MESSINIAN CORRELATION: SALINITY CRISIS

by

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The remarkable progress made in recent years on a perplexing and often controversial geological problem - the geodynamic setting in which the Mediterranean Evaporite was deposited and the global implications of the event - is due in large part to the work of the interdisciplinary IGCP Project on Messinian Correlation.

Late Miocene evaporites have been recognized in circum-Mediterranean land sections for a long time. When seismic studies in the Mediterranean Sea also suggested the presence of evaporitic bodies, intense study was initiated to create depositional models which would explain these deposits. In 1975, after several years of study, conducted often along provincial and sometimes dogmatic lines, a proposal was made to the IUGS/UNESCO International Geological Correlation Programme (IGCP) that a Messinian Correlation Project be created to serve as a unifying agent for Messinian investigations.

The scientific purpose of this project was to study the terminal part of the Miocene (Messinian Stage), characterized in the entire Mediterranean basin by a "salinity crisis." This crisis resulted in the deposition of evaporites whose volume is estimated at 10^6 km^3 . It seemed plausible that the event, occupying but a brief interval of geological time, would have had a catastrophic effect on the faunas of the Mediterranean area. The investigation of the salinity crisis was expected to lead to an understanding of biodynamic and evaporitic sedimentation processes and cycles, to a classification of the evaporites and an evaluation of their mineral potential. The development of a better understanding of the causes and world-wide repercussions of Messinian events was certainly among the principal objectives of the project.

Sedimentological study of the circum-Mediterranean evaporites has shown them to be highly varied petrographically, structurally and environmentally. The presence of desiccation features and stromatolitic surfaces as well as other shallow water features, provides a strong argument for their deposition in shallow water settings. Analogies with recent subaerial and subaqueous sites in the Persian Gulf, Dead Sea and circum-Mediterranean salinas provide a variety of models for the various facies found in the Mediterranean Evaporite. Whether or not they were formed in a sabkha environment is not clear. The evaporites are unusual in that primary gypsum is retained, probably

because the beds were exhumed by erosion shortly after burial.

The evaporites of the deep basin, touched but not penetrated during DSDP Leg 13 in 1970, were recovered for the first time during DSDP Leg 42A in 1975. The evaporite distribution and the distribution of the marginal terrigenous clastic sediment yields a facies pattern like that produced in a desiccated basin.

One of the perplexing sedimentological and stratigraphical problems in the deep basin sequences is the abruptness with which vertical, evaporitic facies change to hemipelagic sediments. The absence of transitional facies argues against any depositional model which calls on vertical tectonism to explain the change from shallow to deep water sedimentation.

Paleoenvironmental reconstructions of the Mediterranean during the Messinian are based not only on sedimentological evidence but also on paleontological data. Significant omissions in the post-Messinian planktic foraminiferal fauna suggested that large scale biodynamic changes had occurred in the Mediterranean environment as a result of evaporite deposition. Arguments that both the pre- and post-Messinian basins were deep came from analysis of ostracode, benthonic foraminifera and fish faunas. Although the Messinian evaporites themselves are sterile, the inter-evaporitic sediments of Messinian age yield diatom and ostracode faunas that are of non-marine origin.

Additional faunal data came from reef deposits in the circum-Mediterranean areas of southern Spain, Tuscany and Sicily. Late Miocene reefs show unusual growth forms and anomalous assemblages which are interpreted in terms of restricted conditions. These restrictions began to show up in the Mediterranean flanking basins prior to the Messinian.

Much of the heated debate over the Messinian revolved around the concept that evaporites were formed in a desiccated basin thousands of meters below world sea level. This notion seemed to strain the concept of Lyellian uniformitarianism.

Opponents of the deep-basin desiccation model argued that the presence of transitional sedimentary sequences from the Messinian into the Pliocene in the Vera Basin of Spain, southern Sicily, and the Ionian islands, was proof that the proposed catastrophic infilling of the Mediterranean in the early Pliocene could not have occurred. Counter-arguments were based on the recognition by other investigators of unconformities and re-working within these same sequences.

The controversy has led to careful scrutiny and re-evaluation of land sections in the satellite basins of the Mediterranean, and a much better understanding of them. In organizing the Messinian Seminar series under IGCP Project "Messinian correlation", Project Leader Maria Bianca Cita wisely decided to get the investigators onto the outcrops. Debate, often heated but always professional, was the hallmark of these field excursions: investigators whose ideas had clashed in the literature were able, for the first time, to argue together in front of the evidence.

Cuevas de Almanzora, Vera Basin, southern Spain. (Center: Maria Bianca Cita, Project Leader of IGCP Project 96 "Messinian correlation".)

