Sedimentological features of asbestos cement fragments in coastal environments (Taranto, southern Italy)

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Abstract

Asbestos cement materials (ACMs) are widespread in coastal environments as result of illegal dumping activities. The study area is located in the northern sector of the Ionian Sea (northern Mediterranean Sea), in the Mar Grande basin (Taranto city). This study shows the complex dynamics of building materials containing a high amount of ACM discharged into the sea and subject to erosion, transport and deposition in an overcrowded beach (Marechiaro bay). The interdisciplinary research (sedimentology, stratigraphy, geomorphology, mineralogy) allows defining the temporal dumping succession and erosion phases, the diffusion of ACM in coastal environments, the mineralogical characteristics and physical status of the ACCMs. Our results show that from 1992 (the year of the Italian law ban for asbestos materials) to 2000 a significant increment of dumping operations occurs. At the present day, the cliff formed by dumping debris has been subject to erosion developing a new beach composed of man-made sediments.

Keywords: sandy beaches, pollution sediments, asbestos

1. INTRODUCTION

Coastal zones are important naturalistic areas with a significant social and economic value. Although their remarkable role, shelf and beach environments are the final delivery sink of various harmfulness materials produced in continental areas and transported by different agents (rivers, wind, acquifers, etc., Ambrose et al., 2019). In particular, heavy metals coming from industrial activities (Al-Shuely, 2009; Ramasamy, 2022), various PCBs pollutants (Tolosa et al., 1995; Ragab et al., 2016; El Nemr, 2016), and plastic materials (Reynold et al., 2020 and references therein), often containing PCBs (the beach plastic pellets - Karlsson et al., 2021), are mostly ubiquitous in coastal areas. These pollutants are imported into coastal environments through ordinary activities (industrial, mining, urban, touristic, fishing or mariculture activities) or by episodic incidents (e.g. the accidental oil spills from the sinking of oil tankers) representing a hazardous threat for marine ecosystems and human health (*see* a complete and recent review in Fuller et al., 2022). A further dangerous issue is the illegal/uncontrolled direct dumping of large volumes of pollutants which often form actual coastal landfills (Nicholls et al., 2021). They are often the legacy of historical and recent fluid or solid waste disposal activities, on which the action of waves, tides, currents and global sea-level rise induces erosional processes and a continuous dispersal of pollutants in shallow marine and beach environments (Goodman et al., 2020).

The presence of coastal landfills with historical or recent construction and demolition wastes is globally widespread, but it is generally considered less dangerous despite they are constitutes of debris coming from buildings, roads, railways, bridges, etc. (Osmani and Villoria-Sáez, 2019) and thus made up of glass, wood and steel, mortar, concrete, bricks and excavated soil (Noor et al., 2020). Conversely, the construction and demolition wastes contain a variable quantity of Asbestos Cement Materials (ACMs) deriving from corrugated roofing, slabs, pipes, tanks, flues, fire retardant coating, vinyl-asbestos floors, sound-absorbing panels, cement screeds and grouts (Obmiński, 2020). During the 20th century, Italy has been the first asbestos producer and one of the most important consumers in Europe (Virta, 2006). The Balangero quarry (Piedmont Region) active from 1917 to 1985 (Mirabelli et al., 2008), has been the largest European Chrysotile quarry. Eternit and other companies have built large industrial plants for the production of AC artifacts from the beginning of the twentieth century (1907 in Casale Monferrato - Piedmont Region), Broni (Lombardy Region) and Bari (Apulia Region) during the 30's until the end of the 80's. It has been calculated that about 75% of the ACMs in Italy has not been removed or reclaimed. The rate at which such operations take place is about 1% per year. Therefore, it is easy to predict that in 2100 not all asbestos present in Italy will have been reclaimed (Marsili et al., 2017).

The ACMs containing asbestos are considered highly dangerous for the public health such that the mineral has been banned in many Western Countries (while it is still used or produced in Russia, China, India, Brasil – *see* a complete list at http://www.ibasecretariat.org/). However, the ACMs have been often subject to illegal or improper dumping caused by a complex and expensive disposal procedure (Paglietti et al., 2016; Liu et al., 2017) especially in countries affected by the prohibition. Frequently, the presence of dangerous fragments is globally reported along beaches by media and local authority alert announcements and many coastal areas (mainly in England, United States, Australia and northern Mediterranean Countries, *see* http://www.mesothelioma.com) have been under seizure or reclaimed.

