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FOREWORD

The Ocean Sciences in Relation to Non-Living Resources (OSNLR) programme of the Intergovernmental Oceanographic Commission 0OC) run jointly with the United Nations (Office of Ocean Affairs and the Law of the Sea) was introduced in 1982. Its aim is to perfect the knowledge of the origins and distribution of useful substances in the marine environment. The notion of the environment is linked to this programme because of the harmful effects that exploitation of these substances could cause.

The composition of multi-disciplinary teams, capable of intervening in research, particularly in developing countries, is of urgent necessity, in view of the number and diversity of the problems ta be resolved: the type of resources, the mechanisms of their generation and origins, their location in the ocean, ta cite only the most essential. In this context, the training component has a very important role to play in liaison with the programme. The international IOC Training, Education and Mutual Assistance in the Marine Sciences SEMA) programme takes into consideration the requirements of the OSNLR programme in suggesting appropriate solutions which could be used as worldwide benchmarks.

Analyses carried out by specialist groups of experts have shown the urgent necessity to develop studies on the coastal environment. The dispersion of useful substances in this milieu is influenced as much by hydrodynamical as by morphological factors (coastal and seabed). Fluxes linked to different elements caracterising the continent/ocean interface, such as those associated with the modification of coastal areas, should be well known as they influence the many parameters of the evolution of the environment. Within these fluxes there are fluxes of organic matter in which breakdown begins to occur, influencing the chemical balance of the oceans.

However, a global approach and the development of the OSNLR programme can only be considered in a more precise manner when several conditions, such as scientific interest in the proposed programme and its plan of application, existence of regional projects and the availability of the necessary resources (equipment, finance and groups of specialists), are available.

Thus, the Officers of the OSNLR programme adhere to the conditions of implementation, within the regional context, well-defined research not only with a view to increasing knowledge, but also to make possible the training of scientists and technicians. In order to do this, groups of regional and sub-regional experts are gradually being formed (Western Pacifie, Caribbean, Indian Ocean, Central Eastern Atlantic, South-West Atlantic) to organize research activities, training and development, on the basis of close collaboration with the Guiding Group of the Programme working from IOC.

In this way, and taking into account the similarities between the research programmes of IOC and ICSEM international Commission for the Scientific Exploration of the Mediterranean Sea), a regional component relative to the Mediterranean could be established associating the two Commissions through the OSNLR programme. This decision was taken during a joint meeting held in Monaco (14-15 December 1989) during which a regional group of experts was formed.

The first work accomplished under OSNLR considered the coastal process with priority given coastal sediments dynamics (insular and deltaic).

A series of conference and lectures took place on the occasion of the Congress at Perpignan which concerned various aspects of these sedimentary processes, and the regional Mediterranean investigations will be of help in this, and will make a considerable contribution ta the knowledge of these phenomena and their consequences.

The understanding of the coastal environment is of an increasingly important priority among the world's environmental problems. The Mediterranean, thanks ta the variety of models it provides, is becoming a particularly promising field of investigation. Planned regional programmes will, without doubt, provide much useful knowledge.

M. VIGNEAUX
Chairman, OSNLR Programme

AVANT-PROPOS

Datant de 1982, le programme OSNLR (Ocean Sciences in Relation to Non-Living Resources) est un programme conjoint de la COI (Commission océanographique intergouvernementale) et des Nations Unies (Bureau des affaires maritimes et du droit de la mer) qui a pour objectif essentiel de parfaire les connaissances sur la genèse et la distribution des substances utiles dans la domaine marin. La notion d'environnement est liée à ce programme en raison des nuisances que l'exploitation de ces substances ne peuvent qu'engendrer.

La constitution d'équipes pluridisciplinaires, susceptibles d'intervenir dans les recherches, en particulier pour les pays en voie de développement, est une obligation d'application urgente, compte tenu du nombre et de la diversité des problèmes à résoudre: nature des ressources, mécanismes de leur genèse et localisation en domaine océanique pour ne citer que les plus fondamentaux. Dans ce contexte, la composante formation joue un rôle déterminant en liaison avec le programme.Le programme international TEMA (Training, Education and Mutual Assistance) de la COI prend en considération les impératifs du programme OSNLR afin de proposer des solutions appropriées susceptibles de servir de référence mondiale.

Les analyses réalisées par des groupes d'experts spécialisés ont mis en relief l'urgente nécessité de développement des études sur les envionnements côtiers. Dans ces milieux, la dispersion des substances utiles obéit tant aux facteurs hydrodynamiques que morphologiques (littoraux et fonds marins). Les flux liés aux différents éléments caractérisant l'interface continent/océan comme ceux associés aux modifications des franges côtières, doivent être bien connus car ils conditionnent de multiples paramètres de l'évolution de ces milieux. Dans une cinématique semblable, se meuvent les flux de matière organique qui sont le théâtre des premiers stades de dégradation et influencent la balance chimique des océans.

Cependant, une approche globale ne peut être envisagée et le programme OSNLR ne peut concevoir son développement qu'au travers d'action plus ponctuelle dans la mesure où diverses conditions sont remplies, dont les principales sont: intérêt scientifique de l'intervention projetée et du modèle d'application; existence d'une proposition régionalisée et obtention des moyens nécessaires à sa réalisation (équipements, financements et groupes de spécialistes).

Les responsables du programme OSNLR se sont donc attachés aux conditions de mise en oeuvre, au sein d'ensembles régionaux, d'actions de recherches bien délimitées susceptibles de faire avancer les connaissances mais aussi de servir de support à la formation des scientifiques et techniciens. Pour ce faire, des groupes d'experts régionaux et sous-régionaux sont mis progressivement en place (Pacifique Ouest, Carat)es, Océan Indien, Atlantique du Centre Est, Sud-Ouest Atlantique) et ont pour mission d'organiser, sur la base de réseaux des activités de recherche, formation et développement, en coordination étroite avec le Comité directeur du Programme, oeuvrant
à la COI.

Dans cet esprit, et compte tenu de grandes similitudes entre programmes de recherches de la COI et de la CIESM (Commission internationale pour l'exploration scientifique de la mer Méditerranée), une composante régionale relative au domaine méditerranéen pouvait être établie en association entre les deux Commissions concernées par le programme OSNLR. Cette décision a été prise lors d'une réunion commune tenue à la Principauté de Monaco (14-15 décembre 1989) au cours de laquelle un groupe régional d'experts a été constitué.

Les premiers travaux réalisés dans le cadre d'OSNLR ont abouti à considérer les processus littoraux avec une grande priorité portant spécialement sur la dynamique sédimentaire côtière insulaire et deltaïque.

L’ensemble des conférences qui vont se dérouler à l’occasion du congrès de Perpignan intéressent divers aspects de ces processus sédimentaires et les investigations régionales méditerranéennes aidant, doivent apporter une contribution considérable à la connaissance de ces phénomènes et à leurs conséquences.

La connaissance des domaines côtiers est une priorité de plus en plus grande qui s’inscrit parmi les préoccupations environnementales mondiales. La Méditerranée, grâce à la diversité des modèles qu’elle regroupe, constitue un champ potentiel d’investigations particulièrement prometteur. Les programmes régionaux projetés seront, sans nul doute, riches d’enseignements.

M. VIGNEAUX
Président du Programme OSNLR

PART I

RÉUNION DU GROUPE CONJOINT COI-CIESM D'EXPERTS POUR LA COMPOSANTE MEDITERRANNEENNE DE OSNLR

1. INTRODUCTION

Le Programme "L'océanologie et les ressources non vivantes" (OSNLR) est un programme conjointement soutenu par le COI et les Nations Unies (Bureau des affaires maritimes et du droit de la mer). Il a pour objectif de promouvoir des recherches sur les ressources marines non vivantes, en priorité celles des zones côtières: parmi celles-ci la zône côtière en elle-même (CZAR: Zone côtière considérée comme une ressource en soi).

Le développement du Programme s'effectue au plan régional dans le cadre de projets spécifiques adaptés aux différentes régions, à leurs caractéristiques naturelles, aux moyens humains, matériels et financiers disponibles. Il est également réalisé dans le cadre de la coopération avec d'autres programmes et organismes.

Lors de la réunion *ad hoc* COI-CIESM consacrée à l'élaboration d'une composante méditerrannéenne du Programme OSNLR (Monte Carlo, Principauté de Monaco, 14-15 décembre 1989), il a été accordé un intérêt particulier à l'étude des transferts sédimentaires, en distinguant les systèmes à fort flux continental (zones deltaïques) et les systèmes insulaires, souvent à budget sédimentaire déficitaire.

Les thèmes, relatifs à la distribution des budgets sédimentaires en milieu marin, apparaissent d'une importance particulière pour l'interprétation de l'évolution des zônes côtières et de leur réponse aux modifications de l'environnement littoral en relation avec l'élévation du niveau de la mer ou les perturbations liées aux activités humaines. Les conséquences sont particulièrement nettes en ce que concerne l'érosion côtière à laquelle sont soumis les littoraux de nombreuses îles méditerranéennes, Chypre et Malte notamment.

Aussi, le Groupe d'Experts a retenu au titre d'une composante conjointe COI-CIESM de OSNLR un thème général relatif à la dynamique sédimentaire côtière dont le calendrier des études proposées prévoit trois étapes:

(i) **Systèmes côtiers insulaires de Méditerranée**

(ii) **Systèmes deltaïques méditerranéens**

(iii) **Littoraux méditerranéens.**

Il est envisagé également de conduire des études d'impact de l'environnement qui nécessitent une approche à la fois pluri et interdisciplinaire, comprenant les connaissances des processus marins, l'état de pollution marine, les activités socio-économiques actuelles.

Il apparaît extrêmement important de définir une stratégie favorisant la mise en oeuvre de conditions communes pour la recherche nationale afin de satisfaire les demandes spécifiques et collectives de divers départements (administration, gestion et développement) et des secteurs industriels et économiques concernés.

2. DÉVELOPPEMENT GÉNÉRAL D'UN PROJET CONCERNANT LES SYSTÈMES CÔTIERS INSULAIRES DE MÉDITERRANÉE

La COI dans le cadre de la coopération entre l'UNESCO et la Commission des Communautés Européennes se propose de soumettre à cette dernière pour financement un projet, d'une durée de cinq ans, relatif à la dynamique des milieux côtiers insulaires s'appuyant, en particulier, sur les cas de Chypre et de Malte, Etats membres de la COI et de la CIESM.

Un avant-projet a été préparé par la COI dont les éléments relatifs au contexte, à la justification et les objectifs à développer sont précisés dans les paragraphes qui suivent. Un texte sur les problèmes d'environnement côtier relatifs à Malte et à Chypre figure à l'annexe I.

2.1 OBJECTIF GENERAL DU PROJET

L'objectif final du projet est de développer les connaissances sur les mécanismes responsables du comportement des environnements côtiers insulaires de la Méditerranée.

L'objectif immédiat est de développer les capacités de recherche des pays méditerranéens participants en matière d'aménagement et de gestion des environnements côtiers. Le projet concerne tout particulièrement (voir annexe) les pays ou partie de pays pour lesquels les environnements littoraux font l'objet d'une exploitation touristique intensive et qui, du fait de leur insularité, posent des problèmes d'environnement très spécifiques: étroitesse du plateau continental, importance économique relative de la zone immergée par rapport aux zônes émergées, surexploitation urbanistique, touristique et économique des zone côtières, conséquences au niveau de l'érosion côtière.

2.1.1. Contexte du Projet

Pour de nombreux pays, la ressource la plus importante de la zône économique exclusive est la zône côtière elle-même. Pour les états insulaires, ou pour les états dont l'environnement insulaire constitue, au plan géographique, une part majeure du territoire national, l'importance économique de la frange littorale est considérable, en particulier pour les îles de petites superficies pour lesquelles la mer (littoral et plateau continental) offre des possibilités d'expansion économique d'autant plus essentielles qu'elles sont rares, à savoir:

(i) les activités portuaires
(ii) la pêche et l'aquaculture
(ii les ressources minérales: pétrole, gaz, placers, sables, graviers
(iv le tourisme.

Trop souvent, le développement de ces possibilités s'effectue dans un climat de connaissances scientifiques insuffisantes. Il s'ensuit des conséquences économiques et/ou environnementales peu prévisibles. Des efforts doivent donc être faits pour développer des connaissances élémentaires permettant de mettre en oeuvre des politiques d'aménagement et de développement en accord avec les contraintes de l'environnement. Il est important pour cela de faire appel à des études globales prenant en compte l'ensemble des facteurs en présence. Les problèmes rencontrés ne peuvent se résoudre de manière sectorielle, mais uniquement au travers de plans d'action faisant simultanément appel à toutes les disciplines concernées.

2.1.2 Justification du Projet

L'une des préoccupations majeures de diverses îles de la Méditerranée, en matière d'environnement, est la lutte contre l'érosion marine (voir annexe 1). Les raisons de cette dégradation peuvent être d'origine naturelle: remontée du niveau de la mer, subsidence de certaines régions. Le plus souvent, elle est la conséquence des activités humaines dans la région considérée. Les ouvrages à la côte (jetées, épis), les travaux sur les cours d'eau (barrages, dragages) diminuent le volume des sédiments apportés à l'océan. L'utilisation des sédiments de plages comme matériaux de construction entraîne une diminution de stock sédimentaire disponible, diminutition que la mer compense en érodant le littoral.

L'aménagement du trait de côte accroît la réflexion des houles, et renforce la turbulence des courants de retour.

Des pompages de la nappe phréatique peuvent entraîner un affaissement du littoral et faciliter l'action érosive de la mer. La construction des digues et épis répond trop souvent à un problème local sans prendre en compte l'ensemble des facteurs du milieu. Leur construction devrait être précédée d'études de la dérive littorale et des processus hydrodynamiques, au risque de seulement déplacer plus en aval la zône où s'exerce l'action érosive de la mer.

Sur certains rivages, les herbiers (zostères et posidomies) jouent un rô1e prépondérant dans la fixation des matériaux meubles. Ces herbiers sont cependant très sensibles à la pollution et au rejet de matériaux. En Méditerranée, leur développement est un danger risquant de perturber non seulement la dynamique sédimentaire mais également tout l'écosystème.

En résumé, les processus s'exerçant sur la zône côtière sont étroitement liés; toute action sur l'un d'eux entraîne une réaction en chaîne aux conséquences souvent imprévues. Lorsqu'un aménagement du littoral s'avère nécessaire, le choix du site, les moyens à mettre en oeuvre passent nécessairement par une étude préalable basée sur: la connaissance des données naturelles, les mécanismes de l'évolution, et le suivi du système "après construction".

2.1.3 Les objectifs à développer

La gestion et la protection du littoral en général nécessitent des études, pour la plupart de caractère pluridisciplinaire, focalisées sur les volets suivants:

(i) Suivi de la configuration du littoral et de son évolution. Levers des profils de plages. Les processus directement soumis aux houles et à la marée seront considérés sur des périodes de temps suffisamment longues et couvrant d'une part les différentes saisons et, d'autre part, les variations annuelles, voire séculaires.

Des études particulières seront consacrées à l'évolution de la configuration du littoral grâce à l'exploitation des données satellites (évolution à court terme) et - quand ils existent **B** des documents cartographiques anciens dont la qualité et la précision peuvent être considérées comme satisfaisantes depuis une centaine d'années, et qui constituent des données de référence précieuses pour connaître l'évolution des côtes.

(ii) Etablissement des bilans des flux de matériaux fluviatiles à la mer et des transits sédimentaires le long des côtes. Ces bilans et leurs variations dans le temps seront réalisés par des unités spatiales et temporelles de différentes échelles, adaptés aux situations étudiées. Les transports liés aux courants seront envisagés à une échelle saisonnière annuelle et pluriannuelle. Les effets des aménagements sur les flux des matières venant des terres émergées ou transitant sur les littoraux seront interprétées sur la base d'une comparaison des données actuelles et de celles **B** quand elle existent - antérieures aux aménagements. En l'absence de ces données, une approche de l'évolution des bilans sédimentaires peut etre dégagée de la comparaison des documents cartographiques successifs (voir point (i)).

(iii) Etude géophysique (sismique superficielle haute résolution) et géomorphologique des fonds marins littoraux, en particulier au droit des plages et des zônes principales d'aménagements. L'objectif sera de déterminer les caractéristiques morphologiques et structurale pouvant jouer un rôle dominant sur l'évolution des littoraux et sur leur réponse aux aménagement (tenue des plages, des ports, des constructions en bord de mer, etc.).

(iv) Etudes géologiques des fonds marins notamment: (a) aux alentours des zônes susceptibles de constituer des resources de matériaux meubles transitant sur le plateau ou le long du littoral; (b) au droit des plages soumises à des évolutions importantes; (c) dans les zônes susceptibles de receler des substances économiquement intéressantes: sables et graviers, carbonates, autres substances utiles (dépôts phosphates, glauconitiques, organiques, etc...).

(v) Océanographie physique: étude des courants, des vagues (hauteur, période et longueur d'onde, angle d'approche à la côte, caractéristiques du déferlement.

(vi) Modélisation des processus. A partir de l'ensemble des données recueillies on cherchera à modéliser les processus de transports sédimentaires (modèles mathématiques ou modèles physiques) en essayant, autant que faire se peut, d'appréhender les mécanismes de manière globale et non pas locale.

2.2 CAMPAGNES OCEANOGRAPHIQUES: MALTE ET CHYPRE

Deux campagnes océanographiques sont proposées, ayant pour objectif l'étude de la géologie et de L'hydrodynamique de la zone côtière de Chypre et de Malte.

Afin d'élaborer les plans de travail des croisières océanographiques et de leur suivi ainsi que de déterminer les besoins en équipement et en formation, deux Ateliers sont prévus :

(i) le premier à Malte;
(ii) le second à Chypre.

Ces Ateliers offriront l'occasion de considérer les études à conduire sur les sites significatifs choisis. Malte et Chypre ne disposant pas dans toutes les disciplines envisagées (géomorphologie, sédimentologie, hydrodynamique, télédétection, engineering côtier, impact environnemental, pollution marine, écologie) de l'expertise nécessaire, des solutions devront être étudiées. Certains membres du groupe d'experts se proposent de participer personnellement dans le projet et de trouver des aides auprès d'équipes scientifiques extérieures.

3. ELABORATION D'UN PROJET D'ETUDE DES SYSTEMES DELTAIQUES MEDITERRANEENS

Afin de comprendre les processus qui sont à la base des similitudes et des différences existant entre les deltas méditerranéens, les facteurs qui contrôlent leur caractère doivent, pour chaque delta, être précisés. Parmi ces facteurs sont à considérer : le climat dans le bassin versant, la néotectonique, les processus océanographiques à l'embouchure et la géométrie de la marge continentale. Ceux-ci différeront d'un delta à l'autre et seront la cause des différences rencontrées dans les processus sédimentaires deltaïques.

Les deltas méditerranéens possèdent une particularité unique; celle d'offir une excellente information sur l'histoire des systèmes durant plusieurs milliers d'années grâce au système fermé que représente la Méditerranée. Ceci permettra des comparaisons et ainsi de savoir comment les changements naturels et anthropogéniques affectent le delta grâce à l'archivage sédimenté préservé (paléodelta).

En outre, certains systèmes deltaïques sont actuellement actifs comme ils l'avaient été pendant les bas niveaux marins des périodes glaciaires. Aussi, ils peuvent fournir une information fondamentale pour comprendre et interpréter la sédimentation quand des masses considérables d'apports sédimentaires fluviadiles s'échappent du plateau continental.

Une équipe de scientifiques méditerranéens devra être constituée ayant pour objectif d'entreprendre l'étude d'ensemble des caractéristiques sédimentaires importantes. Elle sera chargée d'examiner chacun des deltas (des 3-5 deltas) de manière cohérente pendant approximativement 1-2 ans. Il s'agira de comprendre comment des combinaisons différentes de processus conduisent à des caractères géologiques spécifiques.

En raison des efforts déjà déployés ou en cours, relatifs aux systèmes deltaïques plus importants comme le Nil, l'Ebre et le Rhône, il s'avère nécessaire de préciser les termes de référence des futures études requises ainsi que de déterminer les lacunes existantes.

3.1 DIFFUSION D'UN QUESTIONNAIRE ET ORGANISATION D'UN ATELIER

Dans ce contexte, il est envisagé de lancer un questionnaire sur l'état actuel des connaissances ainsi que sur l'information disponible et les études en cours ou projetées. L'analyse des réponses donnera lieu à l'établissement d'une synthèse séparée pour chacun des deltas. La liste de destinataires sera composée des adresses pour action de la COI, des adresses fournies par le fichier de la CIESM et enfin, des adresses indiquées par les membres du Groupe d'experts.

Une première synthèse sera effectuée par un comité restreint d'experts et présentée lors d'un Atelier consacré à l'élaboration du projet relatif aux systèmes deltaïques méditerranéens.

La possiblité de l'établissement d'une base de données sera également examinée ainsi que la coopération avec les réseaux existants.

Les travaux de cet Atelier bénéficieront des réflexions menées par l'équipe scientifique qui conduit actuellement des études sur le delta du Po qui est une zône de très forts flux sédimentaires.

Une autre zone devant retenir particulièrement l'attention lors de la tenue de cet atelier est le delta de la Medjerda, en Tunisie. Ce fleuve qui se déverse dans le golfe de Tunis se caractérise par un débit hydraulique moyen d'un milliard de m3/an et un débit sédimentaire moyen de 20 millions de tonnes/an. Il s'agit donc d'un système à fort flux continental dont l'étude présente un intérêt non seulement pour la Tunisie, mais aussi en tant que référence pour les autres pays du bassin méditerranéen.

La plateforme deltaïque de la baie de Thermaikos, en Grèce, qui présente un grand intérêt sur les plans scientifique, économique et socio-culturel, sera également considérée.

4. LITTORAUX MEDITERRANEENS : ATELIER A ALGER

Ce troisième volet des études relatives à la dynamique sédimentaire de la zone côtière intéressera dans une première phase les côtes de la rive sud de la Méditerranée telles que celles de l'Algérie.

L'Algérie profondément ancrée dans le continent africain borde la Méditerranée avec ses 1.200 kms de côtes. La diversité des climats allant de l'aride à tempéré a déterminé pour une grande part la situation économique et sociale des régions, les contrastes des reliefs ayant aggravé ou favorisé la position des unes par rapport aux autres.