Cuevas de Almonzora, Vera Basin, southern Spain: turbidite sequence in foreground; Mio-Pliocene boundary in rear.

Sedimentological and paleontological studies as well as geophysical interpretations of geomorphic and seismic data provided the evidence pertaining to the Messinian depositional models. Seismic studies indicated that there is considerable interbasin heterogeneity. An innovative study based on inversion of phase velocity dispersion of Rayleigh waves and

reflection/refraction seismic data led to the conclusion that the Balearic and Tyrrhenian basins were formed prior to the salinity crisis.

Additional geophysical evidence yielding the same conclusion was derived from the discovery of extensive Messinian erosion surfaces that ran from as much as 500m above to 2000m below sea level. This physical evidence for a severe drop in base level, coupled with an imaginative passive margin geophysical model which predicted the presence of this erosion surface, further substantiated the pre-Messinian presence of deep basins.

One of the most interesting topics in Messinian studies is that of biostratigraphic correlation. The definition of Mediterranean stage boundaries, always a subject of great interest, became even more intensified as a result of controversies over different evaporite depositional models. At the start of IGCP Project 96, the length of the salinity crisis was believed to be about 1.5 Ma. Because of extensive biostratigraphic work, especially with respect to diatom cross correlations with other ocean basins, it now appears that the salinity crisis itself occupied but a small part of the Messinian, about 0.5 Ma. (see Fig. 1).

Rapid strides have been made in tying together vertebrate biostratigraphy to marine biochronology resulting in the well known Mediterranean vertebrate stages being correlated with

TIME (Ma.)	GEOMAGNETIC SCALE			GEOCHRONOLOGY		PLANKTIC BIOSTRATIGRAPHY					
	POLARITY	EPOCH	ANOMALY	SERIES	STAGE	FORAMINIFERA				NANNOS	
						BLOW	OUTSIDE MED.	MEDITERRANEAN ZONES			
								SATELLITE BASINS	DEEP BASIN		
4		GILBERT	3	PLIOCENE	ZANCLEAN	N-19	<i>G. margaritae</i>	<i>G. margaritae</i>	M PL-3	NN-14	
									M PL-2	NN-13	
									M PL-1	NN-12	
5						N-18		?			
		5	3'	MIOCENE		N-17	<i>G. acostaensis</i>	?	RESTRICTED	NN-11	
6		6			MESSINIAN				<i>G. mediterranea</i> and <i>G. conomiozea</i>		
7		7	4						<i>G. humerosa</i>		<i>G. acostaensis</i> and <i>G. pleisotumida</i>
8			4'								
		8			TORTONIAN						
9		9				N-16		<i>G. acostaensis</i>	<i>G. acostaensis</i> and <i>G. merotumida</i>		

Figure 1. Messinian stratigraphy. (Modified from Smith, 1977 after data from Berggren and Van Couvering, 1974; Bizon and Bizon, 1972; Cita, 1975; Ryan et al., 1974; and Stainforth et al., 1975). Cross hatchured area represents the duration of the Messinian salinity crisis.

Messinian fluviatile sequence, Tuscany, Italy. Center: Isabella Premoli-Silva (Italy).

the world-wide planktic zonation scheme and magnetostratigraphy.

Geochemical studies of the evaporites suggested that the initial evaporites were marine in origin which were reworked as a consequence of erosion on the flanks of a deep desiccated basin, and subsequently led to the formation of an upper evaporite of non-marine origin.

Studies of stable isotopes from the evaporitic sediments, coupled with the nature of benthonic faunas, indicate that the eastern Mediterranean was strongly influenced by continental waters during the late Messinian. The fresh water influx seems to have been episodic and highly variable.

In addition to providing evidence about the nature of water entering the Mediterranean during the Messinian, stable isotope studies have also provided an indication that the post-Messinian basins were deep. Oxygen isotope ratios from planktic and benthonic foraminiferal tests indicated a thermal gradient between surface and bottom waters of a magnitude that could only be explained by a deep basin.

In summary, the overwhelming body of evidence that has been derived from sedimentological, paleoecological, geophysical, biostratigraphical and geochemical studies on the Messinian problem supports the concept that the Mediterranean basins were discrete and deep prior to the Messinian, that all the salts were precipitated in a topographically deep basin, that the upper layers of evaporites were deposited in a desiccated shallow water environment, that large scale tectonic movements were not responsible for the observed vertical facies changes, and that the Pliocene flooding of the desiccated Mediterranean was a sudden catastrophic event.

Messinian reef, Tuscany, Italy. Foreground: Kim Kastens (U.S.A.), Rob Kidd (U.K.); Background: Ranier Gersonde (F.R.G.), Maria Bianca Cita (Italy).