Although it seems a widespread environmental issue, there is an unexpectedly poor scientific literature on this topic. There are only few papers on reclamation procedures for coastal landfills containing ACMs (e.g. the capping methodologies suggested by Tomasicchio et al., 2010), but the erosion/transport/deposition dynamics of these materials along cliffs, beaches and shallow marine environments have never been analyzed.

In order to increase the knowledge about the ACMs pollution in marine environments, we apply an interdisciplinary (geomorphological, sedimentological, mineralogical) approach to analyze a coastal sector located along the northern Ionian Sea (Mar Grande, Taranto, Southern Italy) where a large amount of construction and demolition wastes has been directly dumped into the sea. Consequently, the marine erosional processes have induced the formation of a steep cliff and the action of waves and littoral drift have contributed to disperse these materials.

For this reason, the aims of this paper are: - recognizing the geometry of the sedimentary bodies made up of construction and demolition wastes along the present-day cliff; - dating different dumping actions; - describing the erosional processes along the cliff; - recognizing the presence of ACMs and describing them in terms of quantity, quality and physical state; - mapping the presence of ACMs fragments in the beaches adjacent to the cliff; - showing the lateral variations of these fragments with the long-shore transport; - evaluating the reliable risk for the public health related with the presence of ACMs on beaches and proximal marine environments.

2. STUDY AREA

The city of Taranto is known as "the City of the Two Seas" as it is located on the Ionian Sea between the Mar Piccolo and Mar Grande marine basins (Fig. 1). The Taranto coastal area is one of the most polluted sectors of the European Union. The industrial center (Fig. 1) is responsible for the production of about 92% of the Italian dioxin (9% of the whole European dioxin). The results of epidemiological studies conducted on the Taranto population show a dramatic mortality excess and an abnormal increase in congenital malformations in children (Zona et al., 2019). For these reasons, the Taranto area has been included in the list of Sites of National Interest (SIN - Law 426/1998 and Ministerial Decree of 10/01/2000). The SIN occupies a total area of 115 km^2 which includes the marine-coastal areas of the Mar Grande and Mar Piccolo basins (with a total extension of the sea surface of 73.1

km^2, of which 51.1 km^2 in the Mar Grande basin and 22 km^2 in the Mar Piccolo basin). Indeed, the Taranto seas (Mar Grande and Mar Piccolo basins) are deeply impacted by the presence of the largest steel industry in Europe (ex-Ilva), an ENI oil refinery, fishery facilities, and an Italian Navy port (Caroppo et al., 2012). The pollution is mainly concentrated in marine sediments as final repository of litters with different origin and transport agents. The analysis of these polluted sediments shows a high content of organotin compounds (Massari et al., 2021) and heavy metal as Cd, Cu, Hg, Pb, Sn, Zn, etc. (Cotecchia et al, 2021; Rizzo et al., 2022) beyond the limits of the National laws. Moreover, illegal dumping operations occur along the coastal areas: recently, more than 150 cars and 500 tons of other large-scale marine litters (tyres, motorcycles, drums with materials of unknown composition, washing machines, televisions, bathroom furniture, etc.) have been removed from the Mar Piccolo basin.

The Apulia beaches develop on the Adriatic and Ionian Seas and are generally made up of mixed sands which include: siliciclastics, carbonate lithoclasts and bioclastic sands (Moretti et al., 2016; van Loon et al., 2017; Lapietra et al., 2022). However, Ionian beach sands are typically bioclastic with a lesser percentage of carbonate rock fragments coming from the erosion of limestone or calcarenite promontories (Milli et al., 2017; Lapietra et al., 2022).

The San Vito promontory (Fig. 1) is located between the Mar Grande basin and the Ionian Sea. It represents the closest and traditional marine area for bathing activities as it is located far away from the Industrial center and the Taranto urban center. In particular, Marechiaro bay (literally, “clear sea”) develops along the northern sector of San Vito area and it is part of numerous pocket beaches that characterize the promontory (Fig. 1). The beach is comprised between two rocky headlands made up of Quaternary carbonates (MIS 5 calcarenite deposits – Lisco et al., 2016; Valenzano et al., 2018) that have been later used to place two submerged piers (a large submerged pier to the East and a smaller emerged one). The Mar Grande basin coastal currents are conditioned by the morphology of the sea-bottom and by diffraction processes (De Serio and Mossa, 2015) which induces a counterclockwise circulation (Gaeta et al., 2016), and the local East-directed littoral transport in the northern se in the northern sectors of the San Vito promontory.

