the in the lower bed are truncated (small arrows) by a dissolution surface marked by a mud lamina (black, large arrow). A dissolution pit filled by mud cut through the lower bed (black, below the large arrow). Realmonte Mine, salt unit C; plane light; vertical extent of photograph is 5 cm.

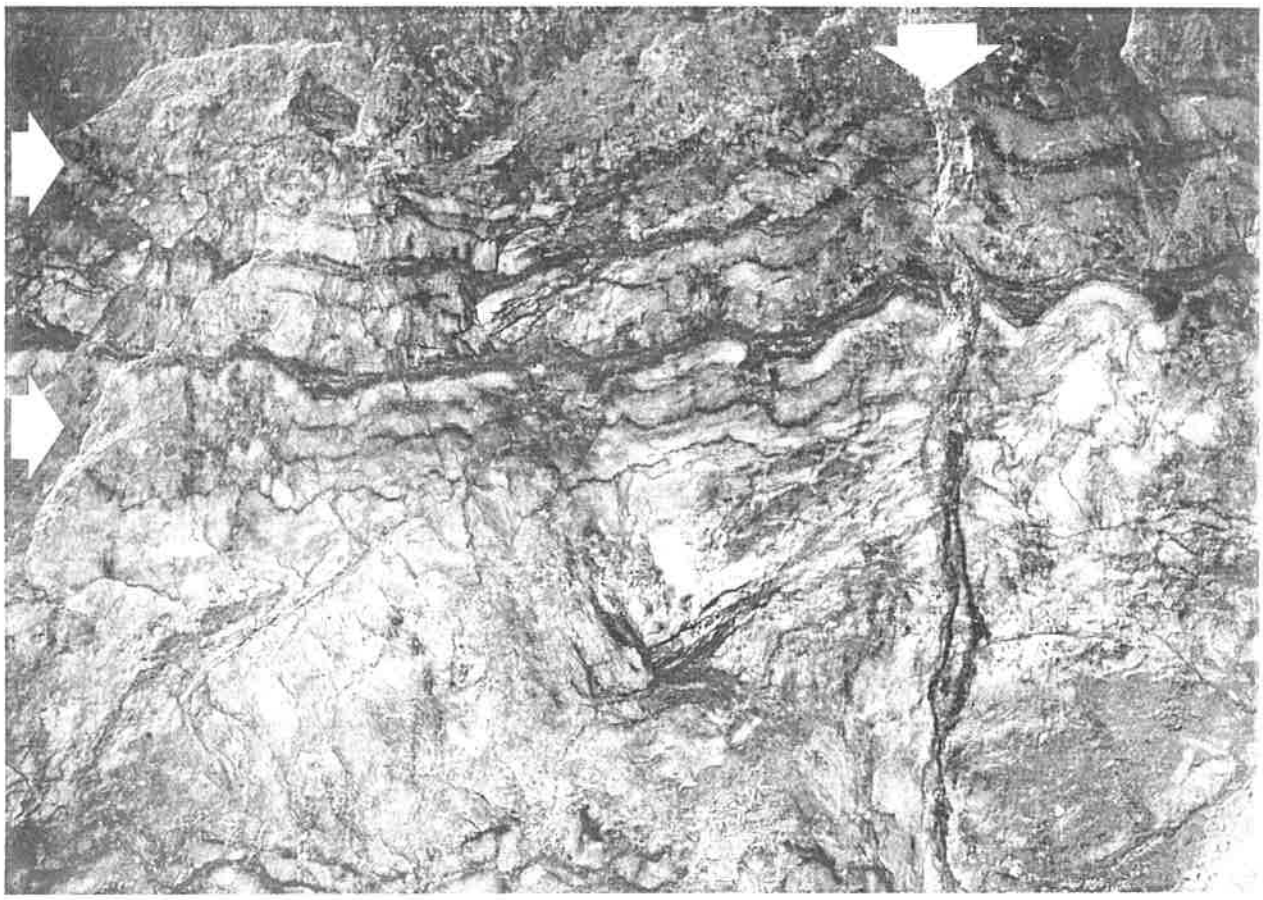

Figure 7 - Deep contraction crack (large arrow) cutting down through the buckled beds of unit C (marked by small arrows at left), as exposed at the wall of the gallery at -128 m depth. The crack is 3 m-long and is filled by red clay.