D'ici l'an 2000, la population algérienne passerait à plus de 33 millions d'habitants dont 70% seront concentrés dans la zone Nord qui représent 4% de la superficie totale du territoire. D'où le déséquilibre dans l'occupation de l'espace et les menaces déjà sensibles sur le littoral. De plus, le littoral subit chaque année le choc de 8 millions d'estivants entre juin et septembre. La pollution urbaine et industrielle, avec les eaux usées, les déchets solides et les rejets chimiques qu'elles produisent ont entraîné des modifications notables des milieux côtiers. Les risques naturels : séismes, inondations, tempêtes et autres évènements occasionnels, affectent l'utilisation de ce potentiel et aggravent les difficultés de sa gestion.

Une réunion de spécialistes sera organisée à Alger pour prendre en charge une étude approfondie des mécanismes de transit de sédiments côtiers et de dynamique littorale.

5. PUBLICATION DES CONFERENCES ET COMMUNICATIONS SUR LE THEME OSNLR

Les trois conférences présentées dans le cadre du Congrès de la CIESM par MM. Charles A. Nittrouer et Mahmoud El Sayed et Mme Anna Spiteri (lue par M. Micallef) ainsi que les communications qui ont suivi apparaissent en partie II du présent document.

A N N E X E I

LES PROBLEMES D'ENVIRONNEMENT COTIER EN MILIEU INSULAIRE

I EXEMPLE DE L'ARCHIPEL MALTAIS

1. Présentation générale

L'archipel maltais, situé à 44 milles de la Sicile et 185 milles de la Libye, se compose de trois îles très proches les unes des autre. L'île de Malte est la plus grande avec 246 km’, Goza a une surface de 67 km2 et Comino seulement 2,8 km .

A la fin de 1984, la population de Malta était de 332 000 habitants, avec un taux de croissance de 16,8. La densité de 1 052 habitants par km‘ est la plus forte d'Europe après Gibraltar.

L'économie est basée sur l'agriculture, la pêche, la construction navale, quelques industries, le pétrole (plusieurs gisements prometteurs ont été récemment découverts). Durant l'année 1985, 528 000 touristes ont effectué un. séjour dans les îles de l'archipel maltais.

La zone côtière est une importante ressource intensivement utilisée pour le transport, les communications, la construction navale. Elle est également un lieu de grande productivité biologique et un grand. nombre d'anses offre des possibilités **B** outre celles pour les loisirs **B** pour le développement de l'aquaculture. En ce qui concerne le tourisme, la plus grande partie du littoral étant bardée de collines, la nombre et l'étendue des plages sont considérés comme trop limités eu égard à la demande.

Malgré l'importance que revêt la frange littorale, la recherche océanographique à Malte est dans sa phase initiale. La recherche scientifique en général, et la recherche marine en particulier, ont été négligées au profit des questions touchant au développement de l'agriculture qui, dans le système éducatif maltais, a bénéficié (pendant longtemps) d'une priorité. La nécessité de renforcer la recherche marine se fait maintenant sentir au travers de deux demandes nationales urgentes : le besoin de diversification des facteurs de croissance économique répondant aux demandes croissantes de la population **B** les solutions à trouver aux problèmes d'environnement maria, résultant d'une utilisation excessive da la zone côtière.

Quelques études réalisées au plan national ont pu apporter des solutions à certains problèmes écologiques. Elles sont toutefois de dimension modeste en raison du nombre insuffisant de spécialistes océanographes, des difficultés des problèmes à resoudre et des ressources financières limitées.

Il serait nécessaire de procéder à une évaluation objective des ressources permettant d'assurer, grâce à une révision. cie la politique de gestion, un développement équilibré du littoral. Dans ce but, une collaboration étroite entre océanographes, ingénieurs du littoral, éoanomistes, sociologues et gestionnaires, s’avère nécessaire.

2. Les problèmes relatifs à la protection et à la gestion des plages

Le littoral maltais est considérablement utilisé pour de multiples activités socio-econamiques. Plusieurs entrées naturelles des îles ont pour cette raison été progressivement converties en part ou élargies poux accueil1ir de nouvelles constructions. Des séries Ce brise-lames, de jetées` ont été construites pour protéger ces ports. Ce développement, qui a eu lieu à un rythme très rapide et sans le soutien de données scientifiques fiables, provoque souvent la dégradation des plages pourtant déjà considérées comme insuffisamment étendues. Or une attention particulière doit être accordée à la dégradation du littoral étant donné les répercussions possibles sur le tourisme et l'économie en général.

Au nord de Malte et dans l'île de Gozo, diverses plages montrent déjà des signes de déterioration caractéristiques de l'érosion côtière. Les effets des facteurs responsables de cette dégradation sont localement amplifiés par la structure naturelle du système et notamment l'étroitesse du plateau entourant l'archipel. Le stock de sable disponible au large est, de ce fait, très limité. Dans ces conditions, la diminution, due aux aménagements, des apports de sable venant des terres émergées a des conséquences très sensibles. Les constructions sur le littoral ("bétonnage" pour l'essentiel) ont visiblement privé le trait de côte des apports de matériaux **B** y parvenant autrefois au moment des précipitations **B** et qui compensaient las départs de sable dus à l'action des courants.

Parmi les autres facteurs responsables de la dégradation, il faut également mentionner les variations du système des courants côtiers provoquées par la construction de structures : jetées, épis. Il faut également mentionner les conséquences de la pollution marine sur les végétaux tapissant les fonds marins. Les herbiers sont souvent des facteurs essentiels de la stabilisation de ces fonds. Leur disparition peut avoir des conséquences importantes sur les transits sédimentaires. Bien que l'étude des pollutions elle-même sorte du cadre du présent projet, les effets négatifs qu'elles peuvent avoir sur l'évolution morphologique das littoraux ne peuvent pas être négligés.

II LE CAS DE CHYPRE

1. Présentation générale

Situéé à une vingtaine de milles nautiques seulement des côtes syriennes et libanaises l'île de Chypre a une superficie de 9 300 km2 et, une population d'environ 630 O00 habitants.

La frange côtière est également utilisée à Chypre de manière intensive. D'importantes concentrations industrielles et portuaires se sont développées à Limassol et Larnaca. Des complexes touristiques ont vu le jour en maints endroits de la côte sud de l'île pour répondre à la pression touristique très forte. Comme à Malte, ces activités s'exercent sans aucun support de données adéquates sur le milieu marin et lorsque des problèmes surgissent` les réponses apportées sont toujours très ponctuelles et sans vision globale des phénomènes.

Il est paradoxal de constater que, malgré l'intérêt que revêt pour un Etat tel que Chypre le domaine marin, celui-ci reste mal connu du point de vue physique. Les données concernant les paramètres hydrodynamiques, les processus sédimentaires ou les facteurs de l'érosion ne sont que peu, ou pas étudiés, l'essentiel des études en milieu, marin concernent les questions biologiques. Toutefois, parmi les travaux entrepris par le Département des pêches, il importe de remarquer un développement d'études sédimentologiques, bathymétriques et hydrographiques en liaison avec la nécessité reconnue de mieux connaître les paramètres pilotant la configuration, la nature et l'évalution des fonds marins au voisinage de la côte.

Les autorités chypriotes désirent développer un programme d'aménagement cie la zone côtière allant de Paphos à l'ouest à Larnaca à l'est et prenant en compte nomhre de données telles que l'érosion des côtes, les sites à protéger (archéologiques, touristiques, portuaires), l'évolution de certains secteurs originaux (tombolo de Limassol, lagune de Larnaca), les processus sédimentaires cantrôlables, etc. La grande diversité des modèles littoraux du sud de Chypre autorise non seulement une intervention pluridisciplinaire, mais permet de dégager des références autorisant des extrapolations à d'autres régions de la zone orientale de la Méditerranée, voire d'autres régions. Un thème d'intervention du. type "connaissance et aménagement de la zone côtière et du proche plateau continental" serait de nature à intéresser au plus haut point les interlocuteurs chypriotes et pourrait par ailleurs s'intégrer dans les thèmes retenus par la communauté scientifique européenne. En effet, sur le plan de la formation, des progrès doivent être réalisés pour donner aux spécialistes nationaux les connaissances élémentaires leur permettant de prendre en compte l' ensemble des phénomènes avec une vision générale et pluridisciplinaire. Pour l'instant, les géologues et ingénieurs chypriotes ne sont pas toujours très familiarisés avec les démarches et méthodes scientifiques indispensables pour l'aménagement et la protection de la frange littorale.

2. Les prablèmes rencontrés sur le littoral de Chypre

Les problèmes rencontrés sur le littoral, chypriote concernent ici encore principalement l'érosion des côtes. Le littoral est un domaine particulièrement sensible en raison de la pression du tourisme qui est d'un million de personnes par an. Le pays se trouve dans l'obligation de maintenir ou de créer des plages de sable sur le littoral sud de Chypre, de canaliser une urbanisation galopanta et de préparer un schéma d'utilisation de l'espace littoral.

Certains secteurs de l'île sont particulièrement touchés par l'érosion, notamment les baies de Larnaca et de Limassol où la disparition de plages à galets menace les zones urbaines et donne une idée de l'importance du phénomène.

Il est indispensable de dégager un programme intégré d'aménagement et de gestion de la zone littorale méridionale de Chypre, de la baie de Larnaca à l'est jusqu'à Paphos à l'ouest. Le rapide développement industriel, urbain et touristique de cette côte, doit en effet prendre en compte l'ensemble des données fondamentales concernant la nature des terrains côtiers, les caractéristiques physiques, écologiques et économiques des sites concernés. Ce programme passe nécessairement par l'établissement d'un bilan de connaissances et par des interventions pluridisciplinaires de recherches en vue d'une bonne appréhension des évolutions naturelles ou provoquées de ces régions.

Les mesures prises jusqu'à maintenant pour protéger la côte ont été la construction d'ouvrages de défense, mais sans que des études précisas quant à leur impact réel aient été faites. Des brise-lames ont par exemple été construits à l'est de Limassol pour protéger un important complexe touristique, mais malgré leur efficacité relative ils entraînent des processus à'érosion accrus au-delà de ce secteur.

On peut également dénoncer les prélèvements de sable et de gravier sur les plages ou la construction de barrages dans l'arrière pays, qui ont favorisé l'érosion de la côte.

Divers travaux doivent être menés dans ce domaine:

- étude des caractéristiques physiques de l'environnement sur la côte sud chypriote ;

- évolution ancienne et tendances évolutives de la zone littorale. A ce titre pourrait être entreprise une étude détaillée d'une zone urbanisée comme par exemple les baies de Larnaca et de Limassol ,

- étude du secteur compris entre Zygi. et la cap Kiti qui est une zone sauvage en projet d'aménagement ; cette étude permettrait d'appliquer les connaissance de l'océanologie côtière à l'aménagement d'une zone littorale vierge en sauvegardant autant que possible les caractéristiques naturelles.

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PART II

SUBMITTED PAPERS

THE FATE OF AMAZON SEDIMENT DISCHARGE

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ABSTRACT

Intense resuspension by tidal currents and northwestward advection by alongshelf currents control the fate of the Amazon sediment as well as many dissolved components of Amazon discharge. Much of the sediment accumulates on the continental shelf, and the preserved stratigraphic record indicates dramatic fluctuations of sedimentation on many time scales. Approximately two-thirds of Amazon sediment discharge (measured at Obidos) can be accounted for by accumulation on the shelf and by transport northwestward. Most of the adjacent shoreline is eroding. Therefore, a likely sink for the missing sediment is in the lower portion of the river (seaward at Obidos).

INTRODUCTION

The Amazon River annually supplies to the Atlantic Ocean aver a trillion cubic meters of water, a billion tons of sediment, and near' a billion tons of dissolved solids. These materials come from a drainage basin at the equator that contains several highland areas and a very large rain forest. On a worldwide basis, the Amazon discharges 18% of all river water (Oltman, 1968), 10% of fluvial sediment (Milliman and Meade, 1983; Meade *et al*, 198'), and 8% of dissolved solids (Livingstone, 1963; Gibbs, 1972).

The Amazon discharge enters a dynamic marine environment, where diverse interactive processes are at work. The processes operating on the continental shelf adjacent to the river mouth control the amount and character of the Amazon's discharge reaching the rest of the Atlantic and the world ocean. On the Amazon shelf, between the Para estuary and the Brazil-French Guiana Border (Fig. 1), material input (water, solutes, particulates) and energy expenditure (tides, currents, winds, waves) are enormous. This situation produces a myriad of complex and interdependent oceanic processes. Sediment is a common link between the diverse processes, because most of them affect and/or are affected by the particles found on the Amazon shelf.

Realization of the complexity and importance of the Amazon shelf led to the development of A Multidisciplinary Amazon Shelf SEDiment Study (AmasSeds), a research study by geological, chemical, physical, and biological oceanographers from Brazil and the United States. Many processes acting at the interface between very large rivers and the ocean, cannot be understood simply by extrapolating from observations of smaller. river-ocean systems that are more easily studied. Among the unique oceanographic processes are displacement of estuarine mixing and circulation into the ocean, control of primary productivity and nutrient uptake by turbidity, marne sediment influenced by non-Newtonian fluid muds, and rapid sediment accumulation (centimeters per year) with formation of an extensive subaqueous delta.

In addition to interdisciplinary studies, AmasSeds is designed to broaden the fundamental knowledge within the oceanographic disciplines. AmasSeds contains five research groups that focus an the following topics: physical oceanography, turbidity effects on geochemistry, sediment transport, diagenetic/authigenic processes, and sedimentology/stratigraphy. Each group contains 6-10 principal investigators from the U.S. and Brazil.

The primary focus of this paper is on geological research, in particular, on the fate of particulate discharge. Early research that helped to justify and design the AmasSeds study will be sumarized. In addition, preliminary AmasSeds results from physical, chemical and biological oceanographic studies will be described as they relate to geological oceanographic research.

THE AMAZON SEDIMENT DISPERSAL SYSTEM

Rivers, in general, are the largest supplier of particulate and dissolved materials to the world ocean, *and* large river systems can have a disproportionate impact on global ocean budgets. For example, the four largest systems with regard to sediment discharge (Ganges-Brahmaputra, Amazon, Huanghe, and Changjiang) supply nearly 40% of the world's fluvial sediment (Milliman and Meade, 1983).

Presently, the Amazon dispersal system stretches for about 5000 km from the Andes mountains to the Caribbean Sea (Fig. 2). The large size and equatorial location minimize fluctuations in Amazon discharge. Figure 3 shows that water discharge rises to a maximum in May/June and falls to a minimum in October/November. Tidal effects on the Amazon propagate 800 km upstream to the city of Obidos (Fig. 2), and little research regarding discharge has been done between there and the river mouth. Consequently, estimates of discharge to the ocean have uncertainty.

Research on the Amazon shelf had its roots in the 1960s and 1970s (see Nittrouer and DeMaster, 1986). Gibbs (1967) extended his research on the Amazon River out onto the shelf. Brazilian federal agencies supported Project REMAC (Recursos Minerais da Margem Continental) and GEOMAR (Operacoes de Geologia Marinha) cruises, which included geological and geophysical examination of the Amazon shelf. Several geochemical studies of the Amazon River and the Atlantic Ocean extended into portions of the Amazon shelf.

The immense discharge of Amazon water causes estuarine-like circulation on the shelf to bring bottom water landward (Gibbs, 1970). Tidal currents routinely exceed 1 m s-1 and have a strong across-shelf component (Gibbs, 1982; Curtin, 1986b). The North Brazil Current (NBC) flows northwestward, sweeping the outer shelf and upper slope with speeds also exceeding 1 m s-1 (Flagg *et al.*, 1986; Richardson and Reverdin,1987). Easterly trade winds blow continuously, with wind stresses that can exceed 1 dyn cm-2 (Picaut *et al.*, 1985) and which maintain surface gravity waves.

Dissolved chemical species are supplied to the waters of the Amazon shelf: in solution with river water, by release from river-borne particulates, and with open-ocean water driven by the landward-flowing bottom currents. Inorganic removal onto particulates (Sholkovitz *et al.*, 1978; DeMaster *et al.*, 1986) and biological uptake by primary productivity (Sholkovitz and Price, 1980; Milliman and Boyle, 1975) are important geochemical processes on the Amazon shelf, and both are controlled by the transport and settling of suspended sediment.

The physical processes operating on the Amazon shelf produce large shear stresses, which advect suspended sediment northwestward and maintain high concentrations in surface (> 10 mg l-1) and bottom (> 100 mg l-1) waters, seaward to at least the 30-m isobath (Nittrouer *et al.*, 1986a). The seabed surface of the Amazon shelf is dominated by modern mud from shore to about the 60-m isobath, and by exposure of a transgressive sand layer farther seaward to the shelf break (Barreto *et al*, 1975; Nittrouer *at al.*, 1983). The mud, has formed a subaqueous delta with gently dipping topset stata (0-40 m water depth), steeply dipping foreset strata (40-60 m), and thin bottomset strata at the base (Figueiredo *et* al., 1972;

Alexander *et at.*, 1986; Nittrouer *et at*, I986b). The diverse range of energetic physical processes active on the Amazon shelf created many questions about the extent of the present accumulation of mud (Milliman *et al.*, 1975b; Gibbs, 1976; Kuehl *et al.*, 1982).

Sediment is accumulating on the Amazon shelf at rates up to 10 cm y-1, however, little of no accumulation is occurring on the inner shelf in less than about 15 m water depth or northward between 4· N and 5· N (Kuehl *et al.,* 1986). Approximately two-thirds of the river discharge is accumulating on the Amazon shelf or being transported farther northward (Nittrouer *et al,* 1986). The additional one-third of river sediment could be accumulating on the coastline north of the river mouth, along the Brazilian state of Amapa. Another possibility is that estimates of Amazon sediment discharge to the ocean are inaccurate, bocause significant net accumulation occurs between Obidos and the river mouth.

INTERDISCIPLINARY OBSERVATIONS OF SEDIMENTARY PROCESSES

Currents on the Amazon shelf are dominated by two principal components, a cross-isobath, barotropic, semidiurnal tidal flow (Fig. 4), and an along-isobath, vertically sheared, subtidal flow directed northwestward along the shelf (Geyer *et at.*, 1991). Moored measurements indicate that the semidiurnal tidal currents have a pronounced spring-neap variation, with maximum currents over the inner shelf reaching 2 m s during spring tides and only 0.7 m s-1 during neap tides. The tidal currents also show spatial variability. The amplitude of the semidiurnal constituent decreases seaward and northwestward (Fig. 4).

The strong tidal currents probably dominate the energetics of the bottom boundary layer, controlling the magnitude of the bottom stress and the resuspension of sediment (see Kineke *et al.,* 1991). The stratification associated with the freshwater plume is generally far enough above the bottom over most of the shelf that salt stratification does not inhibit bottom turbulence; however the stratification due to suspended sediment becomes very large over some portions of the Amazon shelf, with suspended concentrations of 10-100 g l-1 (fluid mud) in the bottom 1-3 m of the water column. The shelf (Fig. 5) can be characterized by three regions: a coastal zone (< 12 m water depth) which is well-mixed in temperature, salinity, and suspended-sediment concentration (1-3 g l-1); a mid-shelf region (15-30 m depth) with a stratified water column and suspended-sediment concentrations increasing toward the bottom (-0.8 g l-1); and an outer-shelf region (>40 m depth) characterized by near-bottom suspended sediment concentrations of approximately 0.1 g-1

The distribution of suspended sediment and the resuspension of sediment from the seabed, severely affect biological and chemical processes on the Amazon shelf. In the water column, the net balance between silica production and regeneration rates indicates that on a vertically integrated basis little or no net primary production of biogenic silica is occurring at high-turbidity sites, but that lower-turbidity/higher-chlorophyll areas exhibit significan(net production (DeMaster *et al,* 1991). DeMaster *et al.*, (1986) showed that most of the 210Pb (half life 22y) deposited in the Amazon subaqueous delta was derived from shoreward advection of open-ocean waters, followed by scavenging onto and settling with sediment particles. 224Ra and 223Ra (half-lives of 3.6 and 11.4 days, respectively) are produced in muddy Amazon shelf sediments, and, despite short half-lives, the isotopes are traced great distances from the Amazon shelf indicating advection rates of 1 m s-1 or more (DeMaster *et al.,* 1991).

On the Amazon shelf, the intense reworking of the seabed, and the presence of lateritic debris promote extensive suboxic zones where reduction of Fe and Mn dominate diagenetic reactions (Aller *et al.*, 1986). Preliminary reaction-rate measurements suggest that in some cases, pore-water solute profiles were developed during the prior 1-to-2 months, as a result of biological and/or physical reworking (Aller *et al.,* 1991). Deep-burrowing benthic organisms (especially Callianassid shrimp) are common near the mouth of the river and are responsible, together with physical reworking, far massive sediment-water exchange. On the open shelf, mobile layers of fluid mud cause the rapid exchange.

Therefore, diverse oceanographic studies of the Amazon shelf indicate that high concentrations of suspended sediment are maintained by tidal currents, and are advected northwestward by alongshelf currents. The distribution of suspended sediment on the Amazon shelf can control the removal of certain chemical constituents from seawater and the supply of other constituents to seawater. Therefore, processes involving sediment affect the fate of both particulate and dissolved. components of Amazon discharge.

GEOLOGICAL OBSERVATIONS OF SEDIMENTARY PROCESSES

As part of AmasSeds, a suite of coring devices was used to obtain samples with progressively deeper penetration into the seabed, ranging from 50 cm - 12 m. Stratigraphy of cores is examined through microscopy, radiography, and sedimentological techniques (for example, grain size and mineralogy). Temporal aspects of sedimentation are documented by radiochemical techniques (such as 234Th, 210Pb, and 14C), and by reoccupation of stations. Deeper stratigraphy (down to as much as 100 m in the seabed) is studied through high-resolution seismic profiling.

Observations at anchor stations on the shelf near the river mouth reveal relatively minor changes in the seabed on diurnal time scales, but much more distinct changes on fortnightly (spring-neap) scales. In March 1990, the surficial seabed was characterized by sandy layers (several centimeters thick) during spring tides, and by soft muddy layers (5-15 cm thick) during neap tides. The changes within the seabed from spring to neap tidal conditions corresponded to decreases in the near-bottom current velocity and generally in suspended-sediment concentration. Punctuation of the stratigraphic record by erosional events is clearly observed in x-radiographs. Erosional boundaries can be recognized by truncations of strata, and, in some cases, of burrows. Corresponding profiles of 210Pb suggest that significant erosional events have a reoccurrence interval of less than 10 y. These events may result from fluctuations in the river discharge or the oceanic processes.