Marechiaro bay shows various physical elements and an unexpected biodiversity. The offshore transition sectors are covered by a large and dense *Posidonia oceanica* prairie (seagrass – Fig. 1C) which hosts many different benthic taxa (Rissoidea molluscs; among the foraminifera: *Rosalina globularis* and *Cibicides lobatulus*) and last individuals of *Pinna nobilis*, recently subjected to mass mortality processes in the Mediterranean Sea (Tiscar et al., 2022 and references therein). The small dunes (Fig. 1C) are covered by robust and stable graminaceous herbs. In the retro-dune sector, a shallow lagoon (Fig. 1C) with abundant reeds and aquatic plants (and a population of migratory birds) occurs. A narrow fluvial incision N-S oriented has been obliterated by agricultural activities. It conserves the geological and biological characteristics of the so-called “Lame” which are the typical Apulian fluvial incisions with sub-vertical flanks and flat bottom (Pieri, 1980).

3. MATERIALS AND METHODS

Preliminarily, a rough description of the study area has been carried out through geomorphological and sedimentological classic surveys along the cliff and the backshore-foreshore sectors. A scuba diving survey has been conducted in the submerged area of the beach, from the shoreface to the offshore transition (5-6 m of water depth).

A detailed description of the stratigraphic succession made up of dumping materials cropping out along the cliff, has been carried out in three different points (1, 2 and 3 – Fig. 2), a few tens of meters away from each other. Remains of commercial products have been collected to date the single dumping stratigraphic units. Five sampling sectors with a 4 m^2 area (points 4-8 in Fig. 2) have been selected along the backshore (eastern sector of the study area), at the same distance from the coastline (about 2 m). The ACM fragments contained in the unit areas were photographed on site by using a white background and a graphic scale (80 ACM fragments with a minimum diameter of 0.02 m). High-resolution photos were selected to perform the morphometric analyses through Image J© software. In particular, four morphometric parameters were calculated: - the Circularity which describes the similarity of the particle shape with a circle; the Aspect Ratio which defines the ratio between the particle length and its width; - the Roundness which highlights the difference between angular (breccia) or rounded (gravel) particles; the Solidity which describes the ratio between the area and the outline convex hull. The 2D analysis of the large fragments of AC is justified by their flat morphology: the measured thickness of the AC fragments can be considered negligible compared to the other two dimensions.

A total of five ACM fragment samples was collected on the cliff (1 in Fig. 2), at the base of the cliff (2 in Fig. 2) and in the backshore areas (4, 6 and 8 in Fig. 2) for the x-ray and SEM analysis. ACM Powder X-ray diffraction analysis (XRPD) was carried out with a Philips X'Pert Pro powder X-Ray diffractometer, employing as working conditions: Cu Ka radiation filtered by means of a curved graphite monochromator; 40 kV and 40 mA of power supply; divergence slit=1°; anti-scatter slit=0.5°; receiving slit=0.2 mm; scan speed of 0.5° (2θ) per minute. The ACM samples, covered 30 nm graphite layer, were subjected to Scanning Electron Microscopy observations (SEM-EDS) (microscope EVO-50XVP LEO); microanalyses were achieved with an X-max (80 mm^2) Silicon drift Oxford detector supplied with a Super Atmosphere ThinWindow©. Petrographic analyses on sands were avoided due to the high risk of fibers dispersion during sampling, grain-size analysis and microscope observations. Moreover, remote sensing techniques were employed in order to evaluate the geomorphological changes of Marechiaro bay over the past fifty years. The landscape analysis of this coastal area was carried out with classical stereoscope techniques on aerial photos (IGM 1954, 1972 and 1978) and manually tracing the geomorphological elements. A comparison between aerial photos (IGM 1978) and present-day satellite images (Google Earth 2022) was also performed to preliminarily recognize the anthropic dumping activities and to evaluate the approximate volume of the relative deposits. Furthermore, an analysis of the erosional and depositional dynamics of the coastal sector was investigated through satellite images (GoogleEarth from 2002 to 2020).

