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N.A. Fedoronchuk

THE LITHOLOGICAL CONDITIONS OF FINE GOLD ACCUMULATION IN THE RECENT CHERNOMORIAN SEDIMENTS OF THE BLACK SEA

Н.О. Федорончук

ЛІТОЛОГІЧНІ ПЕРЕДУМОВИ НАКОПИЧЕННЯ ЗОЛОТА В ЧОРНОМОРСЬКИХ ВІДКЛАДАХ ПІВНІЧНО-ЗАХІДНОГО ШЕЛЬФУ ЧОРНОГО МОРЯ

Fine gold is typical for shelf sediments of the Black Sea. Its accumulation is not associated with only one source, it occurs in different terrigenous-mineralogical provinces of the shelf. Fine gold has different genesis; its distribution in sediments is extremely uneven. Its highest content is found in the Dnieper depression, near Tendra spit and Zhebriyany bay.

The increased content of gold is often found in multicomponent nongraded recent sediments of the shelf – in the muddy and sandy shell deposits. The accumulation of fine gold is confined to the very fine sand in the Dnieper depression. There is a high negative correlation between gold content and psephites, which is represented exclusively by shelly material in these sediments. This negative relationship is natural, because there is no genetic relationship between biogenic psephites and predominantly terrigenous fine gold. Positive correlation between gold and the very fine sand in the sediments indicate that the determining factor is the hydrodynamic regime for the accumulation of fine gold in marine sediments.

Fine gold tends to accumulate in sediments with a high content of minerals residue near Tendra spit. Here the accumulation of gold is directly related to the formation of coastal marine titanium-zirconium placers, evidenced by positive correlations between gold and zircon, ilmenite and anatase.

The maximum gold content occurs in well-graded fine sand sediments in Zhebriyany bay and Zmeinyi Island area.

The lithological control of accumulation of fine gold in the sediments appears differently in various parts of the north-western shelf of the Black Sea and in different terrigenous-mineralogical provinces of the shelf.

Keywords: fine gold, bottom sediments, Black Sea.

Для шельфових відкладів Чорного моря характерна наявність тонкого золота, причому його накопичення відбувається в різних теригенно-мінералогічних провінціях шельфу і не пов'язане з якимось одним джерелом. Тонке золото носить різногенетічний характер, а розподіл його у відкладах вкрай нерівномірний. Найбільш високі вмісти золота спостерігаються в Дніпровському жолобі, поблизу Тендрівської коси й Жебриянської бухти.

В сучасних відкладах шельфу високий вміст золота часто спостерігається в багатокомпонентних погано сортованих відкладах – мулистих і піщанистих черепашниках.

В сучасних відкладеннях Дніпровського жолоба накопичення тонкого золота приурочено до крупноалевритових відкладів, при цьому спостерігається висока негативна кореляція вмісту золота і псефіту, який в цих відкладеннях представлений виключно черепашковим матеріалом. Позитивні кореляції з вмістом у відкладах крупного алевриту свідчать про те, що визначальним для накопичення тонкого золота в морських відкладеннях є гідродинамічний режим.

Поблизу Тендрівської коси тонке золото виявляє тенденцію до накопичення у відкладах з підвищеним вмістом важкої фракції, виявлені позитивні кореляційні залежності вмісту золота з вмістом у відкладах циркону, ільменіту й анатазу.

В районі Жебриянської бухти та острову Зміїний максимальні вмісти золота відзначаються в добре сортованих дрібнопіщаних відкладах.

Літологічний контроль накопичення тонкого золота у відкладах проявляється по-різному на різних ділянках північно-західного шельфу Чорного моря і в різних фаціальних умовах.

Ключові слова: тонке золото, донні відклади, Чорне море.

INTRODUCTION

The presence of fine gold in bottom sediments is a characteristic feature for the Northwestern Black Sea shelf (Shnyukov, Ziborov, 2004, Shnyukov, 2001). Accumulation of gold particles takes place in different facial environments on the shelf (Fedoronchuk et al., 2013) as well as in various terrigenous-mineralogical areas and there is no dominant source of nourishment of fine gold. Fine gold has different origin and its distribution has extremely irregular character in bottom deposits (Reznik, Fedoronchuk, 2000, Ivanova et al., 2006, Fedoronchuk, Suchkov, 2012, Fedoronchuk, 2001, Yushin, 2009).

As it was noted in previous research (Reznik, 1999, 2003, Fedoronchuk, 2001) fine gold has a tendency to accumulate in sediments with poor sorting and which consist of terrigenous and biogenic components, for example in muddy, silty and sandy shell deposits. However there is no obvious dependence between gold content and certain components of sediments. Unevenness of distribution and different origin of fine gold make it complicated to reveal clear patterns of accumulation in the bottom deposits.

