Statistical Evaluation of Exploration of Gold Placers in Adola Area (Southern Ethiopia)

Milan Hamrla

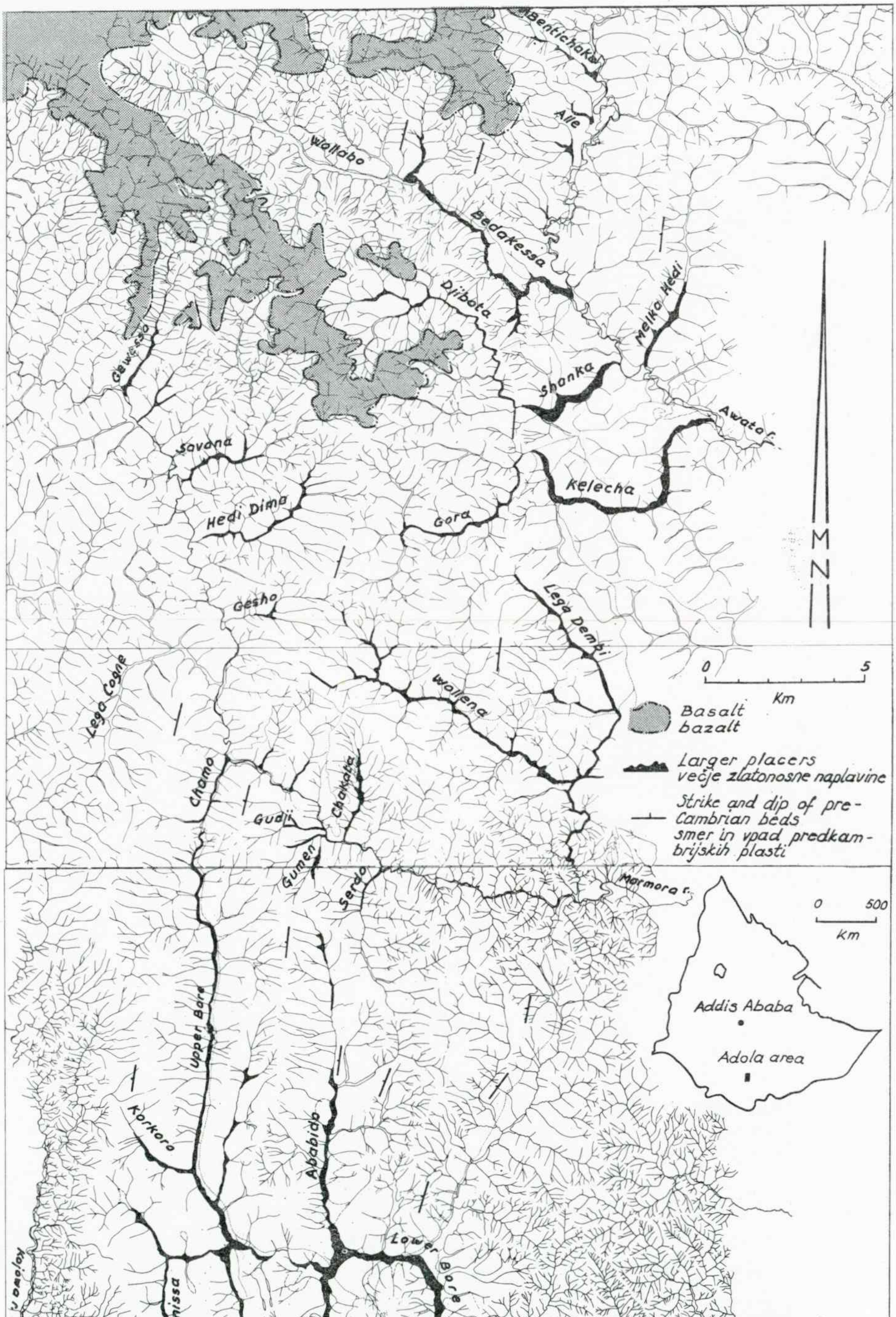
with 11 textfigures and 14 tables

Contents

Introduction

The state owned Adola gold mine is situated in Sidamo province in Southern Ethiopia, some 500 km from Addis Ababa (Fig. 1). It is accessible by a good all-weather road. The gold-bearing placers occupy the tributary valleys of the Dawa Parma river. The known placers are confined to a slightly arched elongated zone of about 150 × 20 km, running N—S. The undulated moderately hilly country is covered by dense forest in its northern part, and the southern one is a semiarid shrub and savanna land. The area is sparsely populated by semi-nomadic cattle-raising Guji tribe.

Alluvial and deluvial gold was apparently discovered in 1936 during Italian occupation. Since then exploration and exploitation activities were carried out with varying intensity up to the present day. Many experts


Bentichaka
Alle
Wallabo
Bedakessa
Djibota
Melka Hedi
Gewesso
Shanka
Awata r.
Savana
Kelecha
Hedi Dima
Gora
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N
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0 5
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Basalt
bazalt
Larger placers
večje zlatonosne naplavine
Strike and dip of pre-Cambrian beds
smer in vpad predkambrijskih plasti
Chamo
Chakata
Gudji
Gumen
Serdo
Mormora r.
0 500
Km
Addis Ababa
Adola area
Upper Bore
Korkoro
Ababido
Lower Bore
Demi
Denissa
Kojemiti
Butti

came endeavouring to improve the mining and to bring it on an up-to-date standard. Mechanised mining was introduced in 1956, but the most important share in production falls to handwork. The discontinuous exploration in the recent years and mining of the richest placers by handworkers decrease rapidly the reserves of gold.