4. RESULTS

4.1 The cliff of Marechiaro bay

The cliff of Marechiaro bay extends for about 500 m in length (Fig. 1C and 2) and it has a sub-vertical shape (Fig. 3). It reaches a maximum of 3 m height in its central sector (Fig. 3A). The carbonate rocky substrate shows an irregular top which locally crops out at the sea level. A laterally continuous sedimentary body made up of the debris occurs at the base of the cliff (OS in Fig. 3B). Debris deposits show a regularly sloped upper surface which extends from the cliff to the foreshore (OS in Fig. 3B); this regular top is frequently reworked by the wave action. The cliff seems to be unstable and recent slide deposits (RS in Fig. 3B) occur on top of the older debris bodies. The instability is induced by storm wave events which are recorded by the accumulation of abundant plant remains and rhizomes coming from the seagrass area, mollusk fragments and plastic materials at the cliff base.

The cliff and debris deposits are composed of man-made materials, mostly coming from demolition work activities (Figs. 3A and B).

4.1.1. Stratigraphy of the cliff

The man-made materials are clearly visible along the cliff, but their stratigraphy is complex. The thickness varies from 0.2 m to 2 m along the western sector of the cliff. In some places (e.g. Fig. 4A – point 3 in Fig. 2), these deposits are characterized by a massive structure rather than a geometric organization in beds or sedimentary units. Moreover, a single 1.5 m thick bed laying on coarser sediments occurs. A thick rope crosses the whole deposit cropping out at different stratigraphic height (Fig. 4A).

In the eastern part of the cliff, the thickness can reach 2-3 m and the clasts of man-made materials are organized in single beds, often showing a lenticular geometry (Fig. 4B). The contact between different sedimentary units is sharp, erosional and shows a pseudo-channelized geometry. The lenticular beds have a low lateral continuity, suddenly disappearing along the cliff (Fig. 2B). The beds differ in grain-size, matrix-content and lithology (types of man-made material). They are made up of angular clasts with diameter > 2 mm (breccias), and they can be matrix-supported (para-breccia) or clast-supported (ortho–breccia), in terms of textural features (Fig. 4). The man-made materials contain cement, mortar, tiles in ceramics, wood and plywood, bitumen, road asphalt pavement, etc. (Figs. 4C and D) deriving from demolition, construction, and renovation activities. Plastics are also widespread as well as various consumer products (aluminum shaving foam/deodorant/beverage cans, detergent containers, pieces of televisions and other fragments of unidentifiable objects). Lastly, many ACM fragments crop out in the upper portion of the succession (Figs. 4C and D).

As regard the cross-shore stratigraphic section (point 1 in Fig. 2), dumping deposits show a prograding geometry (Fig. 5) toward the sea (N-NW) and a relative lateral continuity. The local stratigraphy of the cliff is represented by four separate units limited by different erosional surfaces (Fig. 5). Unit 1 is 0.7 m thick and its base is not visible. It is made up of ortho-breccias with a low matrix content. Clasts are fragments of tiles, hollow bricks and carbonate rocks (limestones and calcarenites). Unit 2 is a 1.2 m thick para-breccia deposit with abundant yellowish sandy matrix. Clasts are mainly represented by cement fragments, but ceramic tiles and railway asphalt are widespread. No fragments of ACM have been recognized in these units. On the contrary, unit 3 is 0.7 m thick and is made up of large ACM fragments. Moreover, unit 4 is a 1.3 m thick para-breccia deposit with an abundant grey silty and sandy matrix. The clasts are dispersed in the grey matrix, and they are represented by cement, mortar and rare fragments of ACM. The upper portion of this unit show also traces of pedogenetic processes and a general brown color (Fig. 5). This brief description confirms the observations carried out in the eastern sector of the cliff (Fig. 4): the upper portion always contains fragments of ACM, whereas they seem particularly widespread in unit 3 (western sector – Fig.5) where the ACMs are chiefly made up of roof corrugated tiles with their typical curved morphology (Fig. 6A). They are chipped, partially broken or in smaller fragments with a diameter ranging from 20 to 2 cm (Fig. 6A). Numerous ACM fragments of large dimension (Figs. 6B and C) are also dispersed in other man-made materials with abundant matrix along the base of the cliff.

4.2 The beach of Marechiaro bay

The scuba diving survey shows that the seagrass begins below 5-6 m of water depth (the locale base level of storm waves) and covers the offshore transition and deeper environments (Figs. 1C, 2 and 7A). The soft-substrate is made up of fine-grained mixed sands with an abundant bioclastic content. The lower shoreface is nearly flat and it contains fine-grained sands (Fig. 7A). It slightly increases its slope (upper shoreface) as result of the progressive increase in grain size toward the shoreline. The survey on the emerged beach sector shows gravel and coarse-grained sand along the foreshore covered by a thick banquette formed by abundant remains of *Posidonia oceanica* (Fig. 3B). The backshore of Marechiaro beach is narrow and it is made up of gravel and coarse-grained sand. It is limited by vegetated low-elevation dunes (Figs. 7A and B) with well-sorted medium-grained sands.