This paper focuses on the study of fine gold particles distribution within different areas in the Northwestern Black Sea shelf. The highest concentrations of fine gold are observed in Dnieper depression, in the vicinity of Tendra spit, Zhebriyany bay and Zmeiniy Island area (Reznik, 2003, Fedoronchuk et al., 2001). An attempt to trace the connection between gold content and litho-

logical types of sediments within mentioned areas, as well as correlation with certain grain sizes, heavy fraction and distinct heavy minerals was made.

The aim of the research is to characterize the lithology as a factor, which controls fine gold accumulation in modern sediments in the Northwestern Black Sea shelf.

STUDY AREA, METHODS AND RESEARCH OBJECT

This research is dedicated to the questions of lithological features and concentration of free gold in bottom sediments in the Northwestern Black Sea shelf in the area of Dnieper depression, nearby Tendra spit, Zhebriyany bay and Zmeinyi Island. The cores were collected by piston corer with a diameter of 108 mm and by bottom sampler «Ocean-0.25» in a compain in 1993-1998. Weight of the samples varied from several kilos to up to 20 kilos.

In Dnieper depression sampling was carried out along the net of profiles which were situated perpendicular to the depression and along two profiles which were situated parallel to it respectively. Profiles were arranged perpendicular to the Tendra spit area. Sampling was carried out along two profiles with irregular configuration in Zhebriyany bay and its north-eastern coastal waters. The samples were collected from the shelf areas in Zmeinyi Island area which were situated symmetrical to the island and along area which is situated between the island and the Danube river coastal waters.

Grain size analysis was carried out in the Laboratory of Marine Geology and Geochemistry of Odessa Mechnikov National University (ONU). The methods of separation through sieves by water and fractional precipitation of fine particles were applied. Free gold content determination was carried out by assay tests in concentrated sediment samples, which previously were enriched in spiral sluice. The analyses were carried out in the Laboratory of Noble and Rare Metals, IGFM by N.P. Semenenko, NAS of Ukraine (A.A.Yushin) and by amalgamation in the Laboratory of Marine Geology and Geochemistry of ONU. Mineralogical composition of heavy fraction of bottom sediments was studied as well.

Processing and correlation of the results of the analyses were carried out in such programs as MS Excel and StatSoft Statistica. Comparisons were carried out for more than 200 samples of the sediments of Chernomorian age. The age was determined by the presence of characteristic fauna.

RESULTS AND THEIR ANALYSIS

High content of gold can be often observed in the modern multi-component sediments with poor sorting such as muddy and sandy shell deposits.

Dnieper depression is the most perspective area for fine gold (Reznik, 2003, Fedoronchuk et al., 2001), and the highest concentrations of fine gold in the bottom sediments of the Northwestern Black Sea shelf were observed exactly there. Content of gold in some places in Dnieper depression reaches up to 3 grams per ton, according to our data (Table 1).

Distribution of gold in the Dnieper depression as well as in the Northwestern Black Sea shelf in general is not even and high values of such statistical parameter as standard deviation supports this statement (Table 1). Chernomorian sediments in Dnieper depression are represented by sands and by widely distributed shell sediments with different values of terrigenous components of variable grain size spectrum. Depending on what is the main constituent of shell sediments matrix whether silt or sand, muddy, silty and sandy shell deposits can be marked out respectively (Table 2). Psephitic part of the deposits within this area is represented only by biogenic components, namely mollusk shells.

Sandy shell sediments are distributed in the shallow part of the study area, on the slopes of the Dnieper depression till water depth of 30 – 33 m. These sediments have sorting from medium to poor, but in general sorting coefficients of sandy shell sediments are somewhat higher than in muddy silty shell deposits, which are widely distributed in deeper parts of the depression and cover the rest of it and areas, which are situated to the south and to the north from the depression. Sandy and muddy types and silty type of shell sediments are the main two kinds of shell deposits, which can be regarded as multi-component lithological systems, which were created by terrigenous and biogenic (Fig. 1).