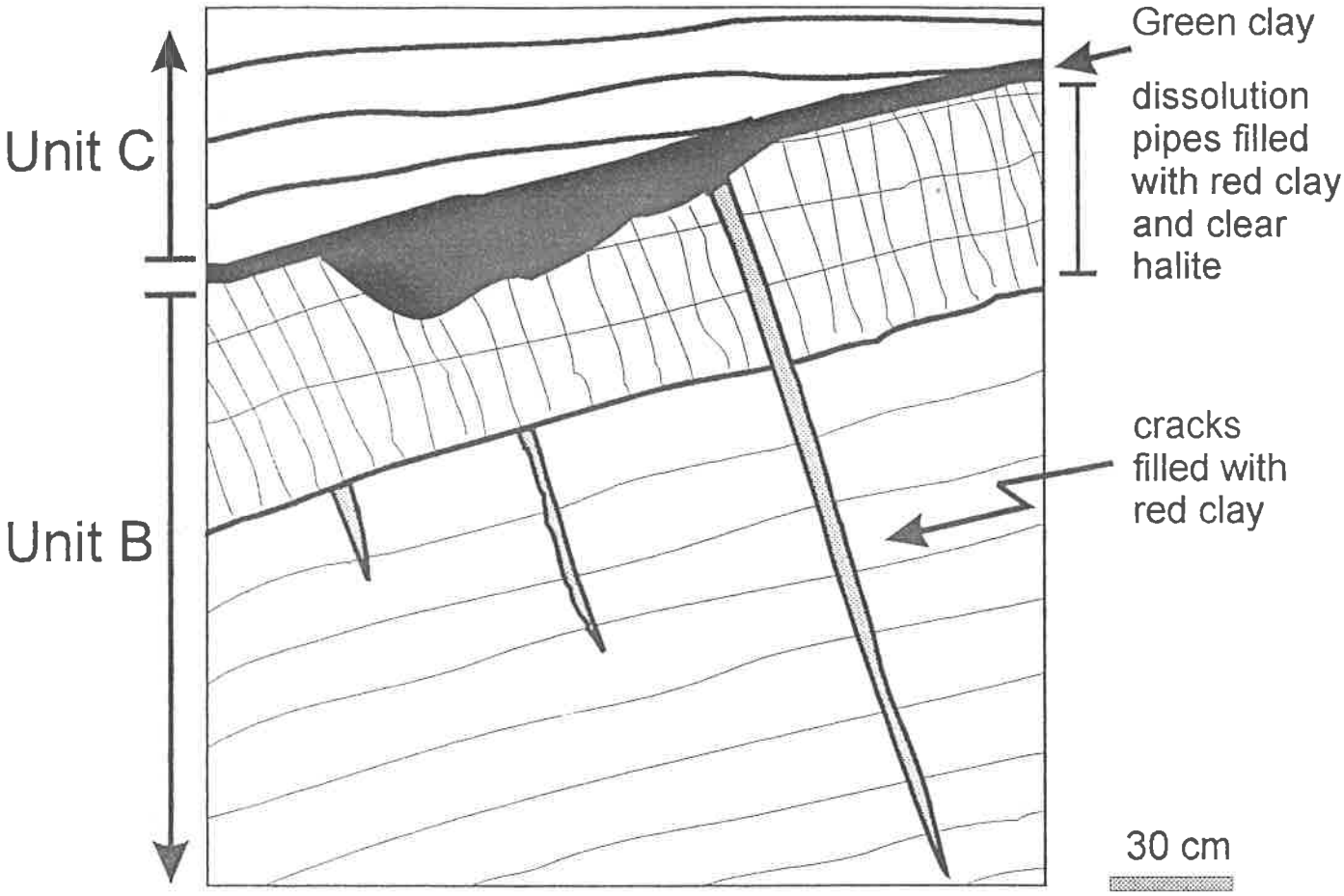

Figure 8 - Schematic diagram drawn from a picture showing successive sets of fissures that initiate from different layers and cut through subaerially modified salt beds. The upper crack is truncated by an irregular mud layer which is onlapped by the mud-halite couplets of unit C. This site was observed in 1995 at a depth of -128 m, but it is no longer visible because of the mining operations (Lugli et al., in review).