4.2.1. The ACM of the beach area

Sands and gravels of the foreshore and backshore sectors shows a particular composition due to the natural and man-made particle origins (Fig. 8A). The natural materials are widespread (Fig. 8A) and they are represented by bivalves, gastropods shells (or their fragments) and *Posidonia oceanica* remains (roots, rizhomas, and egagropoli). The man-made materials are also abundant and they are mainly composed of red brick clasts, ceramic tile of different colors, grey cement, plastics, and glasses

(Fig. 8A). The ACM fragments are less common (Fig. 8A), but they regularly occur along the sandy-gravelly foreshore and backshore areas. To establish the lateral distribution of the ACM fragments, their number for unit area (4m^2 Fig. 8B) has been counted considering the clasts with the maximum diameter > 2 cm (Figs. 8C and D). There is an irregular variation of the clasts number along the beach (Fig. 8E) and this seems to change randomly. A number of 80 ACM clasts were recognized in the 5-unit areas corresponding to 4 clasts for m^2. Their morphology varies from angular or rounded to elongated or circular.

4.2.2 Morphometric analysis on ACM clasts

A simple image analysis was carried out on 80 clasts in the unit areas of the beach sector (points 4, 5, 6, 7 and 8 – Fig. 2) to evaluate the lateral variation of the morphometric parameters. Indeed, ImageJ software directly provides the morphometric parameters using the photo binary images. Using these calculated parameters, it is possible to recognize a lateral variability (Fig. 9A), even though the data are scattered. Data dispersion depends on the final shape of the initial ACM fragments (random) shape. Using the Krumbein (1941) comparison classes, the geometrical system becomes easier (Cruz-Matìas et al., 2019) with a clear correlation (Fig. 9B). ACM clasts are transformed from angular clasts (similar to the breccias cropping out on the cliff) to well-rounded gravels through transport processes. The eroded ACM (formed by cement and asbestos) fractions are then released into the environment.

4.3 Mineralogical analysis on ACM clasts

Five ACM samples were collected for mineralogical Powder X-ray diffraction analyses (PXRD) and Scanning Electron Microscopy observations (SEM-EDS): one on the cliff, one on the debris deposit located at the cliff base and three along the beach of Marechiaro bay (respectively, points 1, 2, 4, 6, 8 – Fig. 2, Tab.1).

The mineralogical analyses show the presence of the following asbestos minerals:

1. Chrysotile (serpentine asbestos, white asbestos), phyllosilicate group, having the following general crystal chemical formula: $Mg_6(Si_4O_{10})(OH)_8$

2. Crocidolite (blue asbestos), the fibrous variety of the Riebeckite: group of double-chain inosilicates, having the following general crystal chemical formula: $Na_2(Fe^{+2}, Mg)_3Fe^{+3}{}_2[(Si_4O_{11})(OH)]_2$

3. Amosite (brown asbestos), the fibrous variety of the amphibole Grunerite: group of double-chain inosilicates, having the following general crystal chemical formula: $(Fe_{+2}, Mg)_7[(Si_4O_{11})(OH)]_2$

All samples contain Chrysotile as main asbestos component (Fig. 10). Sample 6 shows also the presence of Crocidolite (Figs. 10A and B). Samples 1, 2 and 8 contain the association of Chrysotile with both the asbestos amphiboles (Crocidolite and Amosite), while sample 4 only shows the association Chrysotile and Amosite (Figs. 10C). The percentage of asbestos minerals in the samples (calculated with the XRPD analysis, Belluso, 2017) varies from a minimum of 20% up to 32%.

Lastly, SEM-BSE images (e.g. Figs. 10A and B) often highlight the presence of a cement matrix which is subject to a severe decay (crumbled or pulverized matrix).

4.4 Remote sensing analysis

Remote sensing analysis were chiefly carried out to hypothesize the approximate volume of dumped mad-made materials and the evolution of Marechiaro bay during recent time.