The most important observation in the Amapa coastal region (less than 10 *m* water depth) is extensive erosion for approximately 300 km from the river mouth northward along the dispersal system. An accretionary shoreline was expected, because of the proximity to the Amazon and the existence of accretion farther northward along portions of the Guianas (Eisma and van der Marel, 1971; Rine and Ginsburg, 1985). In addition, about a third of the annual Amazon sediment discharge cannot be accounted for by accumulation on the Amazon shelf or by transport farther northward (Kuehl *et al.,* 1986; Nittrouer *et al.,* 1986). Tidal range and currents are extreme on the Amazon shelf, and decrease northward along the coast away from the river mouth (Fig. 4). The tidal effect is significantly reduced north of Cabo Cassipore, and this is where coastal accretion begins (Fig. 6). Regional tectonic processes (vertical movement) also may be a factor in coastal erosion (Faria *et al.,* 1990).

South of Cabo Cassipore, the shoreline is generally erosional (Fig. 6). Arboreal vegetation is observed to be falling into the sea. Distinct erosional terraces have been formed, and are exposing older sedimentary deposits from terrestrial (e.g., fluvial) and coastal environments. 14C dates suggest that these older deposits were formed less than 1000 y ago. Ilha de Maraca may be a remnant of a larger landmass which protruded seaward from the north bank of the Amazon, near Cabo Norte.

At Cabo Cassipore and northward to Cabo Orange, the shoreline is accreting as prograding mud deposits. Mud flats are backed by mangroves. Soft mud forms shallow bars which run parallel to the coast. 210Pb accumulation rates measured for these sediments are about 1 cm y-1. The deposits, in contrast to coastal material farther south, contain unusually fine sediment (clays), unusually high inventories of 210Pb and 234Th, and significant amounts of planktonic diatoms. Together these factors suggest landward transport of shelf sediment.

Seismic studies and piston coring on the shelf off reveal an environmental change during the past several thousand years from erosion to accumulation; a transition opposite to that absences for coastal deposits of Amapa. Modern, soft, brown muds in the topset region are overlying a distinct erosional surface (truncated strata, with a sand/shell lag) below which are alder, over-consolidated, grey muds. 14C dates, suggest that the older deposits were formed about a thousand years ago. The Amazon shelf seaward of Amapa was undergoing erosion of the seabed until about a thousand years ago, when it changed to the present condition of accumulation. The causes cauld be changes in the river discharge, the oceanic environment, or perhaps submersion of the landmass near Cabo Norte

CONCLUDING REMARKS

Two unique points of this paper should be emphasized.

1) The inability to reconcile the Aaron sediment budget with accumulation *on the* shelf/coast and with transport northwestward, indicates the probable accumulation of much sediment in the lower stretches of the river. This observation would have important implications with regard to low-gradient river systems during sea-level rise.

2) Changes during the past 2000 yam in the erosional and depositional character of the shelf and shoreline suggest that natural environmental fluctuations for this area are dramatic, and may be mare severe than potential human impacts.

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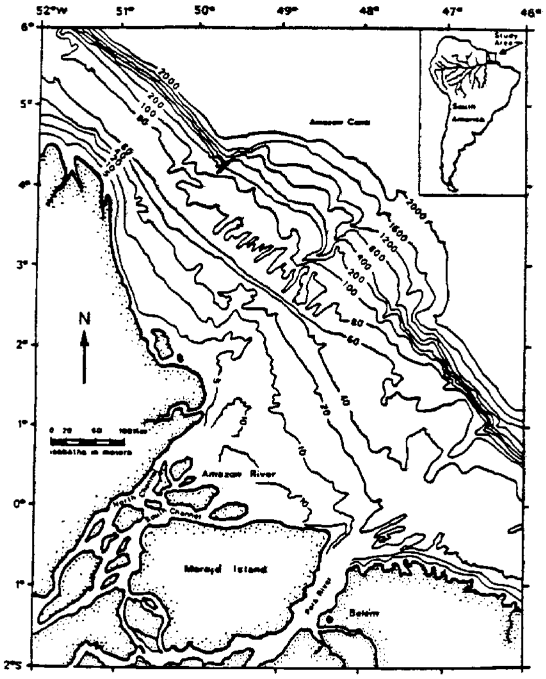

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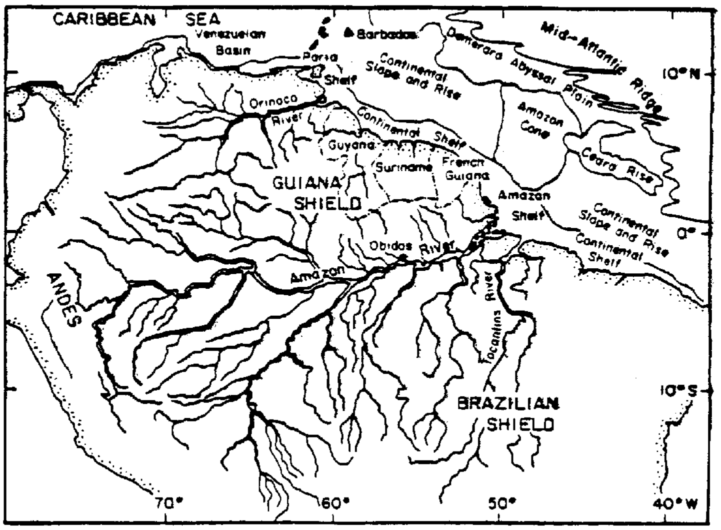

Fig. 2: Map of region influenced by the Amazon dispersal system, showing various geographic locations.

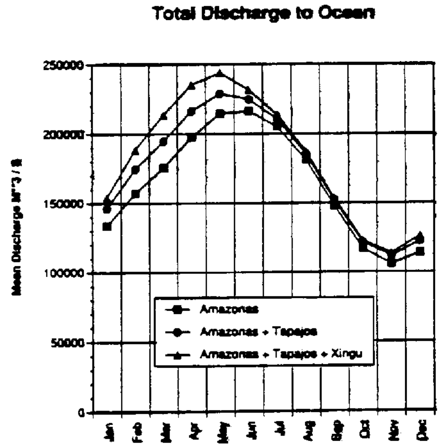

Fig. 3: Discharge of freshwater from the Amazon River to the ocean. These curves were assembled from monthly means for the period 1968-1987 (data supplied by the Brazilian Agency DNAEE). The Amazonas data were collected at Obidos. The Tapajos and Xingu Rivers are the two primary tributaries which enter the Amazon River seaward of Obidos.

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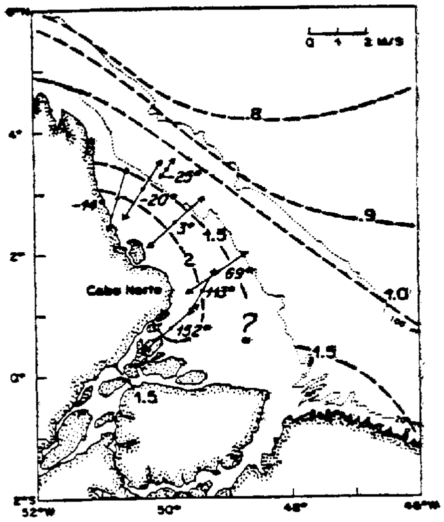

Fig. 4: Chart showing the amplitude (in m) of the semidiurnal tidal constituent (m_s), vectors for m_2 depth-averaged velocity, and phase in degrees for m_2 velocity. The tidal velocity is oriented across-shelf. The tidal velocity is oriented across-shelf. The tidal amplitude decreases seaward and northward along the coast.

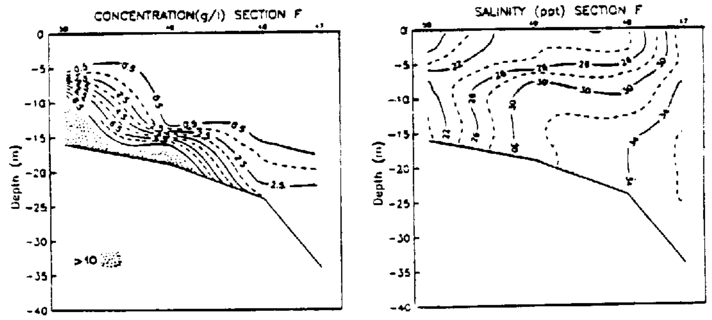

Fig. 5: Cross sections of suspended sediment concentration and salinity across the open-shelf transect (latitude about 3°N) during peak discharge from the Amazon River (May 1990). Salinity distributions reveal a transition from well-mixed waters near-shore to a two-layered water column seaward. Suspended sediment concentrations increase toward the bottom. Fluid muds (sediment concentration > 10g/l) cover broad areas of the seabed in this region of the Amazon shelf.

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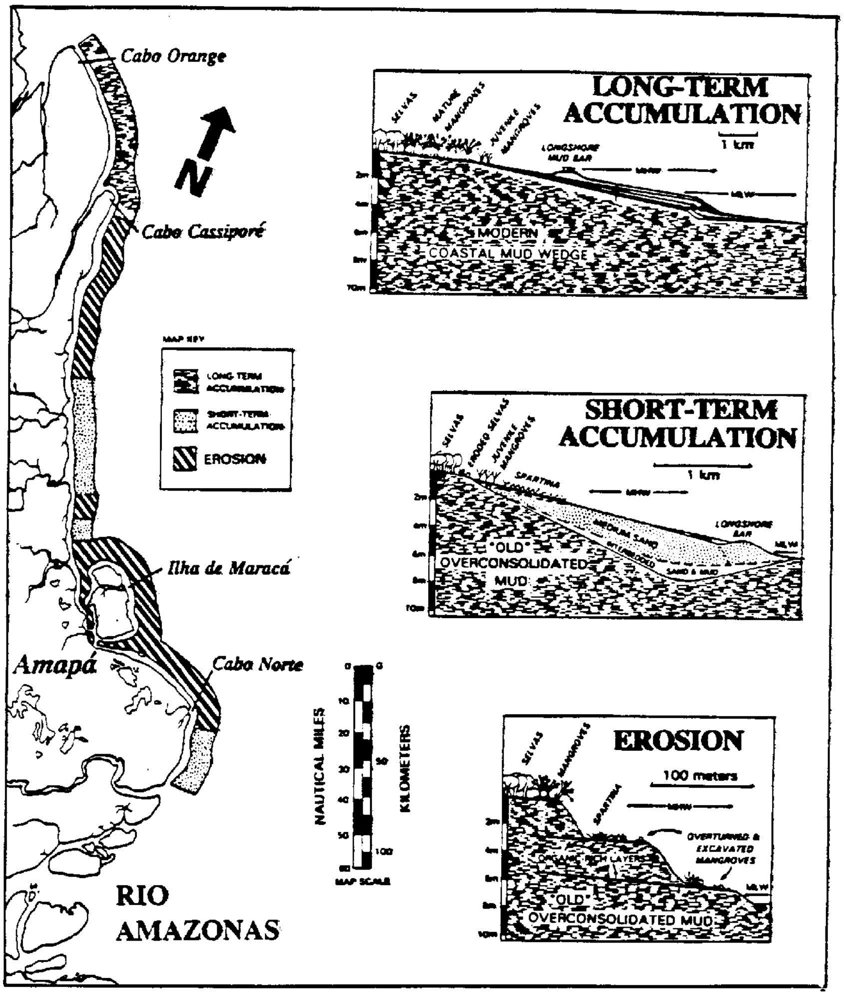

Fig. 6: Descriptions of processes and strata along the coast of Amapa (Nittrouer *et al.*, 1991). Erosional shorelines characterize the coast as far north as Cabo Cassipore, with some localized, short-term accumulation associated with small rivers. A prograding muddy shoreline is found between Cabo Cassipore and Cabo Orange.

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[Fig. 6: Descriptions of ses and strata along the coast of Amapa (Nittrouer *et al.*, 1991). Erosional shorelines characterize the coast as far north as Cabo Cassipore, with some localized, short-term accumulation associated with small rivers. A prograding muddy shoreline is found between Cabo Cassipare and Cabo Orange.]

EFFECT OF RIVER DAMMING AND DEFICIT OF SEDIMENT FLUX ON THE CONTINENTAL SHELF: A CASE STUDY OF THE NILE DELTA

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ABSTRACT

Man's intervention in the flow of the Nile in Egypt dates back to Pharaonic times. Modern intervention began with the construction of the "Delta Barrage" near Cairo in 1861. The practice was developed with the low Aswan Dam constructed in 1902. The Aswan High Dam is the second dam to be built in the vicinity of the Nile's first cataract at Aswan. Its construction began in 1960. The Nile was closed around a temporary structure in 1965, the dam was completed in 1967. Sediment once transported by the Nile River to the coast, average of 100x10 6 t yr-1, is now almost cut off.

The intervention of the River Nile and continued modification of the delta is expected to result in the increased erosion of the surficial shelf sediments.

This paper discusses the effect of river damming and the deficit of sediment budget on the continental shelf off the Nile Delta.

INTRODUCTION

The Nile Delta and its contiguous continental margin form the major sediment repository on the North African margin (Stanley, 1988 a). The River Nile, since Pliocene time, has formed its classic fan-shaped delta (Said, 1981), and has also contributed large volumes of sediment to the adjacent Egyptian continental shelf (Summerhayes *et al*, 1978). Studies of shelf morphology, surficial sediment distribution, transport processes predictions of sea-level changes and subsidence provide basic information for this continental margin (Stanley, 1988 a,b & El-Sayed, 1990).

Until 1964 the Nile River discharge averaged some 1480 m2/sec (Coleman, 1976). Sediment yield is highly variable, but total suspended load was estimated to exceed 111.10' kg/y, with approximately 98% of this sediment being delivered to the coast during the flood period (Holeman, 1968). The grain size distribution of the suspended load was variable throughout the year. During flood it consisted of 25% sand, 45% silt and 30% clay. Thus the river did not carry a large fine-grained sediment-load, but delivered large quantities of coarser sediment to the coast while the delta plain was constructed during the Holocene.

Since the construction of the High Dam at Aswan, the Nile transports virtually no sediment to the sea; the result is erosion of the coastline. Although the effect of decreased sediment flux has been difficult to quantify, erosion rates along several sectors of the coast of the delta accelerated as a result of deprivation of silt nourishment from the Nile (White, 1988).

This paper discusses the effect of river damming and deficit of sediment budget on the continental shelf off the Nile delta.

SUCCESSIVE INTERVENTION OF THE NILE IN EGYPT

Man's intervention in the flow of the Nile dates back to Pharaonic times. Modern intervention began with the construction of the "Delta Barrage" near Cairo in 1861. The barrage sluices were opened to let the flood waters flow, but made possible the beginning of perineal irrigation instead of basin flooding (Halim,1990). The practice was developed with the low Aswan Dam constructed in three stages (1902, 1912 and 1933). The low Aswan Dam was also provided with sluices to let the flood waters flow with their sediment load. This dam was designed to generate hydroelectric power and to store water during the three month flood season with release at the end of the flood. This dam was intended to extend the flood's duration downstream without carrying any water storage over from year to year and, accordingly, without storing any significant amount of Nile silt. The river at this point carried approximately 84 billion cubic meters of water in an average year, calculated for the period 1900 to 1959 (White,1988).

The Aswan High Dam is therefore the second dam to be built in the vicinity of the Nile's first cataract at Aswan (Figure 1). Its construction began in 1960. The Nile was closed around a temporary structure in 1965, the dam was completed in 1967, and by 1970 all 12 turbines were in operation. The High Dam was designed to store the Nile flow (84 billion cubic meters), so there would be no excess beyond the actual needs of 55.5 billion cubic meters, as permitted under the Nile Waters Agreements of 1929 and 1959, and to assure that minimum flow would be maintained regardless of whether there was a flood or a drought upstream (White, 1988).

The three basic functions of the dam as specified in the early project documents were:

to control all floods of the Nile by their detention in the reservoir
to store water from each annual flood so there would be regulated releases for irrigation and other purposes throughout the year and over a period of up to 100 years, regardless of low flow upstream; and
to use the released water to generate hydroelectric power.

According to Milliman & Meade (1983), the Nile with a drainage area of more than 2x10 6 km', once carried an average of 100x10 6 t yr-1 of sediments to its delta in the Mediterranean Sea. As some downstream and marine problems become apparent as soon as the river Nile was dammed, the construction of the Aswan High Dam gave Egypt the opportunity to increase the arable land along the Nile River by nearly 100% and increased dramatically the amount of available electric power. It has also practically eliminated the destructive effects of spring floods on the lower portions of the river valley. Moreover, it has protected Egypt from the disastrous effects of the droughts of Africa for the past nine years. However, damming the river has caused serious erosion to the river promontories and the coastal stretch of the northern Nile delta, as well as reducing, to a large extent, the productivity and fisheries of the Mediterranean off Egypt.

GEOLOGICAL IMPACT OF RIVER DAMMING

The coastal area

The effect of the effective influx of the sediment load has been difficult to quantify. One problem is the erosion of the delta since 1900 after more than a 100 years of standing degradation. Still, the erosion of the Rosetta branch between 1909 and 1945 was only a few hundred meters, while between 1945 and 1972 (presumably most occurring after 1965), it was more than 1.5 km (Sestini, 1976, Figure 2).

Frihy (1988) analyzed a series of aerial photographs (1: 25,000) taken in 1955 and 1983 for the unstable zone of the Nile delta. This analysis revealed a drastic shoreline change during this period, where the outer margins of both promontories have been clearly eroded. The highest erosion rates were 114 m/y and 31 m/y in Rosetta and Damietta respectively. Much of the eroded materials from the tip of both promontories is transported eastward by littoral drift and accreted on their eastern sides. The Burullus-Baltim sector is also erosional showing a maximum erosion rate of 9 m/y (Figure 2).

Analysis of a series of LANDSAT images of the Nile delta for the years 1973 and 1978 show that erosion has occurred all along the delta coast, except for a few areas. The promontories were by far the most eroded areas. Smith & Abdel Kader (1988) reported that the Rosetta promontory retreated at a rate of 275 m/y between 1978 and 1984. The total retreat of this area between 1934 and 1984 was 3700 m. This represents the largest amount of erosion for any location along the Egyptian coast. Unlike the Rosetta promontory, the Damietta promontory does not show regular patterns of change. Erosion at a rate of 35 -50 m/y was found to occur between 1978 and 1984 just east of the Damietta mouth.

The coastline between the two promontories is by far the most stable with the exception of the Burullus headland, showing an erosion rate of 29 m/y between 1978 and 1984. On the other hand, the coastline between Damietta and Port-Said represents an accretional-erosional area.

THE CONTINENTAL SHELF OF THE NILE DELTA: DEPRIVATION OF SEDIMENTS AND CHANGES IN THE BOTTOM CONFIGURATION

Physical aspects

The continental shelf off the Nile delta is made up of a series of terraces separated by low slopes that are cut by drowned channels and by one major submarine canyon (Misdorp & Sestini, 1976 Figure 3). The conspicuous break at 121 m is at the same depth as the average for all continental shelves. It may represent the lowest sea level during the Wurm glaciation.

The continental shelf off the Nile delta is the widest in the eastern Mediterranean. It begins as a narrow strip (15 B 25 km) in the west and becomes wider eastward (48 B 64 km) between Rosetta and Port Said. Probably the most accurate picture of sediment distribution off the delta is given by more than 1000 lead-line observations made by the British Admiralty during a survey by HMS ENDEAVOUR in 1919-1922 (Summerhayes *et al,* 1978). Both the Rosetta and Damietta Cones are covered with mud and sandy mud that also cover the shore face around the main river mouths. Sands cover much of the floor of Abu Quir Bay, as well as the upper terrace off Damietta. Muds predominate on the middle slope, while coarse materials cover much of the lower terraces. Muds also cover much of the outer shelf slope north of Rosetta. Further east, this slope is covered by coralline algae. Recent data shows that the nearshore muds and sands are terrigenous, as are the muds at the shelf edge, while the sands of the outer shelf are calcareous, and consist mainly of coralline algae. A major facies boundary separates the sediments off the delta from the bioclastic and pelletoidal carbonate sands and muds that occur off Alexandria (Figure 4, Summerhayes *et al*, 1978).

The major influencing agents affecting the Nile delta region are winds and waves, though their predominant directions are northwesterly. According to Frihy (1988), wave action along the coast is seasonal in nature, with storm waves in winter (period 7 -8 sec) and swells in summer (period 8 B 9 sec). In winter, waves as high as 2.5 m are generated with a predominant direction similar to that of wind. From wave refraction models and estimated transport values, the energy balance along the Nile delta coast causes higher net transport at the promontories and east facing beaches. The dominant direction of the littoral current within the breaker zone near Burullus is to the east, except during periodic current reversals.

LONG-TERM CHANGES OF THE INNER NILE DELTA SHELF

Examination of long-term changes of mapped distribution patterns of shelf sediments as well as bathymetric charts indicate low sediment accumulation rates and erosion of several areas along the Nile delta shelf.

Toma A Salama (1980) have reconstructed a bathymetric chart of the western shelf of the Nile delta from the Admirality chart of 1919/22, with a contour interval of 5 m. The soundings of this chart are rather accurate and spaced closely enough to allow fair comparison. Comparing their recent survey of the area in 1976/77 made by more sophisticated echosounders and the TORAN navigation system with that of 1919/22 (Figure 5). Areas of erosion and accretion were clearly distinguished. Accordingly, this part of the shelf is subdivided into several areas of distinctive amounts and directions of lateral shifts of bottom contours (Figure 5). In any one section, total 24 ones, nearshore changes are in the same direction and proportionally of the same amounts as offshore changes on the adjacent shelf. Net erosion in the area off the Rosetta mouth and the retreat of the adjacent coastline probably resulted from the drastic decline of sediment upon completion of the Aswan High Dam. In some areas of net erosion, such as north and east of the Burullus outlet, the outer margin of the shelf and perhaps Abu Quir Bay, most of the bottom deposits are relict. Much of the fine-grained material escaped offshore from Abu Quir Bay and the Rosetta fan, while coarser material was redistributed offshore Burullus. Bottoms of coarse material tend to be accretional (e.g., inner Alexandria and Burullus shelves), while bottoms of fine material tend to be erosional (e.g., outer Alexandria shelf, Abu Quir Bay and Rosetta fan). The Rosetta canyon plays a significant role as a sink for the eroded sediments transported offshore from Abu Quir Bay and the Rosetta fan.

Based on comparison of charts of 1919/22 and 1986, long-term bathymetric analysis was studied by Frihy *et al* (1990). The changes are documented on the basis of analyses of 40 profiles in the inner shelf area off the Nile delta (Figure 6). The analysis of these profiles for shifting of bottom contours and volumetric changes in bottom sediments identify areas of erosion, accretion and stability. Erosion of the bottom dominates the inner continental shelf with accretion at sinks such as embayments and the down slope of the inner shelf. A sharp increase in bottom erosion was noticed in front of the Rosetta and Damietta promontories, with bottom accretion at three major sinks; Abu Khashaba, Gamasa and at east Damietta spit (Figure 6).