Psephitic grain size of shell material is characteristic almost for all sediments in Dnieper depression of Chernomorian age. Overlap of terrigenous

Table 1. Free gold content in Chernomorian sediments of the Dnieper depression

Kind of analysis	Gold content g/t			Standard deviation
	min	max	mean	
Assay test	0,009	3,000	0,606	0,8429
Amalgamation	0,090	0,866	0,200	0,1328

Table 2. Grain size composition of Chernomorian sediments of the Dnieper depression

Type of sediments	Grain size fractions % min – max mean				Sorting coefficient S_0, min – max mean
	Psephit, > 1 мм	Psammite, 1-0,1 мм	Silt, 0,1-0,01 мм	Pelite, <0,01 мм	
Muddy silty shell deposit	20,3-70,8 49,5	4,7-29,0 10,9	15,1-69,6 37,6	0,4-7,0 2,0	2,02-16,58 10,17
Sandy shell deposit	27,8-68,8 48,7	13,8-68,5 38,6	1,4-29,1 11,8	0,2-2,0 0,8	2,86-13,50 4,75
Sand	11,9-18,5 15,1	67,5-83,2 78,6	1,2-14,8 5,8	0,4-0,7 0,5	1,22-1,78 1,53

Table 3. Free gold content in the Chernomorian sediments near Tendra spit

Kind of analysis	Gold content g/t			Standard deviation
	min	max	mean	
Assay test	0,002	0,256	0,061	0,0759

Table 4. Grain size composition of Chernomorian sediments in Tendra spit area

Type of sediments	Grain size fractions % min – max mean				Sorting coefficient S_0, min – max mean
	Psephit, > 1 мм	Psammite, 1-0,1 мм	Silt, 0,1-0,01 мм	Pelite, <0,01 мм	
Shell deposit	23,7-66,9 50,1	13,9-63,3 29,6	5,1-58,8 19,6	0,1-1,6 0,7	2,89-13,07 5,43
Sand	7,2-22,4 16,7	66,3-82,6 71,4	9,3-14,6 11,4	0,2-0,6 0,5	1,56-1,87 1,74
Silt	1,1-7,9 3,8	1,1-20,8 6,2	70,9-97,1 89,6	0,1-0,7 0,3	1,38-2,44 1,76

and biogenic processes of sedimentation is clearly reflected on the histograms of distribution of grain size (Fig. 1) where two maximums correspond to terrigenous and biogenic components.

Sands are widely distributed on the slopes of Dnieper depression, in particular they tend to cover uplifted areas of the bottom. The sands have good sorting (Table 2), and do not have significant admixture of shell material (up to 18 %). Shell sediments are the dominant deposits on the rest part of the study area of the depression.

Statistical comparison of the results of grain analysis and the analyses, which were aimed at estimation of gold content in Chernomorian sediments of Dnieper depression showed that gold has a correlation with coarse silt grain size (0.1-0.05 mm) and high negative correlation with psephitic particles which are represented exceptionally by shell sediments.

Classical environments of placer formation can be observed in nearby Tendra spit area, namely constant transit of sediments, which determines the presence of accumulative body; active wave regime of open water area; gradual water depths increase. However gold in Chernomorian sediments is less wide distributed in this area in comparison with Dnieper depression. Never the less, a series of anomalies can be noted with background content >0.1 g/t, and in some samples gold content is > 0.25 g/t (Table 3). Gold distribution in the deposits is very uneven.

Among Chernomorian sediments of Tendra spit three characteristic lithological types were marked out – shell sediments, sands and silt (Table 4).

Sands are distributed along the spit to a water depth of about 10 m (Fig. 2b), they are represented mostly by fine grained quartz deposits, rarely by medium, with a little admixture of detrital shell material (up to 20 %) and increased content of placers forming minerals can be encountered (Fedoronchuk, 2001). Increased values of detrital shell material are reflected in sorting coefficient of sands which notably becomes poorer. Coarse detrital carbonate sands can be encountered among wide spread shell deposits at a water depths of 14-18 m. These sands were created by the processes of crushing of shell detrital material and decrement of the part of large mollusk shells.

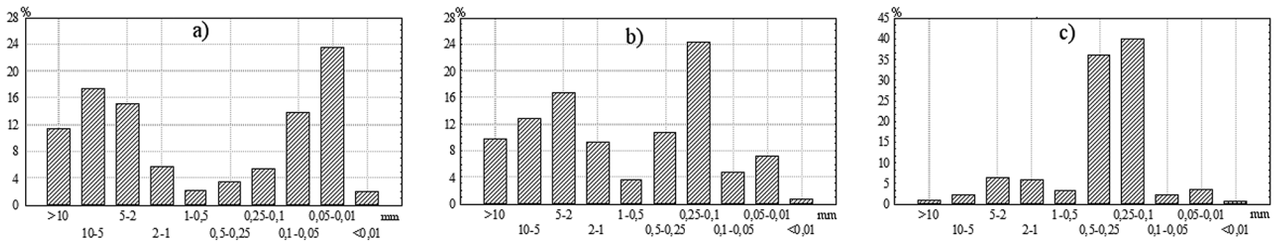

Fig. 1. Average content of grain size fractions in the Dnieper depression in Chernomorian sediments (a – silty shell deposits; b – sandy shell deposits; c – sand).