The stereoscopic analysis of older aerial photos (IGM 1954, 1976 and 1978) shows the absence of detectable dumping operations during this period of time, but changes of the landscape occurred in terms of new urbanization (civil housing and holidays villas) and agricultural activities. On the contrary, the comparison between the main morphological elements in the older aerial photos (mainly the cliff edge and the seashore – Fig. 11A) and the present-day landscape (2022 Google Earth images – Fig. 11B) highlighted the presence of dumping deposits (Fig. 4C). Fig. 4 shows a massive beach progradation during the last 50 years probably caused by the lateral expansion of the ship maintenance area located in the eastern sector of the study area (Fig. 4). Indeed, only large-scale dumping activities generally build anomalous cliff “advancing” process (Fig. 11C).

This gradual process can be also described by analyzing the satellite images of the last twenty years (Google Earth 2002-2020 – Fig. 12). The retreat of the cliff is faithfully recorded by the rapid changes of the easternmost transitional environments.

Comparing the 2002 satellite image with the 1978 aerial photo, the presence of dumping materials is significant. Indeed, a sand accumulation seems to begin along a man-made structure parallel to the coastline (probably, a submerged barrier protection). In 2007, a continuous cordon littoral occurs limiting a sort of tidal flat with a single tidal channel. From 2013 to 2020 (Fig. 12), an actual beach system establishes in this area. The dune occurrence follows the changes in the dominant vegetation and a lagoonal-palustrine basin develops in the retro-dune sector. The alternation of lagoonal and palustrine conditions seems to correspond to slight variations in water depth, vegetation types and organic matter accumulation. The final sketch in Fig. 12 summarizes the main results of the satellite image analysis: a small cliff retreat in the western sector of the bay is recorded by a rapid evolution (only twenty years) of the eastern sector in terms of landscape and sedimentary environments inducing the infill of an original wide marine area the formation and the progradation of a sandy beach.

5. DISCUSSION

The multidisciplinary approach aimed to analyze the complex issue of the ACMs illegally dumped in transitional environments which are typically highly dynamic in space and time (Arienzo et al., 2020). The physical stratigraphy analysis of the cliff shows the geometry and lateral distribution of the man-made materials. In particular, the localized extent of single dumping deposits, the erosional surfaces between different units and the progradational geometry of them could be interpreted as result of repeated dumping operations carried out with dump trucks.

Generally, a progradational geometry is restricted to nearshore sedimentary systems where deposition induces a regression with continuous shifting of the shoreline toward the sea (Bates and Jackson, 1987). Fig. 13 shows dumping operations that could be produce geometries similar to the natural ones (for example, a prograding delta system). However, in this study case, the deposition is carried out through successive dumping operations directly into the sea and along a cliff made up of older man-made materials. Dumping processes form erosional (often channelized) surfaces between different man-made material deposits inducing localized flows along the slope made up of previous deposits (as in natural marine debris flows, Niedoroda, 2006).

Dating analysis on cropping out cliff deposits indicate that they have been dumped during the 90's. The upper part of the cliff is characterized by the abundant occurrence of ACM and they seem to suddenly compare after 1992 (*see* Fig. 5). This data agrees with the introduction of L. n. 257/1992 which ban the use of asbestos. Rare clasts of ACM have been also found in older deposits, but they are randomly distributed in dumping units. After 1992, the abundant presence of ACM becomes the result of illegal material disposal to avoid expensive operations (Paglietti et al., 2016; Liu et al., 2017). Remote sensing analyses confirm the main dumping operations during 80's and 90's. Indeed, aerial photos before 1978 shows the absence of man-made materials discarded along the cliff sector (Fig. 10). Furthermore, no evidence of new dumping operations has been detected after 2002 (Fig. 11). Considering a constant thickness of 2.5 m and that the natural cliff was carved in the Quaternary calcarenites (Fig. 10A) in 1978, a rough volume quantification of dumping deposit could be obtained by measuring the area comprised between the two cliff edges (1978 – 2022).

The volume is about 40.000 m^3. However, part of this material has been eroded and transported toward the adjacent beach (the Mar Grande basin circulation induces a long-shore current toward East – De Serio and Mossa, 2015; Mossa et al., 2020).

The mineralogical analyses confirm the nature of ACMs which is characterized by a variable content of asbestos minerals. This result indicates the presence of man-made materials coming from the demolition of buildings, roads etc., and belonging to different time of construction. Indeed, the percentage of asbestos minerals increased from about 18-20% by weight up to well over 30% by weight between the 60's and the last years of industrial activity. The increment is correlate with the gradual decrease of the asbestos minerals value until reaching the maximum depreciation close to the ban of the asbestos minerals in Italy (Laviano et al., 1997; 2004).