Detailed analysis of the reconstructed profiles revealed several distinctive erosion/accretion characteristics (Figure 7). In general, the net erosion is higher than accretion. The volumetric changes within different depth zones (0 -5, 5 B 10, 15 - 20 and 20 B 25 m) vary along the shore (Fig. 7). Maximum net of erosion of 400 x 10' m’ and 50 x 10' m’ occurred at the Rosetta and Damietta promontories respectively. The shelf zone of Gamasa, on the other hand, is accretional.

The erosion and accretion patterns of the inner continental shelf are attributed to sediment movement. The accreted materials are derived from the tips of the eroded promontories, from Burullus headland, and partially from offshore sources. Frihy *et al* (1990) concluded that the erosion/ accretion pattern in the coastal zone of the Nile delta is primarily a function of: (i) decrease of sediment supply, (ii) subsidence or sea level rise, and (iii) hydrodynamic factors affecting this area.

The diminished Nile flow and sediment entrapment by the High Dam coupled with the effects of intensified irrigation, channelization and land reclamation projects in the northern delta during the past two decades, has markedly reduced fine sediment supplied from the coast to the continental margin seaward of the inner shelf (Stanley, 1988 a). In consequence, the sea floor is not receiving new depositional input from the Nile. Thus, unless replenished, this area almost certainly will be eroded by bottom currents.

The coupling of erosion by bottom currents and reduced sediment input from the Nile is likely to induce depositional changes on the shelf which could be monitored. It is expected that: (i) the configuration of sediment distribution patterns on the mid-shelf will be altered as surficial deposits are displaced toward the east, and (ii) if present conditions are maintained, the mid-shelf mud blanket will probably be further reduced. Also to be considered are the effects of recent depositional changes on the mid-shelf which, in turn, could affect sedimentation patterns on the inner shelf closer to the shore (Stanley, 1988 a).

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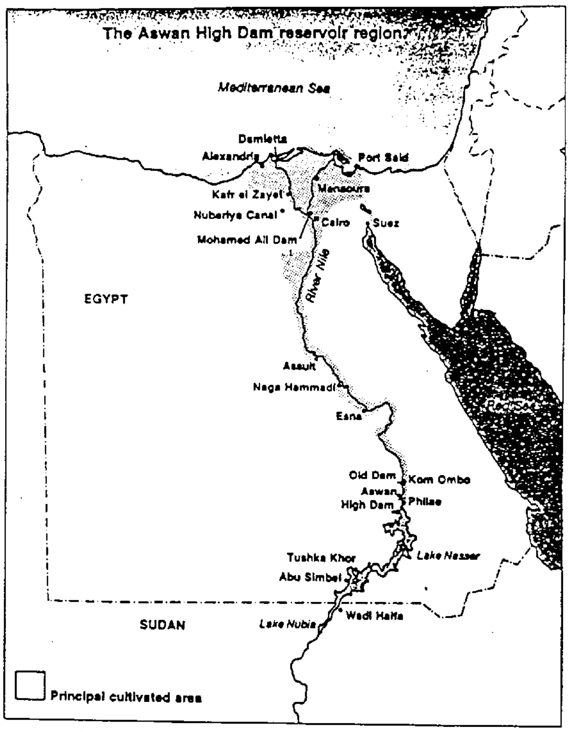

Fig. 1. The different dams along the Nile River in Egypt (Source White,1988).

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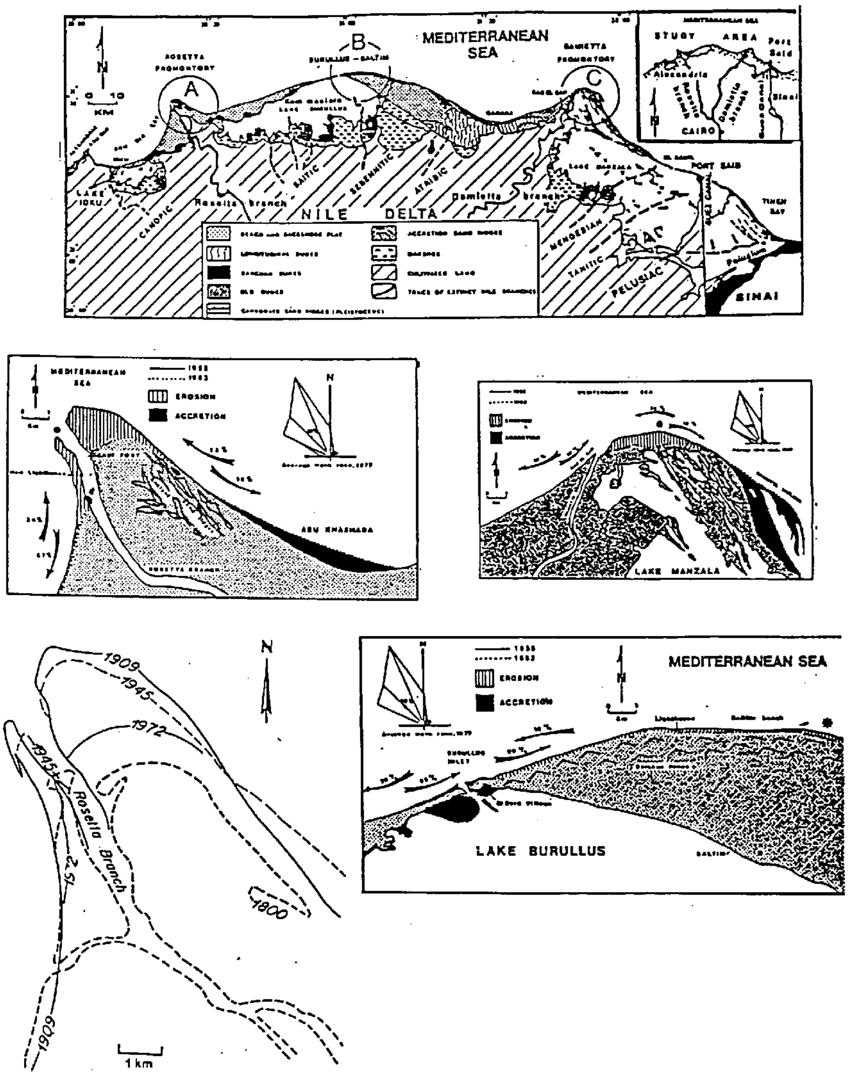

Fig. 2. Erosion of the Nile delta at Rosetta (1909 - 1972), and along its different sectors (1955 -1983) .Source Sestini (1976) and Frihy (1988).

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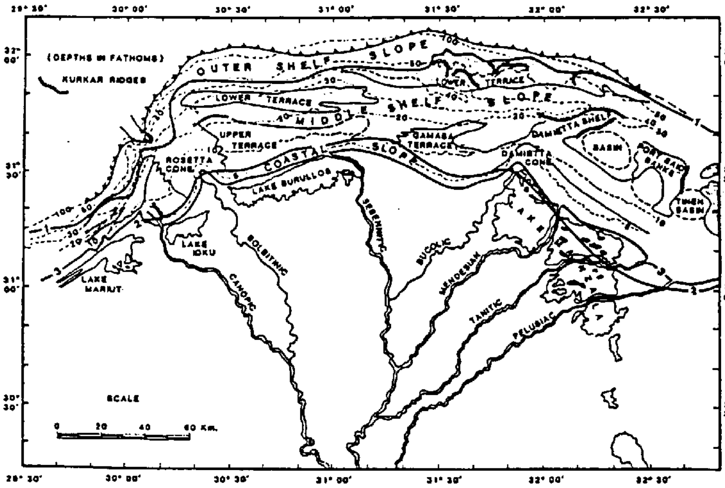

Fig. 3. Continental shelf off the Nile delta (Source Said, 1981 modified from Misdorp & Sestini, 1973).

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Fig. 3. Continental shelf off the Nile delta (Source Said, 1981 modified from Misdorp & Sestini, 1973)

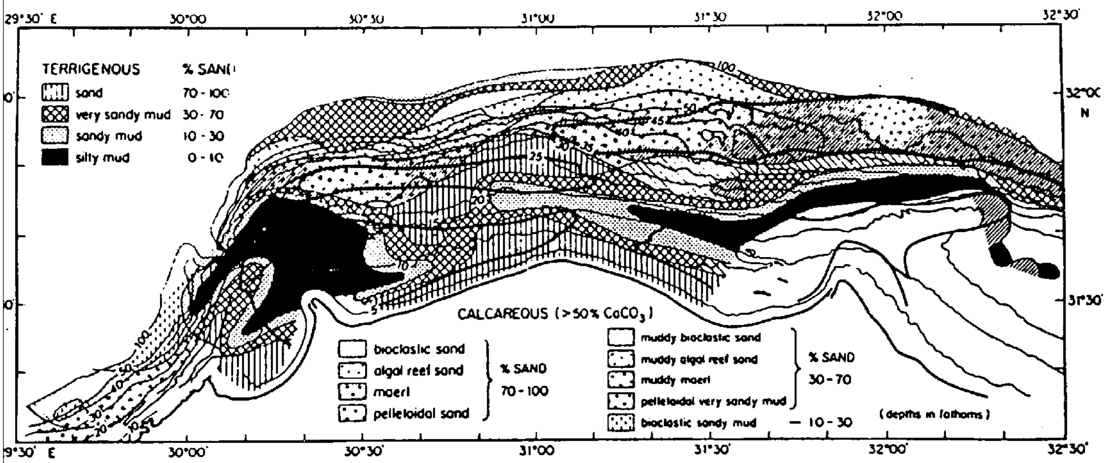

Fig. 4. Distribution of major sedimentary facies on the Egyptian continental shelf (Source Summerhayes *et al*, 1978).

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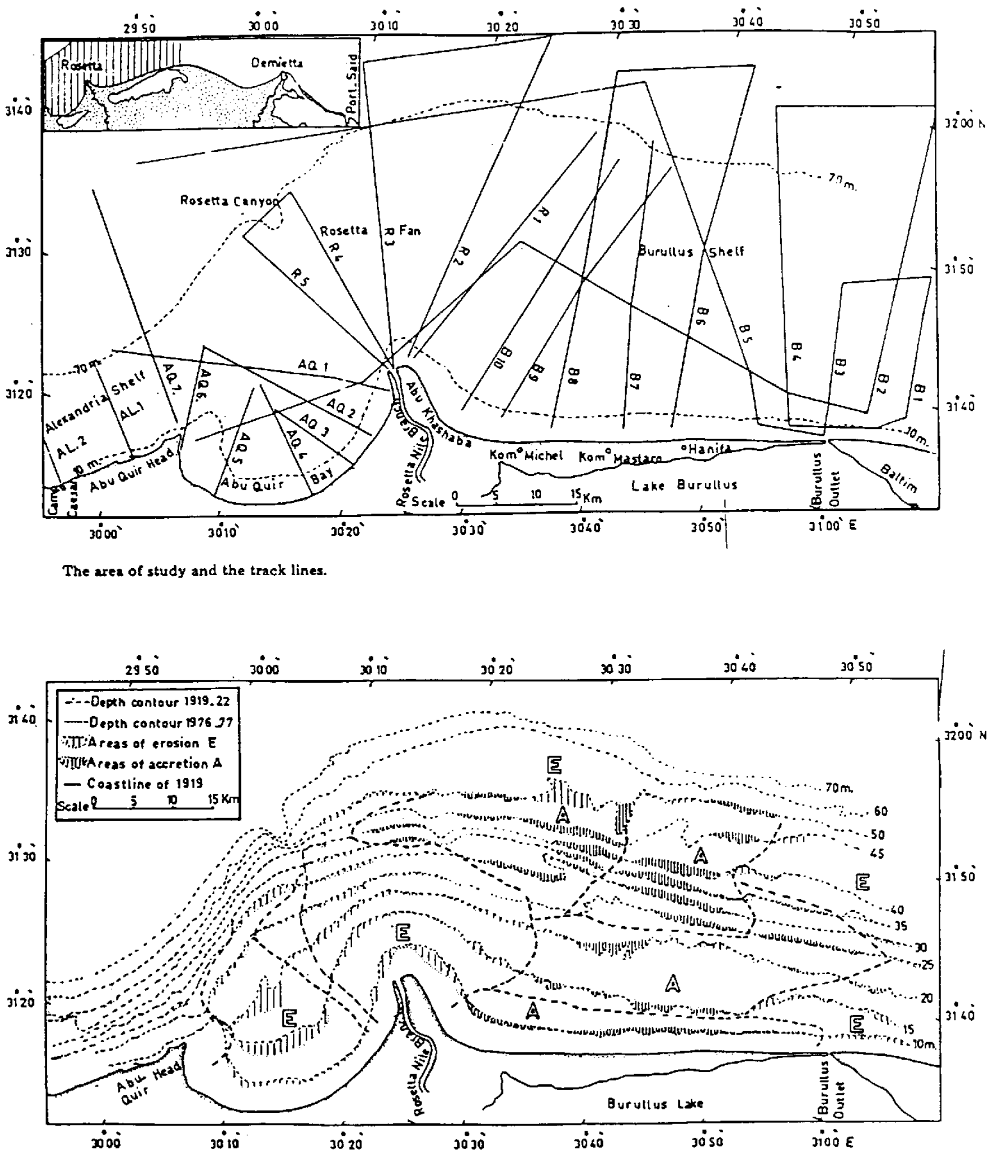

The area of study and the track lines.

Map showing the shifts of the bottom contours, 1922—1977.

Fig. 5. Sounding track lines in 1976-1977 and shifts of the bottom contours 1922 - 1977 as well as areas of erosion and accretion on the Egyptian continental shelf (Source Toma & Salama, 1980).

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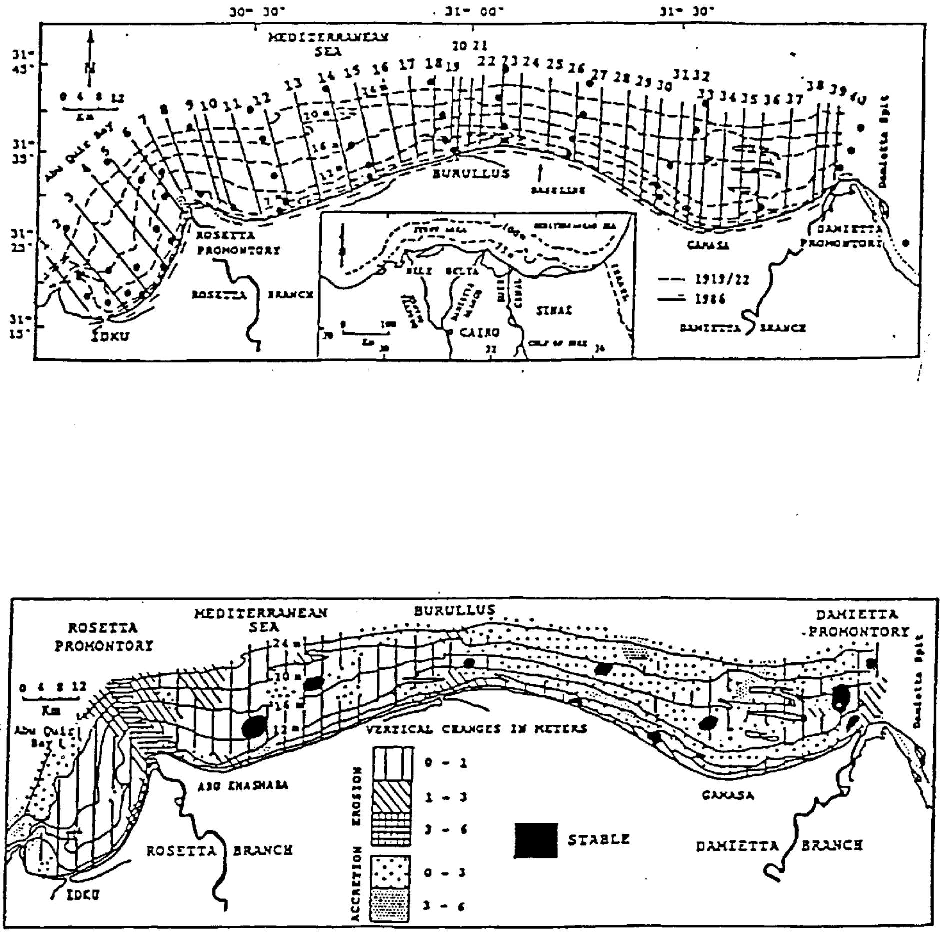

Fig. 6. Sounding profiles in 1986 and areas of erosion and accretion along the Egyptian continental shelf (Source Frihy *et al*, 1990).

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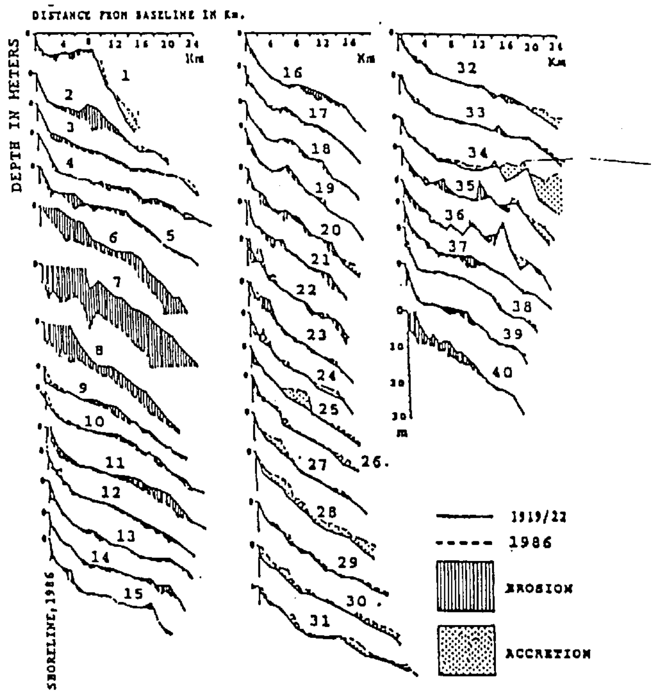

Fig. 7. Bathymetric profile survey changes during 1919/22 - 1986 showing areas of erosion and accretion (Source Frihy *et al*, 1990).

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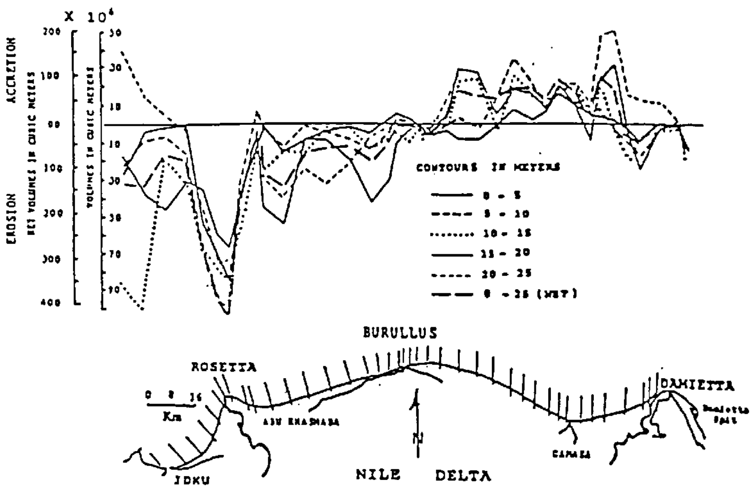
[Fig.7. Bathymetric profile survey changes during 1919/22 - 1986 showing areas of erosion and accretion (Source Frihy *et al*, 1990)]



Volume changes at 5 meter contour intervals along the Nile delta coast from 1919/22–1986.

Fig. 8. Volumetric changes along the Nile delta from 1919/22 - 1986 (Source Frihy *et al*, 1990).

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SEDIMENTARY BUDGET DEFICIT OF CONTINENTAL SHELVES NATURAL AND/OR MAN-MADE CAUSES OF BEACH EROSION THE CASE OF THE PERINSULAR SHELF OF MALTA

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Abstract

The small size and the lack of natural resources of the Maltese Islands makes the coastline, which is only 190 km long, a major focus of great economic importance. Decisions to develop new economic sectors on the coast, namely that of shipping and the tourist industry often prove conflicting, mainly because of lack of baseline information. An understanding of coastal processes especially of sedimentary dynamics which is essential to such decisions is not available. Phenomenae like beach erosion, which can prove detrimental to the tourist industry causes concern but has not yet been properly understood. A comprehensive overall scientific study is needed to allow for the optimum and rational use of the coast.

The origin and present profiles of various beaches are examined, but their evolution can only be explained through a study of a series of parameters which go beyond the present geographic zone under discussion. This paper attempts to present a regional scenario in which natural factors, like the geo- and hydrodynamics affecting the Maltese Islands can only be understood if studied in a wider Mediterranean context. When these are grasped it is then possible to proceed to study what type of effects urbanization has on the coast, especially on beach equilibrium. Aerial photographs, geological and survey maps, available literature and on-site investigations were employed to draw specific examples of some local sites.

INTRODUCTION

The Maltese Archipelago is a group of small islands situated in the central Mediterranean approximately 96 km from Sicily and 290 km from North Africa.

The islands are situated within the Malta-Hyblean Platform (Figure 1), that occupies the foreland margin of the African Plate, and covers some 17000 sq. km. most of which is today covered by shallow shelf-seas. (Pedley, 1990). The Islands lie on the Malta-Ragusa Rise which is part of the submarine ridge which extends from the Ragusa Peninsula of Sicily to the North African coasts of Libya.

The sea between the Islands and Sicily (the Sicilian Channel) reaches in places a maximum depth of 200 m but is mostly less than 90 m; the Malta Channel which is between the Islands and North Africa is much deeper, in places reaching more than 1000 m, for example, it reaches 1100 m in the Malta Basin, the NW trending Pantalleria graben, 15 km SW of Malta (Schembri, 1990).

The Islands have a collective area of 316 sq. km., and a shoreline of 190 km in length, with a submerged area (to 100 m from the shore) of 1940 sq. km. Due to the rocky nature of the shore, less than 40 percent of the shoreline is classified as accessible and only 2.5 percent is made up of sandy beaches.

It has been observed by various visiting experts that most of these beaches seem at present to be undergoing erosional processes, which if not checked would further limit the available beach space.

It has yet to be established whether, and to what extent beach erosion in the Maltese Islands is natural, ie., caused by natural phenomena and is cyclical, and whether and to what extent it is caused by human activities. Before this is ascertained, it is not possible to predict whether the suggested marine constructions, in the form of jetties, breakwaters, groynes, dykes, etc., are presently necessary to protect beaches from erosion to keep the equilibrium; and great care is needed to ensure that such measures will not in the long run behave adversely, ie., accelerate the erosion.