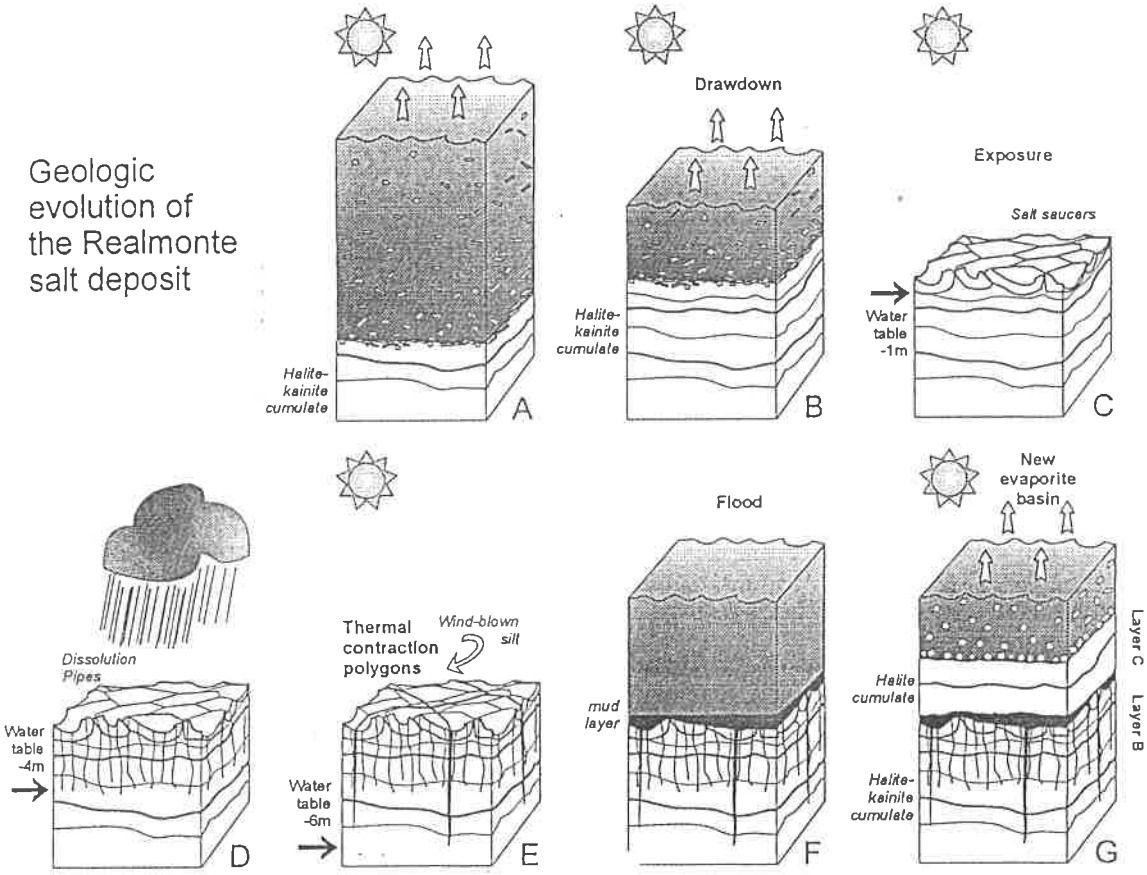

Figure 9 - Schematic diagram (not to scale) showing the geologic evolution of the Realmonte salt deposit: A) subaqueous deposition of halite-kainite cumulate of unit B; B) drawdown of the water level; C) desiccation of the basin and exposure of the salt beds with the formation of salt saucers; D) further lowering of the groundwater table and formation of meteoric dissolution pipes that cut throug the salt beds down to a depth of 4 m; E) formation of deep thermal contraction polygons bordered by cracks 6 m deep that collected wind-blown clay (groundwater table was at least 6 m deep); and, F) flooding of the basin with dissolution and truncation of the topmost buckled salt layers and deposition of a mud layer; G) development of a new evaporite basin with deposion of the halite-clay couplets of unit C (Lugli et al., in review).