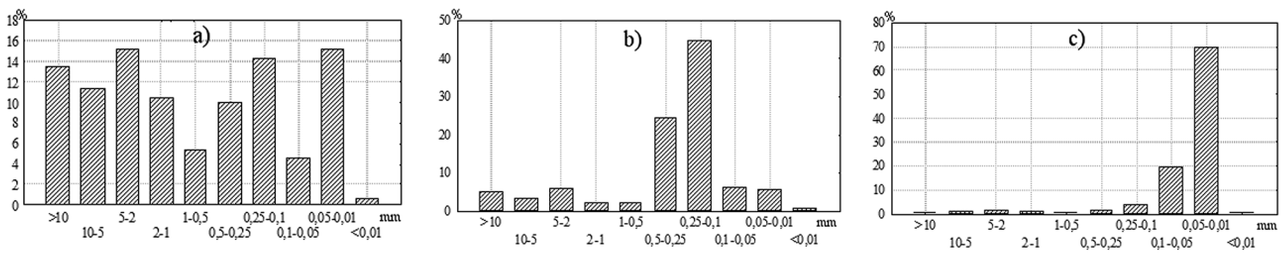

Fig. 2. Average content of grain size fractions in the area of Tendra spit in Chernomorian sediments (*a* – shell deposits; *b* – sand; *c* – silt).

Silty mud has restricted distribution near Tendra spit and can be encountered in the areas away from the spit, in zones, where biogenic sedimentation is subdued.

The most wide spread type of sediments is shell deposits with different content of sand and silt material and extremely poor sorting. Shell detritus and whole shell valves (mainly Mytillus) constitute these shell deposits, where sand particles are not of terrigenous origin, they are the result of the crushing of the shell detritus (Fedoronchuk, 2001).

High content of heavy minerals can be observed not only in sediments of Tendra spit where placers of titanium and zirconium group are represented but also in the bottom sediments on a water depth of ~ 20 m, where placer accumulation is controlled by the influence of wave energy (Suchkov, 1999, Fedoronchuk, 2001). Concentration of these minerals is highly correlated with psammitic grain size and the degree of sorting of the sediments which is a characteristic feature of coastal placers.

Dominance of small particles of gold over fine gold is characteristic for the area of Tendra spit's sediments. Gold content here is not correlated with any of the grain sizes. Although, close connection can be observed between gold content and concentration of anatase, apatite, zircon, ilmenite, tourmaline and in general with heavy fraction value. Here, accumulation of gold is directly connected to coastal titanium and zirconium placers formation.

The surface of the bottom in the area of Zhebriyany bay is covered mostly by silty mud and shell mud (Table 5, Fig. 3).

Concentration of gold according to assay tests vary from <0,004 to 0,310 g/t, and amalgamation method yielded values from traces to 0.229 g/m^3, weighted mean content in the whole area of the bay and coastal waters is 0.108 g/t. The areas with maximum gold content in Zhebriyany bay are grouped and attributed to places where vortex flow creates stagnation zone (Reznik, 1999, 2003).

Table 5. Grain size composition of Chernomorian sediments in Zhebriyany bay area

Type of sediments	Grain size fractions % min – max mean				Sorting coefficient S_0, min – max mean
	Psephit, > 1 мм	Psammite, 1-0,1 мм	Silt, 0,1-0,01 мм	Pelite, <0,01 мм	
Mud with shells admixture	5,6-49,0 24,2	1,6-15,6 8,3	49,1-78,4 66,8	0,3-0,9 0,6	2,89-13,07 5,43
Fine silt mud	0–2,3 1,1	0,4-1,4 0,8	95,1-98,1 96,7	0,4-2,7 1,5	1,56-1,87 1,74