No baseline information on seasonal beach profiles, inshore currents, bathymetry, nearshore topography, or sedimentary dynamics in general exists for much of the Maltese coastline, nor of their interrelationships. No sedimentary budget deficit of any beach has yet been measured. Such information is essential before any beach replenishment development projects can be planned and implemented, to avoid unnecessary costs and possible negative impacts on the environment.

BEACH EROSION IN MALTA

The tourist industry and the local population impose high human pressure on the 2.5 percent of the coastline. This pressure leads to a rise in the demand for the building of more tourist facilities on many parts of the coast.

The hypothetical development of erosion of the Maltese beaches would seem to be linked to a group of factors which are:

B natural phenomena, such as climatic change, which is a known historical event and which has involved a natural reduction of the continental sediment supplies. Other factors such as tectonic movements, bay circulation patterns, sea level oscillations, etc., which may have contributed significantly to the erosion, but have as yet not been assessed, and indeed may prove that beach erosion is part of a cyclic natural pattern.

B human activities which have negative impacts on two levels.

The first is the normal urbanization process, in the form of roads, buildings, dams, etc., which causes the abrupt disruption of the occasional torrents which form at the time of the rainy season and which no longer can reach the beaches with sediment from the watercourses.

The second is the uncontrolled construction of works at the head of the beaches or on the beaches, walls for road supports, quays, swimming pools, etc., which allow an increase in the natural erosive effects of the waves and a modification of coastal circulation.

It has been observed that the only coves which still have a substantial volume of sand are those where there exists either no construction whatsoever or a little construction around them. Also many bays lined by a very urbanized coast and having building activities at the top of the beach such as quays, vertical walls for supporting road structures, etc., are said to be characterized by beaches reduced to only a few square metres.

Beaches free from any building amenities (Ramla Bay, Gozo) or where there is construction only on rocky areas but displaying no buildings at the back of the beach (Gnejna Bay, Golden Sands), seem to be balanced. Sandy areas having constructions at the back of the beach (St. Paul’s Bay, Mellieha Bay are said to be in the process of erosion. Bays which are very urbanized and support constructions at the back of the beach, (Balluta Bay, St.George’s Bay, Xlendi and Marsalforn in Gozo), seem to be affected by erosion processes.

Another reported natural factor that may be contributing to beach erosion is wind action. In some places sand is being swept inland and it has been observed, for example, at Little Armier, that the sand becomes part of the organic process whereby sand is converted into soil, and thus becomes irretrievable.

Erosion by wind can also be seen at Mellieha bay where the sand is blown over the road during easterly winds and into the sea during westerly winds.

Other factors that may have contributed considerably to beach erosion, besides proving detrimental to the environment in general are past development projects. The Risq il-Widien project of the 80's was one such project. The work involved mainly the widening of valley watercourses and the erection of dams across valleys. What actually resulted was accelerated soil erosion, rapid silting up of the watercourses and the catchments areas behind the dams, and therefore also loss of sediment transport to the sandy beaches (Schembri, 1990).

So far no quantitative project has been carried out to measure the extent of beach erosion on the Maltese Islands. When this takes place it is important to study the Islands in a broad Mediterranean context. The study of the geo-, and hydro-dynamics of the Mediterranean is essential to the understanding of the coastal processes of the Maltese Islands; as are the effects of trends in urban development on the Mediterranean coast.

GEOLOGY, TECTONICS, AND GEOMORPHOLOGY

GEODYNAMICS OF THE MEDITERRANEAN

The Mediterranean Sea consists of a series of deep sedimentary basins stretching some 4000 km between Gibraltar and the Black Sea. Together with the Alpine mountain chains with which they are closely associated, these basins occupy the junction between the African-Arabian and the Eurasian continents in a zone marked by earthquakes and volcanic eruptions.

The present narrowness of the Mediterranean, where the continental margins join (according to Biju-Duval et al., 1976, only 10 percent of the surface of the Mediterranean basins is situated more than 100 km away from the continental shelves), has provoked a geologically rapid sedimentary aggradation of the basins at a sedimentation rate of around 0.3 mm/year for the last 5 million years. The result is that the crust is buried under ca. 10 km of sediment or more, and that the great deltas (Nile, Po, Rhone, Ebro) continue far undersea.

Owing to the weight of the sediment, the basins in the Western Mediterranean have subsided at least 7 km, and in the Eastern Mediterranean, 6 to 15 km. This movement implies a progressive migration of the flexure of the continental margins towards a subsidence of the coast, overlaying in places the tectonic uplift movements caused by collision or subduction phenomena (Pirazzoli, 1987).

The effect that the above has had on the evolution of coasts, in the form of emergent and submergent movements of the Maltese Islands have not yet been studied. But it can safely be deduced that such movements did and still do have a direct bearing on the past, present and future beach profiles.

TECTONICS

Many parts of the Mediterranean are tectonically active, characterized by earthquakes and volcanic eruptions in the junction between the African-Arabian and Eurasian continents. For thousands of years, vertical earth movements in the Mediterranean have averaged one to five millimetres per year; when looked at more closely - over periods of 15 or 20 years - the range increases from 3 to 20 mm per year.

An especially strong tectonic influence on the structure of coasts is found in the northern and eastern Mediterranean, from Italy to Egypt. For example, in 1908, an earthquake at Messina, Italy, increased the relative sea level by 57 cm, which may have affected the sea-level of the Maltese Islands at the time.

The water balance is made necessarily fragile by these diverse tectonic forces; the Mediterranean is connected with the Atlantic Ocean and the Black Sea by only shallow, narrow straits which are affected by tectonic deformations. If, for instance, the Strait of Gibraltar closed up, as the present water budget shows a loss, the Mediterranean would dry in the space of 3000 years with a probable drop in the sea level of some thousand metres. This phenomenon is certainly not new: it occurred during the Messinian (between 9 and 6 million years ago) when evaporite layers were deposited on the bottom of the basins. The sea-level rise which followed in the Pliocene, as soon as the strait reopened, was also some thousand metres high. (The Pliocene period is missing in Malta, which means the islands emerged with the drastic drop of the sea-level; the sea-level rise that followed accounts for some of the Quaternary deposits that are found in some places which implies that the islands were in some areas completely covered with water).

In the Quaternary the Strait of Gibraltar seems to have remained permanently open, although the gap has been gradually shoaling since the early Pliocene (Hsu, 1974), and therefore the Mediterranean was affected by the glacio-eustatic variations of the Atlantic Ocean. The Black Sea, on the other hand, was linked to the Mediterranean only during the main Interglacial periods (Stanley and Blanpied, 1980).

GEOLOGY OF MALTA

An understanding of the geology of Malta (Figure 2) is of importance to the study of beach erosion since it has a direct correlation with the geomorphology, morphology and profiles of the beaches. (The sands of all the beaches are of a calcerous nature reflecting the calcium carbonate composition of the Islands).

The islands are almost entirely made up of marine tertiary sedimentary rocks deposited during the Oligo-Miocene eras, in horizontal layers. Also present are some minor Quaternary terrastrial deposits dating from the Pleistocene.

The original horizontal layout of the strata was broken up by faulting caused by earth movements that were probably initiated in the Pleistocene period and continue to the present. The whole block of islands is tilted eastwards, raising the cliffs on the west to about 244 metres and drowning the valleys on the eastern and south-eastern side. The dominant structural feature on the islands is a series of normal faults striking east to west. In the northern part, between the faults, are upthrown and downthrown blocks, that form horsts and graben respectively.

Five different formations are present and these are in order of sequence from the surface and also in order of increasing age:

Upper Coralline Limestone
Greensands
Blue Clay
Globigerina Limestone
Lower Coralline Limestone

The Upper Coralline Limestone varies considerably in thickness, and being the topmost bed, it has undergone severe erosion. On the plateaux and ridges the preserved thickness averages less than 30 metres, but in the graben, it is nearly 65 metres.'

The Greensand occurs as two varieties, a green glauconite marl, and a rust coloured, sandy-textured limestone. The marl thickness ranges from 0.5 metres to 1.5 metres, with a 0.7 metres average; the sandy limestone, which is discontinuous and lenticular in form, has a maximum thickness of 13 metres at Dingli and 18 metres on Gozo.

The Blue Clay is composed of blue-grey,-green and marly clays. Its thickness varies from 80 metres, with an average of 30 metres. The Blue clay increases in thickness from east to west on Malta, varying from 0 to over 65 metres. In Gozo it is generally thicker than in Malta rising to 80 metres.

(Beaches with clayey outcrops in the immediate hinterland, such as at Gnejna Bay, where it slumps out in the form of ca. 45· taluses over the underlying rock, contribute to a type of clayey beach sand with a high cementation factor, which in turn contributes towards the stability of the beach).

The Globigerina Limestone varies from white and marly to a very soft-textured yellowish colour. The average thickness of the rock is about 75 metres. This rock nearly makes up for 70% of most of the surface of Malta and Gozo. The Globigerina Limestone makes for very smooth coastal shores with very little irregularities.

Lower Coralline Limestone is like the Upper Coralline Limestone, semi-crystalline but rather harder. The thickness above sea level averages about 120 metres. It is generally found exposed on cliff sides facing the sea, in the south, southwest and west coasts, rising from the sea to heights of about 70 to 130 metres, such as at Fomm ir-Rih, in Malta, and at Sannat in Gozo.

The above distinct formations allow for the easy identification of the source of the coastal sediments that are transported to the bays.

GEOMORPHOLOGY OF THE BEACHES

Coastal sediment is supplied from various sources such as by rivers or streams, waves, wind and organisms, and it undergoes various geomorphological processes when deposited.

Most of the sediment on coasts was transported there by rivers from the eroding landscape. Direct wave erosion accounts for only perhaps 10 percent of the material moving along coasts. Wind blows sand and dust into coastal water downwind, but the mass contributed by the wind is very small. Waves bring sediment onshore from deeper water, but most of this sediment was previously carried by rivers. (This will be discussed in more detail below).

The grain size and chemical composition of sediment brought to coasts by rivers are primarily determined by the nature of the bedrock over which the rivers have flowed. In Malta these distances are very small and in many instances the most active part of the erosion processes takes place at the immediate hinterland of the bay. In many cases this is the steepest gradient of the valley leading to the beach. The sand deposited on beaches is generally of a sub-angular to angular shape, which signifies that the time of transport was slight, and that it has been submitted to energy of small value. (This requires further study). An analysis of sand taken from beaches above the water shows that two colours of sand have been identified: ochre and grey, which verify that they are derived directly from the parent rocks of the immediate hinterland. Hence Golden Bay has a reddish colour which reflects the colour of the Upper Coralline Limestone outcropping on to the bay.

Wave erosion of sea cliffs initially produces poorly sorted sediment. As the waves cut away the foot of a cliff, landslides bring down great masses of unsorted, broken rock to the shore. This is happening to the headlands at Ras il-Wahx, Il-Karraba and Ras il-Pellegrin, on the North-west coast of Malta. However, waves and nearshore currents are particularly efficient at sorting sediment by size and specific gravity. Along the beaches that are enclosed by the above headlands, it can be observed that beach sand or gravel becomes finer in size, more rounded, and better sorted according to the direction it has travelled. For example at Ghajn Tuffieha bay the prevailing,northwesterly currents hit the headland, "Il-Karraba", move in a circular motion first depositing the broken rock, and eventually shingle, along the south part of the beach, and then pushing the finer sediment to the north, which is the most sheltered part of the beach.

Sandy beaches are usually in a dynamic equilibrium state as long as the governing conditions do not change permanently. This means that such beaches do remain stable, in a broader sense, but that temporary changes may be caused by gales, for instance. In locations with strong seasonal characteristics this can clearly be seen: the beaches in north-west Europe show a winter profile and a summer profile, but will generally not vary beyond those. Although in Malta such drastic profile differences do not usually occur, it has been observed several times, for example, at Mellieha Bay, that during a severe storm the whole beach disappears under water, and it is assumed that sand is carried out and then brought in again by inshore currents during a quiet period.

(Comparing the development of sandy beaches on aerial photographs of 1967 to those of 1988, it is not obvious which bays have undergone erosion, or accretion, and which have not, with the notable exception of Balluta Bay; and which have altered profile, in length, width and thickness. Drawing conclusions when comparing an aerial photograph of a specific year, day and time to another specific year, day and time twenty years later may prove misleading if such phenomena as changing profiles are not accounted for).

Other processes happening on some coasts are those generated by organisms. In many instances organisms provide most or all of the sediment supply. Although this may not be the case on the Maltese Islands, biological activity on the coast does take place. Biological action may remove material from within the rock by boring and excavation. A wide variety of organisms are involved, including molluscs, algae, and echinoderms, (all present on the Maltese shores), and both feeding, i.e. boring, and protection strategies are involved. As yet no detailed studies of bioerosion in Malta have been undertaken.

NEARSHORE TOPOGRAPHY

Studies of beaches are not just restricted to the exposed beach face. It seems highly probable that the nearshore submerged topography and the beach face are related dynamically and, if so, the total zone under wave activity should be considered in questions concerning ’beach equilibrium’ and ’sediment budget’. Sediment transfer within the zone of wave-induced motion on low angle sandy coasts is, frequently, intimately related to the initiation, growth and migration of large-scale bedforms, known under the general term of subaqueous bars. (The sand bar at Mellieha Bay is built up by the backwash of the waves and it never emerges above the water level).

Spits, on the other hand, differ from offshore bars in that they spring from the coast and are supplied with material mainly by longshore drift and not from the sea floor. Broadly speaking there are two main types: those which diverge from the coast at a marked angle and those which run approximately parallel to the trend of the coast.

The orientation of coastal features such as bars and spits is largely governed by dominant wind and wave directions.

It is evident that sediment circulation patterns, rates of sediment movement, and the resulting dynamic equilibrium of the beach, are strongly dependent on the morphology and dynamic nature of the bed topography.

No bathymetric chart of the whole periphery of the nearshore of the Maltese Islands is at present in existence. Those that exist, mainly around the harbour area, dating back to the 50’s, are now outdated.

CLIMATIC VARIATIONS AND SEA-LEVEL OSCILLATIONS CLIMATIC CHANGES

The Maltese Islands emerged only at the end of the Tertiary, i.e. during the Pliocene. This makes only the recent geological period, the Quaternary, of interest for the study of climatic change.

The glacial periods that occurred during the Quaternary did not extend south to the Maltese Islands, but the Pluvial periods are the cause of the transportation of sediment that was initially deposited on the present beaches.

During the pluvial period of the Quaternary, (the Pleistocene and which must have continued in the Holocene), the watercourses of the Maltese valleys, which are all presently situated at the downstream point of valleys, were continuously supplying the beaches with sediments. This implies great volumes of sand deposited on the beaches by runoff. (The sediments found at the bottom of Marsaxlokk Bay, recently dredged by the Malta Freeport Project, have been identified as dating from the Holocene, confirming this idea). The glacio-eustatic variations mentioned earlier (together with other factors), must have checked the continuity of this geomorphological process and may account for the reason why no large accumulated beaches are presently found on the islands.

The climatic change that occurred later reduced the amount of rainfall and today, watercourses are only drained occasionally by sediment carrying torrents during the rainy season.

SEA-LEVEL OSCILLATIONS

The causes of sea-level changes are mainly due to climatic changes and tectonic movements as mentioned earlier. In Malta, changes in sea level, caused by tectonic movements, have submerged the mouth of some valleys where they extended to the coast, giving rise to headlands, creeks and bays. Prime example being the wide Pwales valley at Xemxija Bay, the valley is also a graben between the two horsts, the Bajda and Wardija ridges.

No surveys as yet have been done about former sea levels round the coasts of the Maltese Islands but many have been identified along other Mediterranean coasts.

MEAN SEA LEVEL

The mean sea surface topography of the Mediterranean Sea, deduced from data from the SEASAT satellite, shows the presence of differences in elevation as high as 50 m between a low situated in the Eastern Mediterranean and a high in the Gulf of Lions (Barlier et al., 1983). The accuracy of this representation of the surface topography has been estimated to be better than 0.5 m on a global scale.

In the Western Mediterranean there is a generally increasing slope of 3 to 7 m of the sea surface between North Africa and Europe. The difference in elevation reaches ca. 20 m between Libya and the Gulf of Genoa and more than 15 m between the Ionian Sea and the North Adriatic. Steep slopes appear near southern Italy.

In the Eastern Mediterranean, the most striking feature, however, is the marked depression in the Eastern Mediterranean, around the Hellenic are, which marks the Ionian Trench, where subduction is active west of Crete, and stretches as it deepens around the transform faults of Pliny and Strabo. The slope of the mean sea surface topography is particularly abrupt between this depression and the neighbouring Aegean Sea, which obviously constitutes a gravimetric sill between the Eastern Mediterranean and the Black Sea.

HYDRODYNAMIC FACTORS

GENERAL OCEANIC CIRCULATION

The Mediterranean Sea has two main basins, separated by a submarine ridge between Sicily and Africa, (on which the Maltese Islands stand). Each has its own separate counterclockwise current. There are three principal water layers: a surface layer of variable thickness, an intermediate layer of warm, saline water from the eastern Mediterranean, and a homogeneous deep layer reaching the bottom.

The North-West current that traverses from the west to the East of the Mediterranean is also the predominant current that influences the longshore drifting of the Maltese Islands. (This current seems to fall into and follow the path of the Pantalleria rift). (See Figure 3).

WAVES, SWELL AND TIDES

There are many types of waves and they all play different roles in shaping coastal landscapes by direct wave action and transport of sediment.

Swell, which is the regular pattern of smooth, rounded waves that characterizes the surface of the ocean during fair weather is usually composed of several wave trains of different wave lengths. These are often moving outward from more than one generating area. The direction of swell is not always easy to distinguish especially when it enters local wind fields. The visual observations that were carried out at Delimara point, at the entrance of Marsaxlokk Port over a period of 9 years, 1979-1987 conclude that the main swell direction is "southerly". From the data recorded, it is doubtful though whether the observer distinguished between the direction of the "sea" and that of the swell.

As deep-water swell approaches a coast, the form of the waves change. As the water depth decreases, the orbital motion beneath the waves is distorted from a circle to an ellipse, then to a to-and-fro linear motion, changing the wave period. This was recorded by the Malta Free Port during observations made at Pretty Bay, Birzebbugia, on February 17, 1988. A long period swell was measured, (T - time being approximately 10 seconds), whilst the wave pattern recorded at the harbour entrance, had a much shorter mean period.

Sediment in the nearshore zone is also moved along the coast by longshore currents generated by waves, winds, and tides. Most of the sediment is moved in the surf zone, (littoral drifting). A smaller amount of sediment is moved by the oblique wash of waves on beaches when the waves are approaching the shore at an angle. (The linear beach at L-Imgiebah, on the north-west coast of Malta may be the result of longshore drifting).

The extent of the work of waves on a beach are also determined by the tidal range. This range is very limited in the Mediterranean and any intertidal notch formed has therefore a correspondingly limited vertical development. The tidal fluctuation around the Maltese Islands is around half a metre.

WINDS

The prevailing winds in Malta, especially during the winter months are the westerlies, the most common being the North Westerly wind, which blows on average one in three days of the year. This wind follows the North-Westerly current mentioned earlier. The North East Wind blows at the time of the equinoxes in March and September. It is a strong wind that can effectively cause erosion because of its long duration each time it blows. The winds over the Malta Islands vary considerably from year to year.

On a regional scale winds also affect sea level and are very important in generating vertical convection and deep water formation.

URBAN DEVELOPMENT ON THE COAST

ECONOMIC DEVELOPMENT

An understanding of the "natural" components discussed above on a regional scale will always serve as a necessary background scenario to any urban coastal development plan that has to do with the Maltese Islands. And for the same reasons, knowledge of the pattern of tourist trends and urban coastal development of some of the Mediterranean countries may also prove useful when it comes to the Maltese Islands.

The Mediterranean coastline is approximately 46,000 km long, 40 percent of which is accounted for by islands. Slightly more than half is rocky, the rest made up of low, sedimentary shores. These beaches have been subjected to the strongest human pressure. It has been said that beach erosion in the Mediterranean is in many cases directly attributed to human activities.

It was estimated that 51 million foreigners and 45 million nationals spent their holidays in the Mediterranean coastal regions in 1984.

The Maltese Islands also have a fair share of the Mediterranean international tourist market and since the islands were opened to tourism in the 1950's, the tourist industry has steadily grown. In 198O almost 730,000 arrivals were recorded, in 1989 the figure reached more than 900,000.

Impact of tourism on land resources in the Mediterranean has been studied on the basis of accommodation capacity and the number of guest-nights, bearing in mind that tourism uses both accommodation facilities and amenities for sport, cultural, or recreational activities. The table below provides an estimate of tourist accommodation capacity and corresponding site coverage for all the Mediterranean countries in 1984. Altogether, about 2200 sq. km. were used by specifically tourist accommodation in the countries of the Mediterranean basin. If this surface area is doubled to take account of urbanization regulations and necessary infrastructure (such as service roads etc.), total site coverage amounts to about 4400 sq. km.

Urban development of the Maltese Islands has been steadily increasing during the past 30 years. Land area occupied by buildings increased from 5 % in 1957, to 16 % in 1983. The development connected with the tourist industry has particularly mushroomed in the coastal areas.

An accompanying factor of this intense development was increased road construction. For example, the 893 km of roads existing in 1957 became 1482 km in 1987, a 66 % increase (Schembri 1990).

Urban development usually denotes progress but as discussed earlier, it can also result in negative impacts on the coast, one of these being beach erosion. To prevent this from happening, intelligent infrastructural coastal planning is imperative.

PREVENTION OF COASTAL EROSION AND REPLENISHMENT OF BEACHES

INFRASTRUCTURAL PLANNING

Infrastructural planning of the coast can only begin after, first a thorough knowledge of all that is involved in natural coastal processes is studied and understood; and second, the impact that urban development can cause on these processes. Especially in disturbing the sedimentary dynamics and in causing beach erosion.

Although the sedimentary budget of Balluta Bay has never been measured, the aerial photograph of 1967 does show a few square metres of sand in the south corner, which was probably fed by a former valley which is now a road. The present bay has very little sand present, and the high wall erected to support the road, plus the building of the swimming pool, leaves no doubt that in this case urban development was the direct cause of erosion. As other past experiments have demonstrated, trying to dump sand in this bay to again create a beach, as has been suggested, would be futile because the same urban negative factors will again apply.