The beach investigation confirms the data collected in the adjacent cliff. Man-made materials of different nature form the present-day beach. The natural component of transitional sands and gravels is strictly represented by the biological fragment component (mainly shells). Furthermore, starting from 2002, wide sectors of the original areas covered by the present-day lagoonal/palustrine environment have been filled by man-made materials (Fig. 11) increasing the ACMs distribution.

Moreover, the results connected with the morphometric analyses indicate that ACM clasts undergo rounding processes caused by transport along the coast. The friction and the impact with other materials induce a fast rounding of ACM fragments as they have a lower hardness degree than other building materials (Adi Atmika et al., 2019). Major friction processes occur along the nearly flat surface of ACM clasts as results of their movement on a sandy substrate which is typical of the foreshore sectors (Stark et al., 2014). Moreover, the manufacture year and the physical/chemical state of ACMs clasts can be fundamental for their behavior in water and collision/frictional processes. All these processes induce a dispersion of asbestos fibers in the beach environments increasing the risk of people's health.

Finally, most of the ACM fragments and clasts observed along the cliff and the beach of Marechiaro bay seem to be characterized by the so-called friable state (Laviano et al., 1997). The “friable” term is applied for any ACMs crushed, crumbled, pulverized, or turned into powder with hand. It is known that asbestos-containing materials are more dangerous to human health the more friable they are. The weathering of ACMs induces physical and chemical changes mainly in the cement matrix causing the asbestos fibers dispersion (Campopiano et al., 2009). SEM-BSE analysis describes the low physical state of ACM samples. The ACMs found along the cliff (Fig. 14A) and at its base (Fig. 14B) show a macroscale friable state and therefore a high risk for human health. This susceptibility to release fibers is significant high in the clasts of the beach.

6. CONCLUSIONS

Several issues remain unsolved after the ban on Asbestos in Italy (L. n 257/1992) and in the European Union (ECD 1999/77). In particular, the asbestos removal and waste disposal are still an environmental/health emergency all over the world. Indeed, the high cost of removal and disposal operations and the lack of suitable State financings have favored the ACM illegal dumping in the environment.

This study deals with the problems connected to ACM dumping processes into the sea. Although asbestos has a high prevalence, it has never been analyzed in detail. In this respect, part of this research focused on appropriate methodologies for analyzing ACM dynamics in shallow-marine environments. For this reason, the first conclusion highlights the need of an interdisciplinary approach (geomorphological, sedimentological and mineralogical) in order to describe this complex issue in a reliable way.

Secondly, several critical issues concern the area of Marechiaro bay which represents the final sink of hazardous materials. The ACM fragments deriving from the erosion of the cliff contribute to the accumulation of material on an overcrowded beach, especially in summer seasons.

In addition, the most important consideration concerns the use of our results. The research findings allowed the local authorities to immediately close the bay preventing access to bathers.

Our study could help decision makers and local authorities to request remediation interventions. The project of reclamation and the use of this area as a coastal city park has already been funded in 2021.

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LIST OF FIGURES

Fig. 1. A. The study area (Marechiaro bay) is located in the southern Mar Grande basin (northern Ionian Sea). The Taranto town is limited by an extensive industrial center (North direction) which is directly connected with the Mar Grande and the Mar Piccolo marine basins (Google Earth 2022). B. Marechiaro beach is a traditional

destination for the citizens of Taranto during summer season (photo taken on June 2020); C. The study area includes many environments with a significant naturalistic value (Google Earth 2022).

Fig. 2. Location of the stratigraphic sections described and/or sampled along the cliff (1, 2 and 3) and unit areas for ACM fragments counting in the backshore sector (4, 5, 6, 7 and 8). Samples of ACM for x-ray and SEM analysis were collected on the cliff (1), at the base of the cliff (2) and in the backshore area (4, 6 and 8). Google Earth 2020.

Fig. 3. The western portion of Marechiaro bay. A. The cliff has a sub-vertical shape and the thickness reaches 3 m. The cliff deposits are stratified. B. The cliff is subject to slope instabilities. A recent landslide (RS) on the older debris deposits shows a flat and smooth upper surface induced by the action of storm waves (OS).