The permanent removal of 10^6 km^3 of salt from the world ocean is not an insignificant event and may have produced consequences outside of the Mediterranean. One of the more imaginative hypotheses based on the Messinian event was the proposal that salt deposition in the Mediterranean basin might have resulted in polar glaciation. According to this hypothesis, the tectonic closure of the Mediterranean from the Atlantic is considered to have disrupted the oceanic salt budget to such an extent that surface salinity of the oceans dropped significantly.

This decline in salinity could have resulted then in expansion of polar pack ice with a consequent increase in the earth's albedo; climatic cooling would have followed. Although the occurrence of Southern Hemisphere Miocene glaciation had been known prior to the introduction of this hypothesis, the latter offered an explanation for the initiation of glaciation.

The crucial issue on which this hypothesis rested was the relative timing of the evaporite deposition in the Mediterranean and the initiation of expanded ice sheets in the Antarctic region. Detailed correlations between biostratigraphic zones and the paleomagnetic time scale established a fairly precise framework against which these events could be compared.

There is evidence to both support and to argue against the hypothesis. The supporting evidence comes primarily from deep sea sediments off Cap Bojador, Africa, where climatically modulated cyclic sediments appear to have been deposited after the initiation of restrictive conditions in the Mediterranean.

On the other hand, studies of piston cores from the Southern Ocean show evidence for a strong increase in bottom water activity (triggered by increased glacial activity) in sediments whose age predates the onset of evaporite deposition in the Mediterranean. In addition, isotopic evidence from pre-evaporite Messinian sediments in Mediterranean satellite basins indicates cyclic fluctuations that can be explained also by glacio-eustatic changes.

We still do not have sufficiently precise geochronological control to critically evaluate the relative timing of evaporitic and glacial events. It may be that the two events produced a positive feed back system in which glacio-eustatic lowering of sea level (due to extra-Mediterranean causes) isolated the Mediterranean and initiated restriction and eventually evaporite deposition. This deposition and its consequent geochemical imbalances may then have further intensified climatic deterioration. There is evidence for a world-wide Messinian glacio-eustatic drop in sea level in such diverse areas as the Sea of Japan, California, Florida and Morocco.

The Messinian Correlation Project was conceived as a five-year study with the hope that concerted interdisciplinary cooperation might resolve some of the problems confronting European geologists for more than a decade. Several international meetings in the early 70's dealt peripherally with the Messinian in terms of stage boundary disputes, and a conference on the Messinian was held in Utrecht in 1973. In addition, several groups of earth scientists were working on the problem, but they were conducting their research along national lines, whereas the problems of the Messinian transcend political and provincial boundaries and even extend beyond the Mediterranean itself.

Part of the success of the Project has been that it has forced investigators to look beyond their own geographic and disciplinary area of study, and in that it has involved earth scientists from all the circum-Mediterranean areas, not just those from nations with extensive science programs. Studies of the Messinian have benefited from the impetus gained by the series of IGCP-sponsored seminars.

The locales of the first and the most recent seminars (see box) are perhaps symbolic of the evolution of ideas and progress that has occurred during the last five years. The first IGCP Messinian Seminar was characterized by questioning and proposing of, at times, vague hypotheses. But it was held in an atmosphere of faith and hope that the future would see solutions to complex problems. Fittingly, the final session of the meetings was held on the steps of the Temple of Concord in Agrigento, Sicily. The most recent seminar was held in Rome, literally in the shadow of the Basilica of St. Peter, symbolizing perhaps the faith that had been initiated four years earlier in Sicily. Though controversies remain and new questions arise, a model of scientific cooperation has been established which provides testimony to the interest that has developed in the geology of a simple yet unusual stratigraphic stage.

Foothills of the Appenines, northern Italy. Foreground: John van Couvering (U.S.A.); Left to right: Lloyd Burckle (U.S.A.), Anna Sokac (Yugoslavia), Richard Benson (U.S.A.), and Ranier Gersonde (F.R.G.).

Recent Meetings

under

IGCP Project 96: Messinian correlation

October 9-14, 1978: Messinian Seminar, fourth in a series of working conferences on the Messinian salinity crisis, devoted to theme "geo- and biodynamic effects of the Messinian salinity crisis in the Mediterranean" (held in Rome, co-sponsored by the Consiglio Nazionale delle Ricerche, ICG and IGCP).

October 23-26, 1978: Symposium on the global recognition of Messinian events (held in Toronto, sponsored by the U.S. Working Group of IGCP Project 96 in conjunction with the joint meeting of the GSA, GAC and the MAC).

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Ramil Wright beside Messinian evaporites (gypsum) in the Pesciera Quarry, 2 km SE of Rosignano Marittimo, Tuscany, Italy.