Another experiment was that carried out in St. George's Bay (St. Julians) in 1980, when imported sand was used to replenish the beach. One year later, all the additional sand had been swept away because of lack of careful planning. During the rainy season, the existing rainwater runoff culvert, allows strong torrents of water from the road to descend upon the beach, washing all the sand into the sea. This culvert will require re-routing towards another part of the bay before and if any decision is taken to replenish the beach. (A Unit Hydrograph of the area, drawn up by a hydrologist, will be useful to plan re-routing).

The same fate, but for different reasons, may befall the present dumping of sand at Wied Buni, at Birzebugia. The dumped sand may find itselfback where it was originally dredged from, i.e. the entrance of Marsaxlokk harbour, because of the bay circulation patterns.

The construction of roads at the back of a beach have many times been blamed for causing beach erosion, because of halting the supply of sand from the watercourses to the beach. This may be true in some cases but some examples show that this factor is overruled if the gradient of the hinterland is high enough to traverse the stretch of asphalt road between the source and the beach.

The Pwales bay is a drowned valley, the water is shallow quite far out in the bay. The track road on the north side of the Pwales bay, allows the only source of sediment from the valley to reach the bay. This must happen in winter when the velocity of the water downstream crosses the coast road and deposits a certain amount of sediment on the beach.

Run-off from Wied Qoton still must supply sediment to Pretty Bay during storms. In the case of this Bay, the jetty erected at the other end of the bay has offered some protection to the bay, especially since the shape of the beach in the bay denotes that there is a inshore circular current. Without the jetty the sand would have been swept away. This proves at first glance, that the construction of the jetty proved beneficial.

Gnejna Bay is fed by two valleys bypassing a knoll to reach the beach. Even though one is a road, the steep gradient enables the sediment that accumulates from the sides of the valley to reach the beach and replenish it. (When comparing aerial photographs of ’67 and ’88 the bay shows no sign of having been eroded).

The behavior of the above examples of dredging, road and jetty constructions may already serve as important case studies to allow better future planning.

The existing Government regulations such as the Building Permits (temporary Provisions) Act 1988, which is the legal instrument which allows such interim protection / or town planning, should consider building and road construction near the beach with special attention. It should also consider innovative ideas, e.g. the construction of an elevated road near a sandy beach that would allow run-off of sediment from watercourses to reach the beach.

The sand (preservation) Act, 1949 (Act XVI of 1949), is another regulation that should be enforced. This act prevents the removal of sand and shingle from any beach, seashore or any other place without specific permission. It has been reported that contractors are taking sand from Ramla Bay, Gozo for building purposes, without permission.

CONCLUSION

The Maltese Islands face major conflicting interests when it comes to making a rational use of the coastal zone. Projects implemented in one area may inadvertently affect another adjacent coastal area. For example, one area designated for industrial use may have an adverse affect on an adjoining area which has been earmarked for touristic development. Moreover, both decisions may also produce dire consequences to the equilibria of the many facets of the marine environment, one of these being beach stability.

To ensure rational use of the coastal zone and protect beaches from man-made erosion, it is necessary for the country to undertake a specific project that will deal exclusively with the coast and erosion. One of the prerequisites of this project would be, to have an adequate number of scientists and engineers in various fields, especially in oceanography, marine geology, geomorphology, hydrology, urban geography, climatology, meteorology and coastal engineering. It is furthermore imperative to set up a Marine Centre that would have as one of its tasks, continuous monitoring of the sedimentary budgets and beach profiles of selected beaches of prime importance.

Thus, equipped with the professional human and physical resources the coastal zone and the dynamics involved would be better understood and hence better managed.

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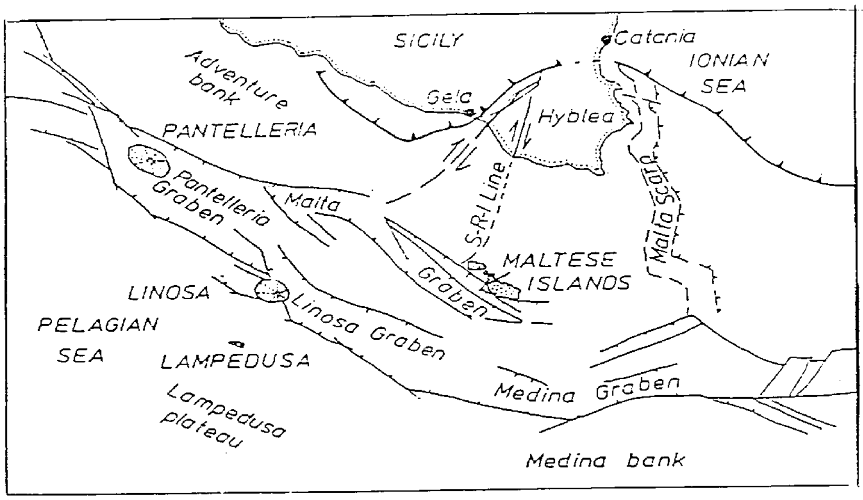

Fig. 1 Main structural elements of Malta/Hyblean Platform (Pedley, 1990)

Fig. 1 Main structural elements of Malta/Hyblean Platform (Pedley, 2990)

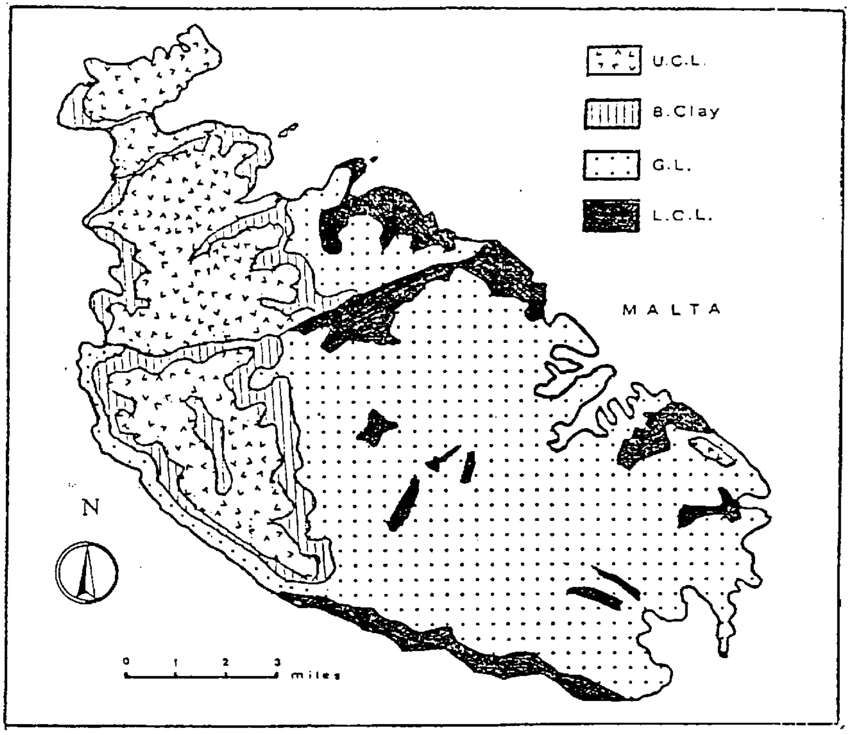

Fig. 2 Map of geology

Fig. 2 Map of geology

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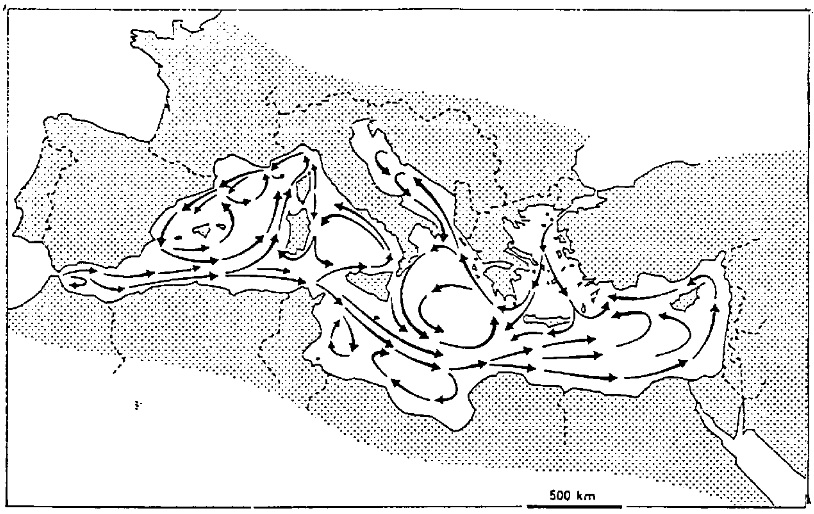

General trends of surface currents in summer. The flow of water in and out through the Strait of Gibraltar is highly complex. Water of lower salinity from the Atlantic enters on the surface, while an almost equivalent amount of Mediterranean water leaves at depth. It is, however, the relatively small difference between the two amounts which provides the major contribution for balancing evaporation and maintaining the level of the Mediterranean.

Source: adapted from H. Lacombe and P. Tchernia (1974).

Fig. 3 From The Blue Plan 1989

Fig. 3 From The Blue Plan 1989

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Capacity and site coverage of hotels and other lodgings. 1984

	No. of hotel beds (000s)	Site coverage coverage (1.000 m2)	No of other beds (000s)	Site (1,000 m2)
Spain	840	33,600	8,923	624,610
France	1,590	63,600	10,894	762,580
Italy	1,598	63,920	5,854	409,780
Malta	14	560	41	2,870
Yugoslavia	319	12,760	1,127	78,890
Greece	323	12,920	3242	2,680
Turkey	68	2,720	182	12,740
Cyprus	27	1,080	137	9,590
Syria	23	920	71	4,970
Israel	63	2,600	162	11,340
Egypt	48	1,920	218	15,260
Libya	9	360	24	1,680
Tunisia	72	2,880	77	5,390
Algeria	27	1,080	37	2,590
Morocco	59	2,360	152	10,640
TOTAL	5,082	203,280	28,223	1,975 610

Nore: The different types of tourist lodging (hotel and other. including related areas) occupy an average surface of 25-100 m2 per bed:

rented. self-carering accommodation	50 *m2*- per bed
hotels	30 m2 per bed
youth hostels	30 m2 per bed
holiday villlages	100 m2 per bed
camping and caravan sites	50 m2 per place
car-parks	20 m2 per place

The average reached is 40 m^2 per bed for hotel accommodation and 70 m2 per bed for other accommodation.

Table 1 From The Blue Plan 1989

NORTHERN ADRIATIC CONTINENTAL SHELF: MULTIDISCIPLINARY APPROACH TO THE STUDY OF PRESENT SEDIMENTATION

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SUMMARY

Research works on sediments and related pollutant distribution and accumulation have been carried out in the Adriatic Sea since the early seventies. Now the study of the Adriatic marine environment is oriented to the quantitative study of key processes in the whole basin as well as in particular areas. The guidelines of past research activities and the multidisciplinary approach of present studies is outlined with some reference to the principal results.

INTRODUCTION

The Adriatic Sea is a relatively shallow, semi-enclosed basin, of great interest in itself, and within the context of the whole Mediterranean because it is one of the areas where dense levantine waters are produced. Its peculiarity is the extension towards northern latitudes; this is the reason why the very shallow northern part of it is subject to large temperature excursions which, together with the fresh water inputs (the Po River supplies about one third of of the river discharge into the whole Mediterranean), affect its particular water circulation.

The Adriatic water renewal rate is not well known. It depends, however, on the fluvial regimes, and on the particular bottom morphology including shelf areas, a central depression and a southern deep with their respective thresholds (Figure 1). Franco (1983) suggested a rather short renewal time (in the order of one year) for the waters in the northern part.

The Po which is the major Italian river (mean water flow 1500 m3/sec), drains a very industrialized and intensively cultivated area, and exerts its influence over the whole basin. The other rivers, which are much less important, may be meaningful on a local scale. The increasing frequency of distrophic situations aroused interest in the study of the Northern Adriatic sea, since it is important to make a distinction between merely natural processes and those also influenced by man.

Most pollutant species have a strong affinity for suspended particles and sediments, thus geochemical and sedimentological processes have been the subject of many research works, especially in the Northern Adriatic Sea. The aim of this paper is to outline the development of the research approach to the definition of the role of sediments in the general system behaviour and in determining the biogeochemical cycles. The overall objective is to understand the set of inter-related processes that govern the transport of mass and energy in the coastal environment, to calculate mass balances and then to formulate a number of models for the simulation of the response of the various components of the ecosystem to environmental changes. The achievement of good results in this field now requires a really multidisciplinary approach.

BACKGROUND

The Adriatic Sea, and especially its northern part, has been extensively studied. However, most research works were dedicated to distinct problems and areas on different time scales and were carried out without co-ordination. Also the idea that the results of strictly disciplinary researches could be useful to studies of a completely different nature is rather new. Because of this the bulk of knowledge is very difficult to synthesize and much information is of limited value for modern quantitative use.

The main references for studies about water circulation, geomorphology, mineralogy, sedimentology, benthic populations, and Po River sediments carried out before the middle seventies can be found in Frascari et al (1988), and Colantoni and Gallignani (1978, 1980). In the second half of the seventies a main target-oriented project on "Oceanography and marine bottoms" was promoted and co-ordinated by the Italian Consiglio Nazionale delle Ricerche. The results were fairly good but their interpretation remained more qualitative than quantitative. A number of papers gave an important improvement to the knowledge of the different phenomenologies. These references were reported by Catalano *et al* (1983). Some basic information has been summarized in the following paragraphs.

HYDRODYNAMICS AND SEDIMENT DISTRIBUTION

Water circulation is the key process which regulates and conditions all the others. The northern part of the Adriatic Sea is very shallow (not more than 75 m deep) and therefore subjet to high temperature variations in the different seasons. The two main patterns of circulation are shown in Figures 2 (a and b) for the winter and summer seasons respectively.

The winter circulation (Figures 2a and 3a) is due to thermohaline forces: oligotrophic waters circulate in a counter-clockwise direction, flowing northward along the Yugoslavian coast and then southward along the western Italian coast. This pattern has the effect of confining the waters, and suspended matter, from the Italian rivers near to the coast and then directing the plumes southwards.

Summer water circulation is different (Figures 2b and 3b) and is characterized by a vertical stratification of the water column, and the overall cyclonic circulation is very slow. An evident pycnocline separates two water bodies one of which is dense for the low temperature and the high salinity. During the rare floods the fresh water from the Po river can expand toward all directions (Figure 3b). South of the Po delta inertial and tidal currents cause only oscillations or under-eddies, and an overall water stagnation may occur in late summer.

The fine material input from northern rivers is relatively poor (the catchments are mainly carbonatic) and these sediments settle along a discontinous narrow belt (Figure 4). In the area influenced by the Po River output (solid transport is about 14 MT yr-1) the belt of fine bottom sediments becomes more important. This particular plume of fine sediments extends southwards and is also fed by Appennine rivers. Further offshore the presence of relict sands indicates an environment of low or absent accumulation of fines.

The thickness of Holocene mud varies from 0 to 20-25 m in the points south of the delta near Ravenna where the subsidence and/or the river input is particularly high. The wave action on the sea bottom can resuspend the sediments even at significant depths (30-40 mt or 90-100 m, according to different authors).

Useful information to determine the various sources of sedimentary materials were obtained using different tracers, including clay minerals and dolomite, as well as some pollutants (Frascari *et al*, 1988, and references therein).

AREAL DISTRIBUTIONS

During the seventies, our research was based on the study of the concentration and areal distribution of pollutants in the surficial sediments of the coastal areas to locate pollutant accumulations and understand the relative importance of the sources. One of the aims of the research was also to understand the relationship between the degree of sediment pollution and some sediment caracteristics, such as grain size, organic matter contents, and physico-chemical parameters (pH, Eh). The use of the Factor Analysis for the statistical interpretation of the results allowed some definition of the multiple relationships between parameters (Frignani *et al* (1978); Bortoluzzi *et al* (1984a and 1984b); Frascari *et al* (1984); and Guerzoni *et al*, 1984).

Frascari *et al,* (1988) reviewed these researches and described the principal results then available on the distribution of pollutants (heavy metals, nutrients, chlorinated hydrocarbons, and radionuclides) in surficial sediments. Figure 5 shows the distribution of Pb. Its pattern is common to many tracers: the main supplier is the Po River and its effect in front of the delta and offshore from the Emilia-Romagna region is evident. Part of the Pb also comes from northern rivers and their contribution is more relevant for certain elements (e.g. mercury). It is also known that the major way for the ubiquitary distribution of many pollutants (e.g. chlorinated hydrocarbons and fall-out radionuclides) is the atmosphere. In a coastal area, however, the presence of these chemicals is mainly influenced by local sources, especially by river outflows. In most cases there is a distinct correlation between the concentration of a pollutant and the grain size composition of the samples even if, on a large scale, other factors such as local inputs, distance from the source, type of source etc., may influence the pattern (Frignani and Ravaioli (1982); Albertazzi *et al* (1984); Frignani and Langone).

RECENT ENVIRONMENTAL RESEARCH

Particular attention was given to sedimentary processes in research work on the North Adriatic Sea, dedicated to the series of processes linked with problems of pollution and environmental management, in terms of events, mechanisms and reactions which involve sediments and particulate materials. In fact in natural water systems nearly all the potentially hazardous species (organic chemicals, heavy metals, radionuclides and others) have a certain affinity for solid particles. Thus, suspended matter concentration certainly is the factor which determines the major transport mechanism of these chemicals. In a coastal area, where the particulate concentration is relatively high, a substantial part of the pollutant input will settle on the bottom and a minor part will leave the system toward the open sea (Frascari *et al* (1988)). In most cases the accumulation of pollutants into the sediment is desirable, because this environment promotes their immobilization and degradation. Once in sediments, any compound may be taken up by organisms, altered or degraded by micro-organisms, absorbed into particles and buried with them or released into the overlying water. The knowledge of these processes is of fundamental importance to the understanding of the behavior of the environment and the fate of pollutants.

The research approaches changed with a view of studying the main processes that determine the behaviour of the coastal environment, their connections and their relative importance. Among these processes we can list the following: a) inputs of water, chemicals, and particles from the rivers; b) accelerated deposition in estuarine and prodelta areas where conditions of increasing salinity are appropriate for the flocculation processes; c) biological particle aggregation; d) scavenging and other processes of sediment-water interaction both in the tidal river and at sea; e) particle transport and distribution with special attention to mud deposition and accumulation; f) bioturbation, mixing and resuspension, their relative importance and relationship with biological and the hydrodynamic conditions of the area; g) early diagnosis and fluxes of nutrients at the sediment-water interface, mobilization of pollutants and authigenic formation of minerals. Much effort has been dedicated to the measurements of fluxes, especially at the sediment-water interface, and to the determination of present accumulation rates using short-lived radionuclides.

Many studies were carried out in areas of the Adriatic which are different and interesting from several points of view. At this step the determination of accumulation rates and benthic fluxes was of crucial importance.

THE DIFFERENT AREAS

The Adriatic coastal system can be divided into several components where some processes show a particular relevance: input systems, marginal areas, coastal zones.

1) The fluvial mouths and tidal rivers are areas where many important processes occur. Research works include: a) input quantification; b) processes of transport and temporary or definitive deposition under different regimes; and c) effects of the mixing of fresh and salt waters on sorption-desorption phenomena, formation of hydroxides and redox reactions. The study of the main branches of the Po delta (Paltrinieri, 1984; Rosso, 1985; Barbanti *et al,* 1986; Boldrin *et al,* 1988; Barbanti, 1989) has the aim of reconstructing the behavior of particles and particle-solute interactions, starting from the section of Pontelagoscuro towards the sea (Figure 6, points 1 and 2).

   The quantitative knowledge of the phenomena at the mouth of minor rivers (Figure 6, points 3-7), streams, channels and port-canals can also make an important contribution to the understanding of the local impact of the pollutant load, and to the acquisition of a broad spectrum of data covering different energy conditions and physico-chemical situations. Several studies have been already undertaken both for scientific reasons and in response to questions from local governments (Corsi, 1980; Astorri, 1982; Barbanti, 1984).

2) The marginal basins (mainly natural lagoons) are the least dynamic environments and, if not largely modified by human activities, can be studied to obtain fine resolution of sediment records of pollution, effects of processes and long-term diagenetic changes. In many cases these environments are used for economic activities and can be badly damaged by distrophic events. All of them present various degrees of eutrophic conditions.

   The most important environment is the Venice Lagoon (Orio and Donazzolo, 1987). Relevant studies of nutrient fluxes at the sediment-water interface were made also in the Sacca di Scardovari (Viel *et al,* 1991), which has no significant input from the Po River and is used for fishing and shellfish breeding, and on the Sacca di Goro (Frascari *et al,* 1990a; Barbanti *et al,* 1991), whose morphology has been modified by anthropogenic activities and is subject to direct input from land - the Piallasse. The salt marshes connected with the port-canal of Ravenna were subject to intense discharges of heavy metals, mainly Hg (Miserocchi *et al,* 1990). The salt-ponds of Cervia were affected by dramatic abnormalities in the salt production, and recent studies contributed to the diagnosis of the causes and to the subsequent restoring interventions (Frascari *et al,* 1984).

3) The North Adriatic coastal area is greatly influenced by economic activities that take place at sea, along the coast or inland, with significant damage to the natural equilibrium. The areas of direct impact of minor river outflows (Figure 6, between the coast and line 12) are very important to understanding the processes of confination of materials in the prodelta areas, the transport of particles and solutes toward other areas and, ultimately, the mass balances for both natural and polluting materials.

   In this area particular problems of environmental management of the coastal zone were studied, such as the effect of artificial barriers. A significant worsening of the conditions of sea bottom (organic matter content, presence of pathogenous bacteria, etc.,) and waters within the protected areas were demonstrated (Correggiari *et al,* 1990).

4) The area most heavily affected by the Po (down to 10-25 m depth east and south of the delta, where direct deposition of particles occurs) and the remanent??remaining/remnant part where sediments receive an indirect supply (after resuspension and transport processes) of materials coming from the Po and other minor rivers is that shown in Figure 6, delimited by lines 12 and 13.

These different situations were the object of several studies of sedimentological and geochemical characterization for the evaluation of the role of sediments in the mass balance of nutrients in the coastal environment (Giordani and Angiolini, 1983; Guerzoni *et al,* 1984).