Fig. 4. The cliff dumping deposits. A. A metric, massive dumping deposit (for the location, see point 3, Fig. 2). The graphic scale is 10 cm in length. B. Alternation of dumping deposits (for the location, see point 2, Fig. 2) with a different content of sandy matrix. The stratification is irregular and the sedimentary bodies have a lenticular geometry with a scarce lateral continuity. The location of C and D figures is shown in light yellow. The graphic scale is 10 cm in length. C and D. Details of the upper portion of dumping deposits. A qualitative fragments classification with different origin is shown. In light green, the ACM fragments. Legend: A: asphalt; B: bitumen; C: cement and mortar; P: plastics; PW: plywood; T: tile (ceramics). Note that the type of man-made materials changes laterally in a few tens of centimeters.

Fig. 5. The stratigraphy of the cliff in the eastern sector of Marechiaro bay. Four main dumping units were recognized. They show a clear prograding geometry with superposed and inclined sedimentary bodies migrating towards the sea. Note the presence of thick debris deposits at the base of the cliff. On the right, the drink cans used for dating analysis. All dumping operations were carried out during the nineties.

Fig. 6. A. Unit 3 contains large scale fragments of ACM. They are broken portions of roof corrugated tiles. Unit 2 and 4 seem to have no detectable fragments of ACM. B and C. Some details of the deposit at the base of the cliff. Abundant fragments of ACM with different dimension. Many AC tiles are in a vertical position. The graphic scale is 10 cm in height.

Fig. 7. A. Marechiaro beach is characterized by a narrow-emerged beach, small dunes and a localized lagoon. Remains of Posidonia oceanica occur in the shoreface and foreshore areas. A large seagrass area characterizes the sea bottom of the offshore transition sector; B. Low-elevation dunes, a narrow backshore area and a thick banquette in the foreshore sector typify the eastern part of this coastal area.

Fig. 8. The ACM fragments in the beach sector of Marechiaro bay. A. The backshore sediments are sand and gravel made up of natural and man-made particles. *Posidonia oceanica* remains and shells of bivalve and gastropods are the main natural materials. Clasts of reddish bricks, whitish ceramic tiles and grey cement are also widespread. The ACM clasts are highlighted by the yellow arrows. B. The unit areas (see location in Fig. 2) used for the counting of ACM clasts is 4 m2. The yellow arrow indicates the graphic scale. C and D. Examples of ACM clasts (indicated by the yellow arrow). Only clasts with diameter > 2 cm have been considered. The graphic scale is 10 cm height. E. The W-E lateral variation of number of clasts (N) along the beach (d - distance from the first point located in the western sector of the beach, Fig. 2, points 4, 5, 6, 7 and 8).

Fig. 9 Morphometric analysis. The graphs show the variation of the aspect ratio, circularity and roundness along the 5 sampling unit areas and the roundness calculated with the Krumbein (1941) comparative tables.

Fig. 10. Mineralogical analyses on ACM fragments collected in different points of Marechiaro bay. A: XRPD on sample 6 (see point 6 in fig. 2): two asbestos minerals have been detected (Chrysotile and Crocidolite). B: Sample 6. SEM-BSE (back-scattered electrons) show the association between Chrysotile (white arrow) and Crocidolite (blue asbestos). C: Sample 4. SEM-BSE (back-scattered electrons) show the association between

Chrysotile (white arrow) and Amosite (green arrows). In both cases, the SEM-BSE images show a cement matrix with scarce cohesion.

Fig. 11. Remote sensing analysis. A. Aerial photograph of the study area (IGM 1978); B. Satellite image of the study area (Google Earth 2022). C. A qualitative comparison of A and B. Major changes affect the cliff sectors, beach shoreline, and man-made structures. Evidence for post 1978 coastal dumping operations is shown by the presence of an anomalous advancing cliff (indicated by the black arrow) at more recent time (2022). Shoreline has also prograded and the small and localized beaches from 1978 have turned into a present-day well-developed sandy beach system.

Fig. 12. Remote sensing on satellite images of the Marechiaro bay (Google Earth 2002-2020). Landscape and sedimentary environments in the eastern side of the bay record very fast changes.

Fig. 13. Sketch of the origin for the occurrence of progradational geometries in the dumping units. This process reproduces the natural shifting of the shoreline in prograding beaches and delta sedimentary systems. Note the occurrence of irregular erosional surfaces (red line) between different sedimentary units as result of the dumping process.

Fig. 14. The physical state of ACM cropping out on the cliff (A) and at the base of the slope debris. The macrophotos clearly show friable ACMs.

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Table 1. Location, associations of asbestos minerals and their % by weight in the sampled ACMs.