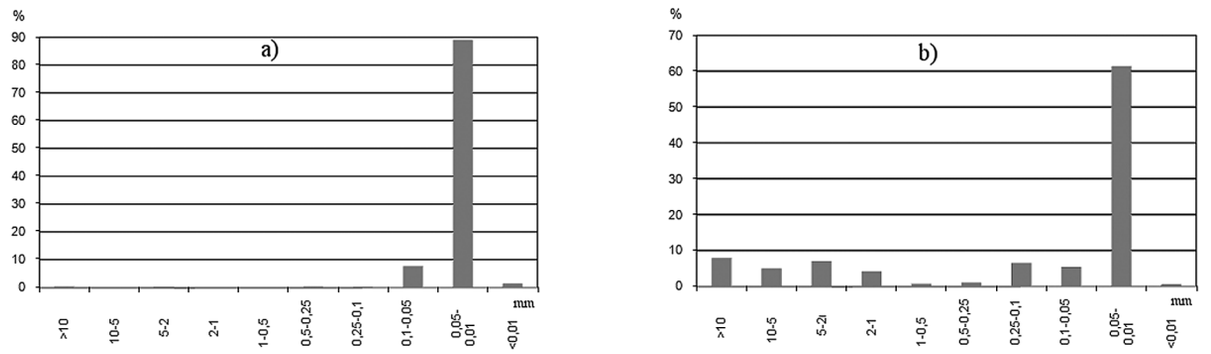

Fig. 3. Average content of grain size fractions of Zhebriyany bay in Chernomorian sediments (*a* – silty shell mud; *b* – fine silt mud).

Quantitative estimations of gold content in the vicinity of Zmeinyi Island was not fulfilled, but according to amalgamation data, signs of gold were encountered in 42 % of the samples. Free gold was obtained almost in all the stations which are situated a bit farther from coastal line, deeper than isobath 20 m. Free gold was not detected closer to the Danube river mouth. It is suggested that velocities of sediment transportation in the mouth area are too high for gold particles to precipitate and these particles accumulate in sediments far away from coastal line. Gold accumulation in the Zmeinyi Island area is observed in silt and in muddy shell sediments with poor sorting.

The bottom sediments of Zmeinyi Island are represented by silty sands in the west, by medium – and coarse grained sands of grey wacke type along the longitude of Zmeimiy Island and to the east from the Island – by shell sediments (Smyntyna et al., 2008). Apparently, the source of silt sediments with good sorting is the deposits of delta front which are being washed; grey anisomerous sands with poor sorting are the result of abrasion of rocks of Zmeinyi Island; shell sediments with poor sorting are constituted by biogenic and terrigenous multicomponent deposits, which accumulation is influenced by the Danube delta which is stretched far from the coast.

In general in the area of Zhebriyany bay and Zmeinyi Island maximum gold content is observed in fine sand and silt sediments with good sorting, and sometimes in silted shell deposits. Accumulation of gold here is the result of interaction of two factors – strong terrigenous supply from the Danube river and sediments flow along coast of the Northwestern Black Sea shelf.

DISCUSSION AND CONCLUSIONS

Fine gold in the sediments of the Northwestern Black Sea shelf of Chernomorian age is tend to accumulate in multicomponent deposits with poor sorting, namely muddy and sandy shell deposits (Reznik, 1999, 2003, Fedoronchuk, 2001). Despite this common tendency, correlation between free gold and types of sediments and their grain size in different facial environments in the shelf can be noted.

As a rule gold particles are correlated with coarse silt in Dnieper depression in sediments of Chernomorian age. Inverse correlation is characteristic for gold and sediments with psephitic grain size because the latter has biogenic origin and fine gold in those deposits is mainly of terrigenous origin (Fedoronchuk, Suchkov, 2012). The correlation of fine gold and coarse silt sediments is determined by similar hydrodynamic regimes in the shelf, when sediments with coarse silt grain size can be deposited along with fine gold. Absence of any correlation between fine gold content and other heavy minerals in the sediments highlights that accumulation of fine gold placers should be considered as a specific type (Fedoronchuk, 2001).

Similar tendencies are common for Chernomorian sediments in Zhebriyany bay and in the Zmeinyi Island area where gold particles are correlated with fine sand and silt deposits as well. Presence of gold here apparently connected with the intensive sedimentary deposits supply from the Danube River and washing processes in delta front area.

Thus, for the shelf areas which are under influence of large rivers discharge and are remote enough to not to experience high energy hydrodynamic environment (Suchkov, 1999), the tendency of accumulation of fine gold together with silt sediments is observed. The presence in these sediments of shells does not influence directly the process of fine gold accumulation.

The part of the shelf near Tendra spit is the area of such hydrodynamic conditions where extensive transit of terrigenous material is the main characteristic

feature. This environment is favorable for small gold particles concentration, but not for fine gold, also the correlation between gold and minerals of heavy fraction is noted, but at the same time there is no connection with any specific grain size. These areas are not very favorable for gold accumulation in the sediments, because along with coarser grain size of gold particles the concentration of the latter is considerably lower than in those areas where fine gold accumulates.

Lithological control of fine gold accumulation in sediments is expressed in a different way in different areas in the Northwestern Black Sea shelf and in different facial environments.

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Одеський національний університет імені І.І. Мечникова,
Одеса, Україна
fedoronch@gmal.com
Рецензент: Є.Ф. Шнюков