Some areas of the Northern Adriatic Sea were subject to direct discharge of wastes, as well as materials derived by dredging and drilling operations. The drilling operations were relatively intense south of the delta during the last 20-30 years, due to the presence of gas fields, and probably introduced pollutants (bentonite, baritine, chromium lignosulphonates, lignites and NaOH) in the coastal environment. A research study, sponsored by AGIP S.p.A, provided insight into the environmental impact and contributed information on the sedimentation pattern in the area. In fact, components of the wastes can be considered as tracers useful to following processes of transport and grain size selection. A research report (Frascari *et al,* 1989) was delivered to the sponsoring organization, and more information can be found therein as well as in Frascari *et al* (1990).

ACCUMULATION RATES

Obviously, the thickness of Holocene fine deposits allows the calculation of the average sedimentation rates over a period of several millennia but, in order to fully understand the present processes of sediment deposition, accumulation, and strata formation, it is necessary to also know the present and very recent sediment accumulation rates (in g/cm2/year) together with their areal and annual variability, and the role of mixing, bioturbation and resuspension to assess the reliability of the sediment record for chronological purposes and to calculate mixing rates whenever possible.

Some radionuclides, such as the natural PB-210 and the bomb and reactor produced Cs-137 can be used over time scales of decades to about one century. After the Chernobyl accident Cs-134 was also chosen as a stratigraphic marker. 239,240Pu is also extremely useful but its use is limited by the difficulty of analysis. 7Be and 234Th are used to quantify short time scale phenomena and rapid sedimentation.

The radionuclide distributions in the sedimentary column can only be due to sediment accumulation and, in this case, the calculation of the accumulation rate is not problematical. Yet Adriatic sediments can be influenced by short time-scale phenomena, such as environmental fluctuations, variations in river discharges and sediment supply, bioturbation, storms, tides and different hydrodynamic regimes and their effect on sediment accumulation is largely unknown and very difficult to assess. Our data (Frignani and Langone, 1991) seem to indicate that in most cases radionuclide activity-depth profiles are more influenced by episodes of mixing, erosion, and rapid sedimentation, rather than by more steady phenomena, such as bioturbation. Often the shape of the profiles is not very helpful in deciding whether or not the effect of bioturbation is significant. In order to bridge this gap, research is now being carried out with the collaboration of biologists to study the amount and activity of benthic fauna at research sites.

Frignani and Langone (1991) discussed the interpretation of excess 210Pb profiles in sediments around and south of the Po delta. To calculate accumulation rates several models were tested (the assumption was that the usual models are not completely met in the coastal environment) and comparison with 137Cs-derived rates were made. The results range between 0.2 and 1.8 g cm-2 yr-1, even if near the Po River delta higher rates are highly probable (Boldrin *et al,* 1988).

Other determinations on a large number of cores are in progress and these will eventually provide a complete description of present accumulation rates and mechanisms over the shelf from Trieste southward. The highest sedimentation rates and inventories are found in areas more influenced by the riverine discharges and the outlets of the Venice lagoon. A maximum value of 6.6 g cm-2 yr-1, was determined using both Chernobyl radionuclides (Baldi *et al*, 1990) and 7Be (Frignani *et al,* 1990), was found near the mouth of the Isonzo River.

One of the open problems is to determine the Kd, and consequently the diffusion coefficient, for cesium radioisotopes in Adriatic sediments. Assessing cesium mobility for diffusion is essential to the understanding of its value in chronology and accumulation rate determinations.

BENTHIC FLUXES

Many efforts were devoted to flux measurements. Benthic chambers and profiles of nutrients in pore waters were used to estimate exchange rates between water and sediments, to apply diagenetic models and to assess the factors controlling sediment contribution to the mass balance of these substances.

Even though the role of sediments in the development of eutrophic phenomena in this area has not been completely clarified yet, there is evidence that fluxes from sediments may significantly contribute to the balance of nutrients in the water mass. Diffusion could be the most probable and constant release mechanism of nutrients from the sediments in bottom anoxic conditions. Resuspension can episodically mobilize large amounts of nutrients from the superficial sediments, if the nutrient concentration in the water is low, but usully storms cause a reduction of the risk of algal blooms because of the effect of dilution of the eutrophic coastal waters.

Giordani and Hammond (1985) and Frignani *et al* (1986) presented data of benthic fluxes of nutrients from *in situ* and laboratory experiments carried out from 1979 to 1982. Fluxes measured in laboratory systems are mostly in the sediment-water direction. The data reported by Frignani *et al* (1986) emphazise the importance of sediments in the regeneration and remobilization of ammonia. Moreover, during an experiment with benthic chambers, it was possible to observe the sediment acting as a buffer for the increasing concentration of phosphate in bottom waters.

Fluxes of ammonia and phosphate from sediments to the overlying waters are much higher in marginal basins than in the sea (Barbanti *et al,* 1987; Frascari *et al,* 1990a; Barbanti *et al,* 1991).

In a recent paper, Giordani *et al* (1990) proposed a discussion of data from a number of stations located south of the Po delta. The fraction of productivity reaching the sea-floor is estimated to be approximately half of the 14C-measured productivity in surface waters, and benthic respiration and nutrient regeneration is sufficient to account for more than half of the oxygen decrease and nutrient increase observed in bottom waters when the system is stratified during the spring and summer. Budgets for biogenic debris reaching the sediment-water interface show that for the Northern Adriatic as a whole about 85% of the carbon, 60% of the phosphorous, 40% of the fixed nitrogen, and 85% of the silica are recycled into the water column.

A research group is now approaching the study of the role of benthic organisms in determining the fluxes at the sediment-water interface (Barbanti *et al,* 1990).

RESEARCH IMPROVEMENTS AND MULTIDISCIPLINARY APPROACHES

The need for a quantitative definition of processes and their connections lead to the proposition of a number of programmes characterized by their multidisciplinarity and by international co-operations.

Research on "Stratigraphic records and environmental changes in the Adriatic/Po basin system" is being carried out within the framework of the programme "The European Palaeoclimate and Man Since the Last Glaciation (EPC)" proposed by the European Science Foundation.

This research is based on the recognition of past environmental changes, both of natural and anthropogenic origin, and on the quantification of the effects that can be found in lake and marine sediments. The principle is that nature and man have already carried out many short- and long-term experiments and sediments can be one of the best archives in which we can find information on the results of these experiments. The main objective of the research is to achieve the maximum detail to study environmental changes over a time scale of millennia, but with resolutions of centuries, decades and years (Frignani and Oldfield, 1989; Oldfield *et al,* 1991).

The existence of a rapid accumulating, fine grained plume of sediments coming from the Po Valley system and from other minor rivers, provides an opportunuty to link changes in the catchments with alterations in the fluvial/estuarine system and with geochemical, sedimentological and biotic evolution of the Adriatic itself. All these changes should be found in the sediment column, where the conditions are favourable to the preservation of the record. Thus the present phase of the programme is the investigation of the detail of the record preserved in lake and marine sediments, using a number of standard stratigraphic, sedimentological and geochemical techniques. Mineral magnetic techniques (Oldfield et al., 1991) will be used for a rapid scanning of sediments so as to decide whether a fine resolution history of recent environmental changes can be obtained. Special attention will be payed to the achievement of a detailed chronology. All the results will be interpreted in the light of the available documentary history instrumental records, and evidence from proxy palaeoclimatic data.

Another programme, "Transfer pathways of iron and related elements in the Northern Adriatic Sea", was proposed by N. Price and has been financed by the EEC within the R&D project in the field of Marine Science and Technology (MAST). It is devoted to investigating the discharge of iron and associated elements from the Po River, and their fate in the marine environment. In particular, it is important to understand the behaviour of iron in the transition area between fresh and saline water, as well as the processes of precipitation and accumulation in sediments of the delta front, lagoons and areas to the south.

Other objectives are: the understanding of the pattern of sorption/desorption of heavy metals and iron between dissolved and particulate phases, as well as the establishment of the diagenetic pathways of iron with burial in sediments involving oxic, suboxic and anoxic substrates.

The research will involve studies of benthic respirometry, pore water trends, major and minor element geochemistry, organic carbon and nitrogen geochemistry, sediment mineralogy and magnetometry and 210Pb stratigraphy.

The analyses and the sampling scheme are designed to permit an appraisal of the seasonal behaviour of elements between dissolved and particulate phases, and the sorption/desorption processes on iron oxyhydroxide and organic matter, the latter being subject to change through productivity cycles.

One of the most important problems is to define the role of organic matter in sediments. The very low concentration of iodine (N. Price, personal communication) shows that the major fraction of organic matter in the sediments is of continental origin. This is also confirmed by other data (Faganelli *et al,* 1990) and means that most of the organic matter produced in the sea, for example by eutrophication, is easily regenerated in the water column and in the very surficial sediments.

Other programmes are intended to develop and test equipment used for *in situ* determinations. Measurements in the Adriatic environment are expected within the programme proposed by W. Helder and approved by the EEC in the STEP field of research: *"In situ* measurements of oxygen profiles in marine sediments and of sediment water fluxes of salutes" (P. Giordani, personal communication). The Adriatic Sea was chosen as a zone of interest because of its special characteristics (low energy environment with locally and temporally low concentrations of oxygen).

In the last two years, great efforts have been devoted to carrying out the "Project on suspended matter processes, patterns and transport under different hydrodynamic conditions in different shelf areas". The research is carried out in collaboration with the group of the US Geological Survey (Menlo Park, California) and with the Dipartmento di Biologia Animale (University of Modena).

The main objectives are: (i) to understand the main dynamic processes of sediment-water interaction. In fact it is important to know the amount per unit area and the thickness of sediment resuspended under different hydrodynamic conditions; (ii) to quantify particle fluxes and the ratio between particle deposition and accumulation; (iii) to quantify the role of resuspension for sediment-water interactions, with special consideration to the exchange of nutrients and heavy metals. In fact, during resuspension, these chemical species can be remobilized into the aquatic environment or scavenged from the waters and accumulated into sediments after particle settling; (iv) to understand the links between the various processes; (v) instrument calibration and testing the use of the Geoprobe technology on a muddy bottom; (vi) development of a logistic organization for the data aquisition over long periods of time. The final goal will be to calibrate ecological models for the marine coastal areas of the Adriatic Sea but the experiment was specially designed to quantify the effects of resuspension.

The point for the experiment (Figure 6) was chosen at 25 m depth in an area which is mainly influenced by materials delivered by the Po River and is outside the zone of early deposition. The research is organized on the basis of the use of the following equipment:

1) the Geoprobe was placed on the bottom, protected by a buoy field (Cacchione and Drake, 1979) which is a tripod especially designed to collect measurements of physical parameters near the sediment-water interface to study sediment resuspension under the effect of waves, tides and currents and the overall sediment and water dynamics in the area of deployment. These parameters are: a) current direction and velocity with electromagnetic current-meters at four levels within the first meter above the bottom; b) torbidity with Optical Back Scattering sensors (high frequency, four levels in one meter); c) turbidity with optical sensors 0ow frequency, 3 levels in two meters); d) pressure (height of the water column) with a quartz sensor (high frequency); f) temperature (two levels in the first meter). The instrument is completed by a photocamera and two current-meters are placed at different levels of the water column above the Geoprobe.

2) A buoy IDRONAUT with equipment for localisation, radio antenna and a vertically mobile CTD probe can collect measurements (temperature, pH, EH, DO, salinity, conductivity, density) at regular time intervals in the water column;

3) two sediment traps (Aquatic Monitoring Institute, Albuquerque, New Mexico) with a mechanism using teflon stoppers to mark the time intervals. The traps were placed at 2 and 10 meters above the bottom, the former to collect resuspended sediment (twoZay intervals) and the latter for settling particles (10-day intervals).

Systematic samplings were made for sedimentological, biological and chemical analyses. Analyses of surficial sediments and sediment cores were carried out in order to measure organic matter content, chemical composition of particles and interstitial waters, activity of radiotracers, and obtain the micro- and macro-biological characterization in terms of density, composition, and temporal variations of the benthic population and their effects on exchange processes. Some of these analyses have been completed on samples of bottom waters.

The first phase of this experiment lasted for ten months and the data processing stage is currently under way. These data must somehow be extrapolated to a larger area (Figure 6) by means of periodic sampling and a suitable set of analyses.

CONCLUSIONS AND PERSPECTIVES

The Northern Adriatic Sea is a natural laboratory for the study of processes of sedimentation and sediment-water interactions, as well as the distribution of pollutants and their impact on the environment. A good qualitative knowledge of the basic linkage between hydrodynamics and dispersal system have been obtained during the seventies and the early eighties.

Now the research is oriented towards the study of processes in a more quantitative way. Assessing the contribution of the Po River input to the overall functioning of the system is still one of the main problems. Furthermore, a number of sub-areas have been selected in order to clarify the processes acting at a local scale.

The studies of palaeoclimatic and palaeoenvironmental records in sediments are a field of research which shows good perspectives in Adriatic. Other present research is devoted to developing *in situ* technologies to measure physical and physico-chemical parameters as well as benthic fluxes. The project based on the use of the "Geoprobe" is probably the most important multi-disciplinary research being carried out to date.

We believe that the Adriatic Sea, especially the northern part directly or indirectly influenced by the Po River outflow, should be chosen at an international level for studies of environmental processes on the basis of a multidisciplinary research approach. A further development, however, will be the extension of the research to the whole Adriatic Sea and to its relationship with the Mediterranean.

Acknowledgments

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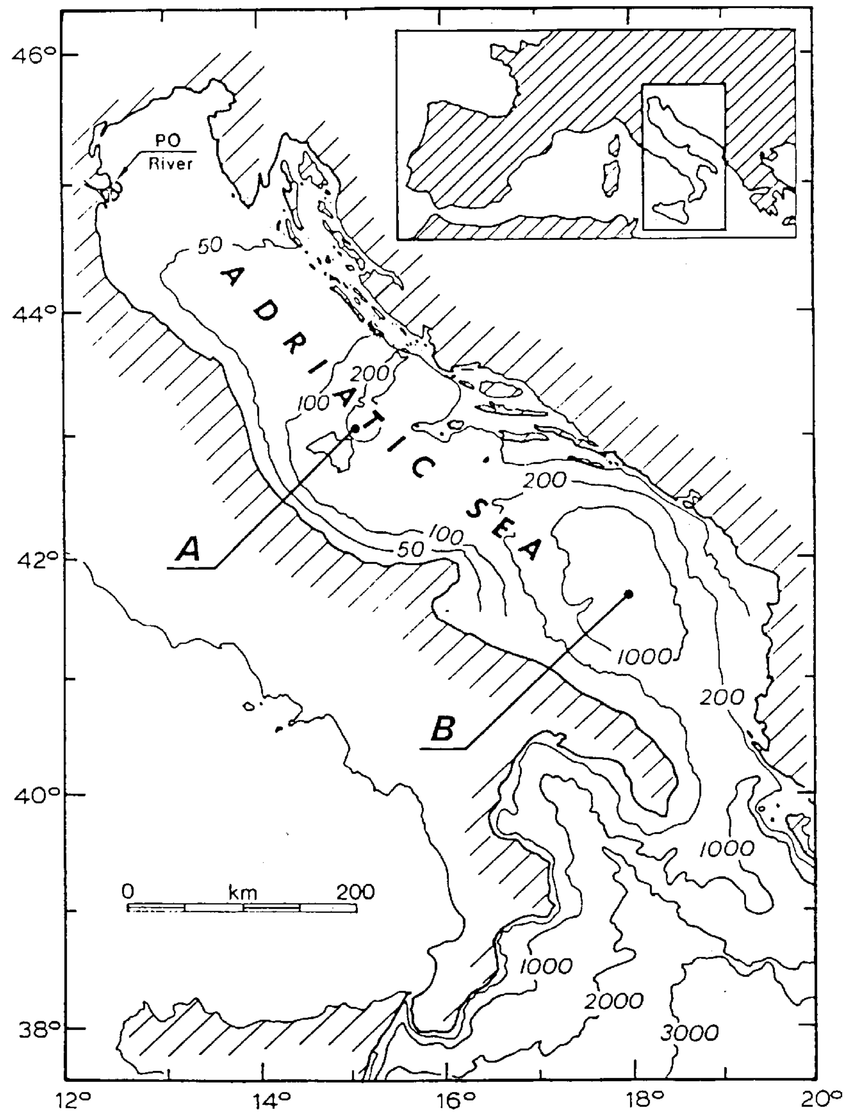

Fig. 1 - Map of the Adriatic Sea with depth contours and morphological thresholds.

[Fig. 1 B Map of the Adriatic Sea with depth contours and morphological thresholds.]

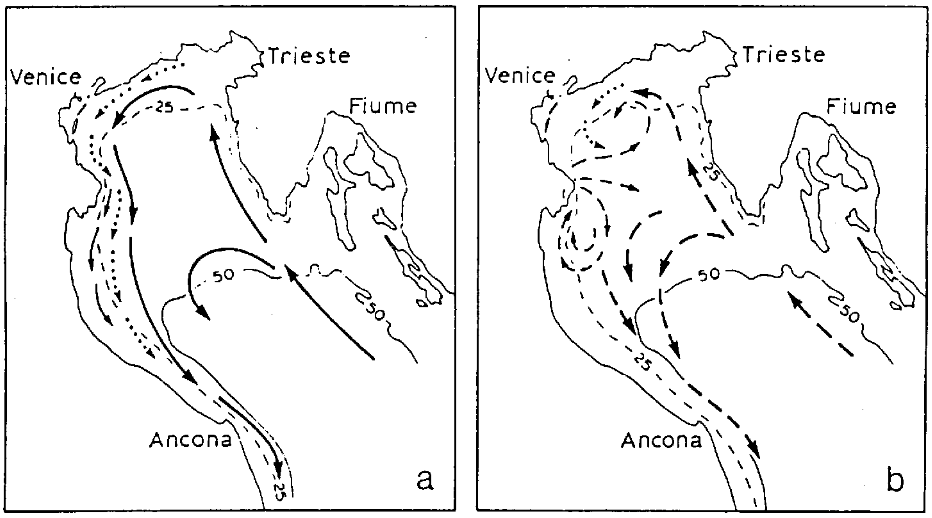

Fig. 2 - Winter (a) and summer (b) circulation of waters in the Northern Adriatic Sea. Thin and dashed lines represent the pathways of fluvial waters from the Italian coasts. Modified from Frascari et al. (1988).

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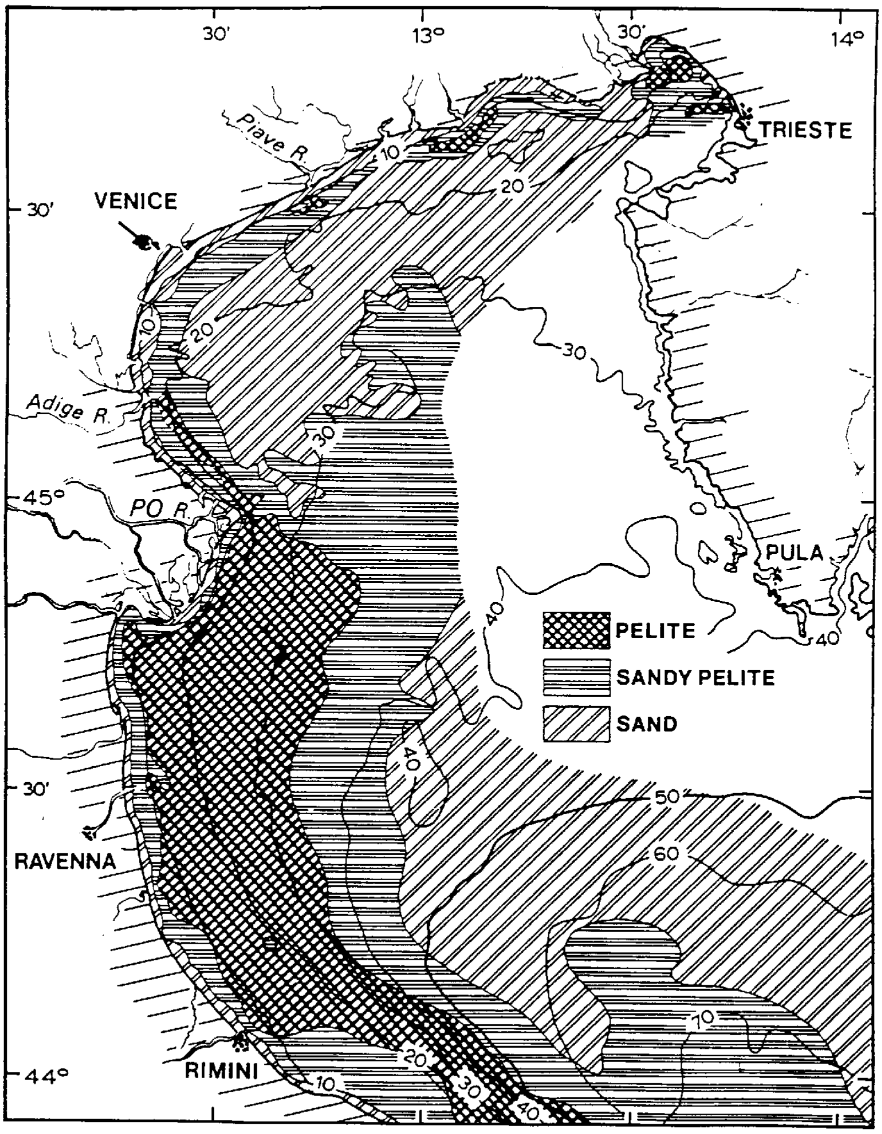

Fig. 4 - Grain size distribution of surficial sediments of the Northern Adriatic Sea. Pelite is the fine fraction (silt plus clay). After Brambati et al. (1984).

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Fig· 3 B Density fields (σ_t), schemes of circulation and behavior of the Po outflows in winter (a) and late summer (b) .After Franco (1984).

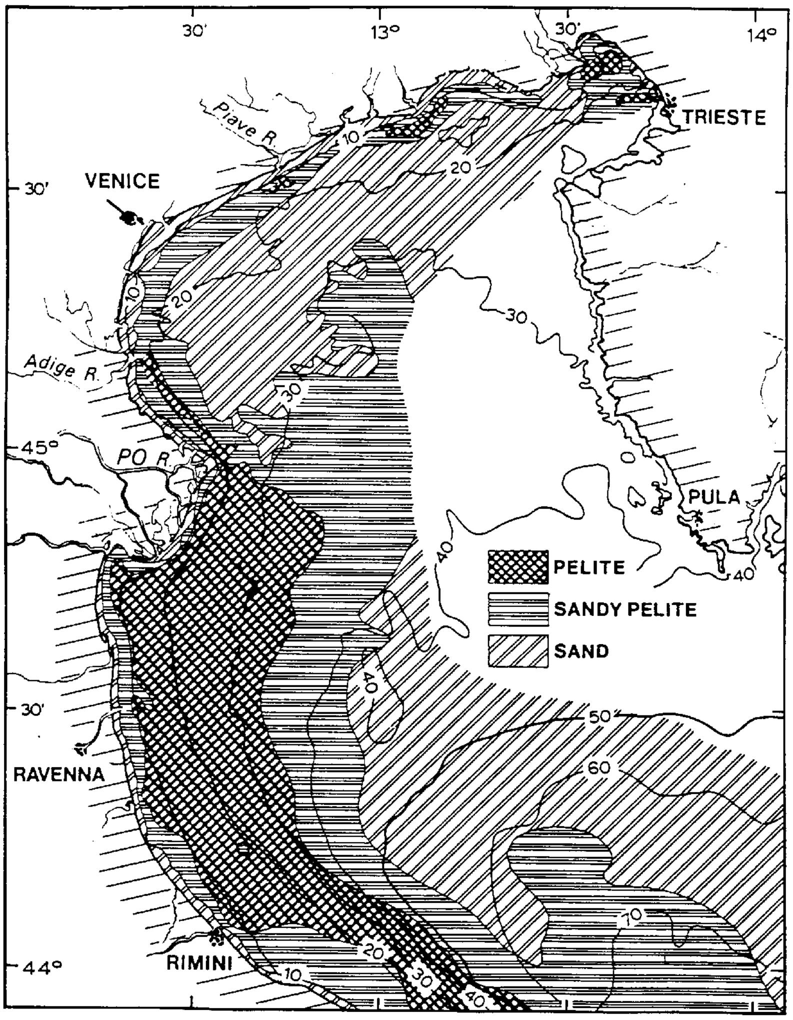

Fig. 4 - Grain size distribution of surficial sediments of the Northern Adriatic Sea. Pelite is the fine fraction (silt plus clay). After Brambati et al. (1984).

[Fig 4 ***B*** Grain size distribution of surficial sediments of the Northern Adriatic Sea. Pelite is the fine fraction (silt plus clay). After Brambati et al. (1984).]

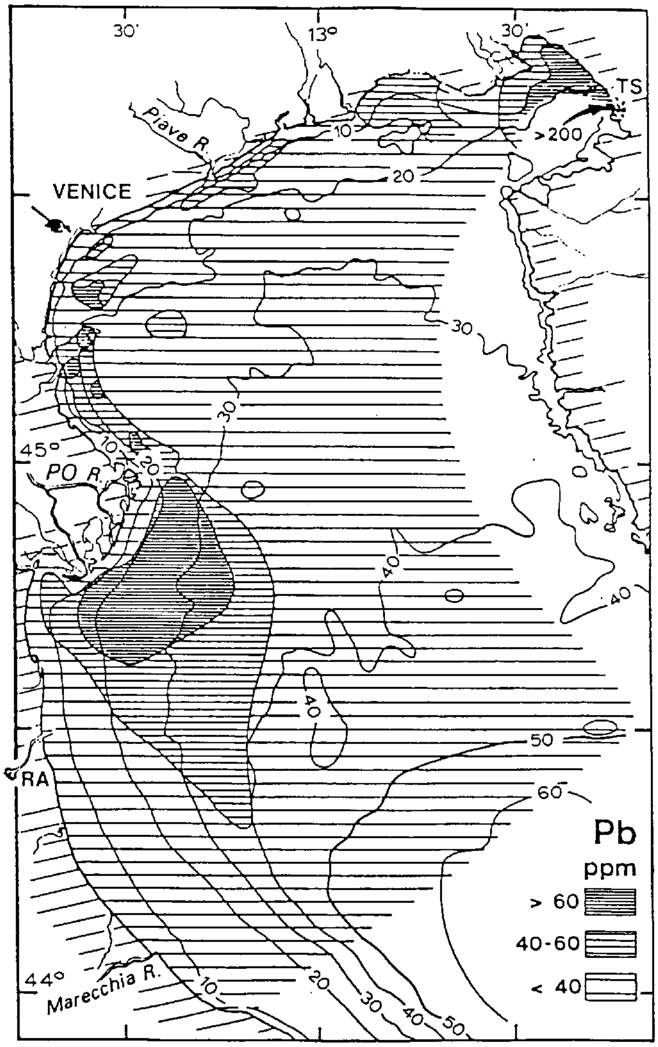

Fig. 5 - Lead distribution in surficial sediments of the Northern Adriatic Sea. After Frascari et al. (1988)

[Fig. 5 - Lead distribution in surficial sediments of the Northern Adriatic Sea. After Frascari et al. (1988)]

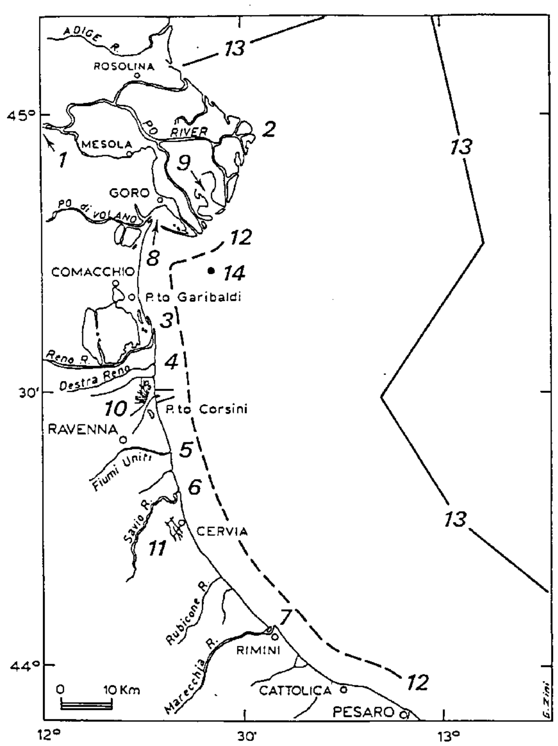

Fig. 6 - Map of study areas and sites. 1) closing section of the Po river near Pontelagoscuro; 2) Po della Pila outflow; 3) Reno River outflow; 4) Destra Reno Canal outflow; 5) Fiumi Uniti outflow; 6) Savio River outflow; 7) Marec-chia River outflow; 8) Sacca di Goro and Po di Volano outflow; 9) Sacca di Scardovari; 10) Piallasse of Raven-na; 11) Cervia salt-ponds; 12) line delimiting the area directly influenced by the minor rivers outputs where the effects of coastal engineering works were studied; 13) line delimiting the principal area for the study of the distribution of materials supplied mainlyby the Po River; 14) Location of the "Geoprobe" experimental site.

[Fig. 6 **B** Map of study areas and sites. 1) closing section of the Po river near Pontelagoscuro; 2) Po della Pila outflow; 3) Reno River outflow; 4) Destra Reno Canal outflow; 5) Fiumi Uniti outflow; 6) Savio River outflow; 7) Marec-chia River outflow; 8) Sacca di Goro and Po di Volano outflow; 9) Sacca di Scardovari; 10) Piallasse of Raven-na; 11) Cervia salt-ponds; 12) line delimiting the area directly influenced by the minor rivers outputs where the effects of coastal engineering works were studied; 13) line delimiting the principal area for the study of the distribution of materials supplied mainlyby the Po River; 14) Location of the "Geoprobe" experimental site.]

STUDY OF THE COASTAL OCEANOGRAPHY AND MANAGEMENT OF THE COASTAL ZONE OF CYPRUS

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The island of Cyprus lies in the northeastern corner of the Mediterranean Sea and covers an area of 9,251 sq.km. The island is broadly divisible into three tectonostratigraphic terrains: Troodos, Kyrenia or Pentadakylos and Mamonia.

The Troodos terrain comprises the Late Cretaceous Troodos ophiolite and its *in situ* Late Cretaceous - Recent sedimentary cover. The Troodos ophiolite is one of the best preserved and most thoroughly studied ophiolite complexes in the world. The ophiolite exhibits a domical uplift that exposes a central core of harzburgite tectonite and serpentinite diapir, stratigraphically overlain successively by an ultramafic-mafic plutonic complex, an extensive sheeted dyke complex, extrusive volcanic rocks (pillow lavas) and metalliferous sediments.

The Cenomanian-Maestrichtian metalliferous sediments are overlain by bentonitic clays which, in turn, pass upwards into a sequence of calcareous pelagic sediments consisting of marls, chalks, cherts and limestones. Towards the top of the sequence there are extensive deposits of Messinian evaporites which in turn are overlain by clastic dominated sediments, marls, biocalcarenites and sands.

The Kyrenia or Pentadaktylos terrain which comprises the Kyrenia Range, is a structurally complex assemblage of Late Palaeozoic to Recent sedimentary and minor igneous and metamorphic rocks in the north of the island. The assemblage is underlain by a sequence of Triasic to Jurassic limestones and dolomites and a series of the pelagic chalks of Maestrichtian age with interstratified flows of dolerite, basalt, trachy-basalt, trachyandesite, dacite and rhyolitic tuffs. They pass upwards into chalky limestones and cherts of Palaeocene to Middle Eocene age. This is succeeded by a thick sequence of microbreccia and other clastic deposits, as well as olistoliths of Mesozoic limestones.

The Kyrenia Range was placed in its present position in Oligocene time and thick flysch deposits of Miocene age were then laid down on both flanks. The range was uplifted in Upper Miocene and an intense erosion started. In Plio-Pleistocene periods, we have depositions of marls, calcarenites, gravels and sands on both flanks of the range.

The Mamonia terrain comprises the Mamonia Complex and lies on the southwestern flank of the Troodos ophiolite and is an allochthonous, highly deformed sequence of Triassic to Cretaceous age. It contains a sedimentary group consisting of quartz sandstones and siliceous sediments, an igneous-sedimentary group of alkaline extrustive and instrusive rocks, reef limestones and hemipelagic sediments; a metamorphic group with serpentinite sheets and slivers of amphibolite; and an olistostrome melange composed of rocks of the Mamonia Complex itself which originated as a series of submarine debris flows.

It is generally accepted that the Mamonia Complex represents a subduction melange emplaced on to Troodos ophiolite during Maestrichtian time.

SOUTHERN COASTAL ZONE

The southern coastal zone of Cyprus consists of calcarenites, sands, gravels and silts of Pleistocene to Recent age. Although the geology of the continental margin of Cyprus is not well known, limited seismostratigraphic studies on the central part of the south Cyprus continental margin, showed that on bathymetrical grounds, it can be divided into two parts: a narrow, shallow, inner portion, about six kilometres wide which slopes gently seawards known as shelf and a wider, irregular outer area known as slope. The slope exhibits a prominent ridge known as Hecateous Ridge or Akrotiri High.

The geology of the shelf is analogous to the onshore geology, and seismic data seem to correlate confidently the seismic basement to the Palaeogene – Lower Neogene series comprising of bedded chalk, chert marl and turbidites which have a southward dip of 10· to 20· and are overlain uncomforably by Pliocene marls and calcarenites. The surface of this sedimentary sequence has a gentle dip to the south and exhibits small highs and lows as well as flattish areas analogous to the wave cut terraces encountered along the southern coast of the island.

The Pliocene/Miocene basement is covered, over most of the area investigated so far, by a mantle of Recent Sediments which comprise of clastic material (slit-sand and gravel) as well as occurrences of normally consolidated soft cohesive sediments, the latter being more limited in extent. It is believed that these sediments represent the sediment transport of the recent rivers that have been eroding the topography since Pleistocene times. Where offshore seismic work was carried out, it showed that these sediments do not correspond to the present river estuaries and this is attributed to the fact that longshore currents have reworked and transported eastwards the loose sediments.

Our knowledge as to the distribution and extent of these sediments in the shallow shelf area of the southern coast is still limited to small areas where seismic work was carried out and large numbers of unknowns still characterize our knowledge.

The present coast outline and nearshore geomorphology is variably characterized by rocky cliffs, extensive sandy or shingle beaches and small coves. Areas of erosion are accompanied by areas of entrapment depending on the sea shore and the geomorphology of the nearshore. Major areas of entrapment and seaward extension are Akrotiri and Larnaca Salt Lakes.

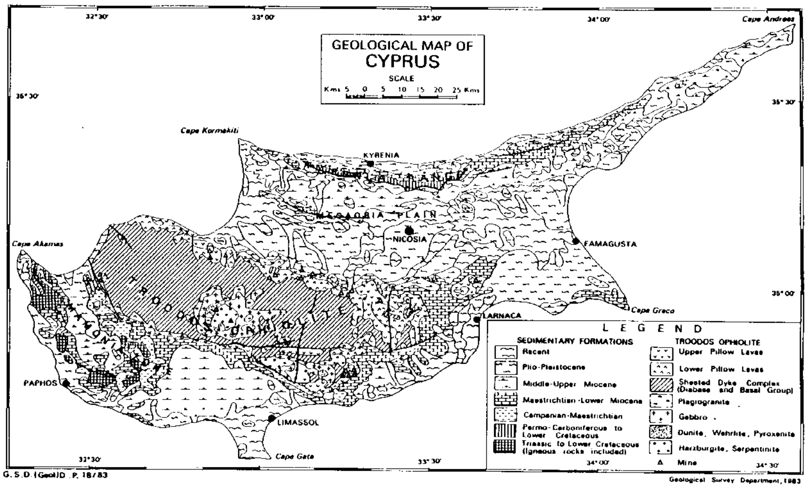
In Cyprus, as in all the Mediterranean countries, touristic development is mainly confined to the coastal zone. More than 80% of the hotels, hotel apartments and touristic villages which can accommodate up to 1.5 million tourists per annum have been constructed along the southern coast of the island.

Until ten years ago our beaches were harrassed by extraction operations of aggregates (natural sand and gravel) for concrete and in some areas damage from such operations is very serious. The construction of the many beach hotels mentioned above brought into focus the need for sandy beaches. The entrepreneurs tried to achieve this by construction wave breakers (either parallel or perpendicular to the shoreline) along the coast in order to induce sand entrapment and enhance the beach. This method of beach enhancement has been adopted by the Public Works Department for certain tourist areas. So far, it seems that the primary aim has been achieved and sand beaches have been developed in front of coastal hotels and tourist villages. However, it has been observed that the erosion rate of the coast line has increased in neighbouring coastal sections leading to the need for construction of additional wave breakers.

Unfortunately, to date, the problem is faced circumstantially and sectorally, and no proper in-depth study of the problem of coastal erosion and development has been undertaken. It is believed that such a serious study would provide the data for the establishment of an overall balanced, coastal management policy.

It is believed that coastal erosion is being further aggravated as a result of the interception of all major sources of sand supply from the land, i.e., the rivers. The Government of Cyprus, in order to solve the acute problem of the shortage of freshwater, has constructed dams on every major river of the island, at the same time depriving clastic material supply to shore processes.

One concrete step towards solving the coastal erosion problem is the recent decision taken by the Government to stop extraction of any material from the coastal zone. What remains now, is to launch a detailed study of the coastal oceanography and management of the coastal zone of Cyprus starting from the southern coast.


GEOLOGICAL MAP OF
CYPRUS
SCALE
Kms 5 0 5 10 15 20 25 Kms
Cape Andreas
Cape Kormakiti
KYRENIA
MESAORIA PLAIN
NICOSIA
FAMAGUSTA
Cape Akamas
Cape Greco
LARNACA
PAPHOS
LIMASSOL
Cape Gata
L E G E N D
SEDIMENTARY FORMATIONS
Recent
Plio-Pleistocene
Middle-Upper Miocene
Maestrichtian-Lower Miocene
Campanian-Maestrichtian
Permo-Carboniferous to Lower Cretaceous
Triassic to Lower Cretaceous (Igneous rocks included)
TROODOS OPHIOLITE
Upper Pillow Lavas
Lower Pillow Lavas
Sheeted Dyke Complex (Diabase and Basal Group)
Plagiogranite
Gabbro
Dunite, Wehrlite, Pyroxenite
Harzburgite, Serpentinite
Mine
G.S.D. (Geol)D. P. 18/83
Geological Survey Department, 1983

DYNAMIQUE DE L'ECOSYSTEME COTIER

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L'espace côtier étant hétérogène son étude et le problème de sa gestion doivent être abordés à plusieurs échelles d'espace et de temps. Plusieurs ensembles peuvent être distingués, globalement définis par la balance production-apport de matière et hydrodynamisme.

L'ESPACE LITTORAL

Le fonctionnement du domaine littoral dépend en premier lieu de la nature et de la quantité des apports continentaux; si l'apport est localisé (débouché de fleuve, rivière côtière, emissaire artificiel) et relativement constant, un prodelta est créé qui représente l'unité littorale de base, véritable écosystème dont la dimension est fonction du flux massique. Par exemple, le prodelta de l'Aude, rivière languedocienne de faible débit, est d'environ 10 km‘.

Cet écosystème est facilement repérable en Méditerranée, car il est marqué par un évasement à des bathymétries faibles (autour de 25 m), où se produisent normalement de forts phénomènes de turbulence. Pour expliquer sa présence, on a fait appel à des mécanismes de floculation et d'interactions organo-minérales, puisque l'apport de sels nutritifs induit également une production biologique qui interagit avec la matière minérale (Monaco, 1975; Aloisi *et al* 1975; Aloisi *et al* 1979, 1982). L'autre phénomène est l'existence d'un front dynamique entre le jet fluviatile et la masse d'eau marine.

Cette origine rend compte des caractères essentiels de cette unité littorale que l'on retrouve aussi bien en domaine marin ouvert qu'en milieu lagunaire. L'accumulation rapide de produits fins argilo-colloidaux entraine la concentration de nombreux éléments naturels et artificiels: carbone organique, métaux lourds, radionucléides, hydrocarbures, pesticides ... De ce fait, cette unité devient le critère le plus sûr pour reconnaiître l'état de santé du milieu littoral.

Compte tenu de sa situation et dans les conditions d'agitation créées par les courants littoraux, de houle ou la turbulence due au vent, cette unité est instable; un suivi effectué dans un prodelta de rivière côtière, a montré qu'à l'échelle annuelle, le dépôt réalisé à la suite d'une période de crue peut être entièrement remobilisé (Courp, 1989). La fonction de cette unité est, donc, d'être à la fois source et puits de matière.

L'environnement littoral n'est donc pas un ensemble homogène et continu, mais une succession de petites unités fondamentales, de dimension variable et de fonctionnement diversifié selon le caractère du bassin versant en amont, et en aval, la dynamique du milieu récepteur. Toute Etude environnementale doit se faire à l'échelle de ce système intégré et en respectant l'échelle temporelle des phénomènes.

LE PLATEAU CONTINENTAL

Le fonctionnement du domaine côtier plus hauturier dépend encore de la production et de l'apport de matière et des mécanismes turbulents susceptibles de la mobiliser. Mais ce domaine est fortement soumis à la circulation générale qui détermine les conditions aux limites du système côtier. A l'échelle plus petite, les modalités de circulation sont influencées par la largeur du plateau, l'orientation des côtes, la direction principale du forçage dolien, la topographie.

Le Golfe du Lion qui fait l'objet de nombreuses études est, à ce titre, exemplaire. Le circuit liguro-catalan longe la plateforme continentale d'Est en Ouest; une branche pénètre sur la partie orientale et une boucle anticyclonique se forme dans la partie occidentale du Golfe (Millot, 1990).

En conséquence, deux ecosystèmes sont nettement distingués: un secteur Est où le front entre les eaux du large et les eaux côtières contribue à bloquer les apports dans le domaine du plateau, au large de l'embouchure du Rhône et un secteur Ouest, au large du Roussillon où la matière est exportée vers le bassin.

La conséquence, au niveau du comportement des particules fines, principaux vecteurs des produits naturels et anthropiques, est: une accumulation dans la partie Est, et une distribution du carbone organique, des métaux, des radionucléides orientée vers l'Ouest, dans le sens de la circulation générale. Le 137 Cs de Marcoule, qui sert de traceur à cette dynamique, permet d'évaluer la masse sédimentaire piègée dans cet environnement à environ 5. 10' T (Calmet et Fernandez, 1990; Fernandez *et al* 1991). Au contraire dans la partie Ouest du Golfe, un flux exporté d'environ 7. 10' T/an, a été calculé (Heussner et Monaco, en cours).

Ces processus ayant été pratiquement identiques depuis quelques 10 000 ans, c'est-à-dire depuis le rétablissement des conditions de circulation dans le détroit de Gibraltar, les constructions holocènes obeissent à ces mécanismes hydrosédimentaires et marquent l'évolution de l'environnement à cette échelle temporelle. Une autre preuve de l'incidence de la circulation sur l'environnement du plateau continental est fournie par l'existence connue, en limite de plateforme, de sables reliques d'environ 15 000 ans qui temoignent d'un non-dépôt voire d'une érosion depuis cette période, donc d'un bilan négatif. Cette bande pratiquement continue et localisée vers 80 à 100 m de profondeur, forme un ecosysème particulier sur toutes les marges.

Il devient évident que le plateau continental doit être étudié, contrairement au domaine littoral, à méso-échelle, c'est-à-dire à l'échelle des phénomènes de la circulation géostrophique; c'est l'objectif du Programme National d'Océanographie Côtière qui vient de débuter, avec un chantier méditerranéen qui est le Golfe du Lion.

Ces mécanismes ne sont pas spécifiques à la Méditerranée, même si, ici, ils sont, peut-être plus clairs. L'équivalent atlantique des accumulations fines de plateforme sont les vasières circalittorales; les conditions de haute energie expliquent le développement des sédiments meubles sur les plateformes des mers à marée.

L'ESPACE MEDITERRANEEN

Tous les espaces côtiers obeissent à cette double influence de la quantité des apports et de la circulation, mais à une échelle plus grande qui est celle de l'ensemble de la Méditerranée, on peut distinguer deux environnements. Le bassin nord-méditerranéen qui à travers les ensembles lituro-catalan, adriatique et égéen reçoit la majorité des apports continentaux de Méditerranée; il constitue, de ce fait, le secteur de la plus forte fertilisation mais aussi de la plus forte anthropisation.

Le climat, la masse et le rythme des apports, la circulation distinguent l'espace côtier sud-méditerranéen, également moins industrialisé.

Les recherches sur l'environnement doivent tenir compte de ce constat et s'adapter, dans chaque zone, aux diverses échelles spatio-temporelles des phénomènes. Pour cela, une stratégie de suivis et d'observatoires doit être mise en oeuvre qui s'appuie et valide la modélisation hydrodynamique. Par ailleurs, on doit tendre à quantifier les phénomènes pour parvenir, région par région, à un bilan plus global faisant définitivement de la Méditerranée un laboratoire s'inscrivant dans les problématiques scientifiques mondiales.

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