After a break of several years some exploration was done again in the second half of 1969 and in the first quarter of 1970. Several larger placers were tested by pitting and drilling. An attempt was made the same time to assess the characteristics of the placers and other parameters by means of statistical techniques as there was a mass of data available. The possibility of comparing exploitation data with those obtained in exploration was useful in evaluation.

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Geology

Basic geological information

No detailed geological and geomorphological study of the goldbearing area was ever made. Some information was collected by Jelenc (1966 a, b).

The area is built up by pre-Cambrian rocks, the older series of which is composed of gneisses, sericite-chlorite-amphibolitic schists and quartzites with emplacements of granites, massive amphibolites and even serpentinites. It is unconformably overlain by a younger series of meta-conglomerates and quartzites. There are remnants of young flood basalts in the northern sector of the area (Fig. 1), capping the highest ridges and belonging to the young Rift valley volcanism or even to the Trap series according to Mohr (1962).

The alluvial gold-bearing placers are confined to depressions in the present relief, representing mainly dry old beds of rivers and streams. The absence of basaltic rocks in gravel indicates the pre-volcanic age of the fluvial cycle of erosion. According to Mohr (1962) there is no firm datum line for the effusions of these lavas, which might even be of Quaternary age. In any case, however, Adola volcanics must be very young.

Two phases are of importance in the development of Adola placers. The landscape at the end of an erosion cycle, probably a peneplained one, was abruptly uplifted, and the erosion created valleys in which the goldbearing placers accumulated. It must have been one rapid and short event as there is only one relatively thin gravel bed directly overlying the basement. After a calm phase in which clayey overburden accumulated over gravel, a second uplift lowered again the local base-level of erosion. It manifests itself by the young and recent erosion. The new drainage pattern has developed on the old one.

Fig. 1. Drainage pattern and larger placers in part of the Adola area

Sl. 1. Dolinska mreža in večja prodišča na območju Adole

Alluvial and deluvial placers originated probably during Quaternary pluvials. The local movement of the floor has been caused by faulting of the Rift system, which has continued up to the present times.

The origin of the primary gold is unknown. Angular gravel and locally very coarse nuggets prove that the primary deposits are very near, and so does the gold-bearing deluvium. The placers extend along the general trend of the basement. The primary gold may have originated and have been derived from the following possible sources:

(a) Hydrothermal quartz veins with sulphides, connected to igneous activity,

(b) Lens-like quartz inclusions in massive amphibolites, interpreted tentatively as products of lateral secretion (J e l e n c, 1966 a, b).

(c) Mineralization in quartzites,

(d) Meta-conglomerates as ancient fluviatile deposits.

Gold was found intimately dispersed in quartz pebbles, and fine gold was found in quartz detritus on slopes as well. Locally abundant black tourmaline appears in vein quartz. Osmiridium minerals have been found together with gold in some placers. These facts would rather point to the primary auriferous quartz veins of hydrothermal origin. The primary sources may be controlled by a certain feature in the trend of the basement, it being a lithologic unit or a tectonic zone. The primary sources are not necessarily rich and may not be profitable to work. They could be located by panning detritus on slopes. No such attempt to trace them working up hill has been made as yet.

Placers

The bulk of the gold is contained in horizontal or low-dipping sheets of fluvial alluvium laying directly over the bedrock. The placers are composed of bedded gravel and sands of different size. They are covered by layers of loam and clayey silt. The length of placers is up to several kilometers (Fig. 1), the width up to several hundreds of meters, and the thickness up to several meters. The gravel-to-overburden ratio ranges between 1 : 1 to 1 : 20. The original accumulations of alluvial material have been locally destroyed by the recent erosion and re-deposited at a lower level. The southern part of the area has been especially strongly affected by the intense headward erosion.

In addition, there are deluvial gold-bearing deposits of detritus on slopes of the valleys, being covered by the same loamy layer. They are often in relationship with fluvial alluvium.

The gold-bearing gravel is mainly coarse and unsorted, the pieces more or less rounded or even angular, depending on the length of transport. It is composed of country rocks, with quartz and amphibolitic varieties prevailing. Cobbles and boulders are often in headwaters.

The distribution of gold is very irregular. There are rich pay streaks alternating with poor or even barren zones. Gold tends to accumulate in the basis of the gravel bed, and it burrows also into the soft schistose bedrock. Gold grains are fine, flaky and smooth prevailingly. Bigger irregular nuggets are found as well. Fragments of quartz often adhere to the gold. The gold contains some silver. It is about 900 fine in average.

The tenor of gold in gravel ranges between traces to 20 g/cu. m, the average being in the order of 1 to 2 g/cu. m. Higher average values are rare. Exceptional erratic values may reach several hundreds of grams. The "overall tenor" (g/cu. m oall) takes into consideration the thickness of gravel and overburden together, and is a useful parameter for evaluation. From the exploitation point of view, the tenor can be boosted up by eliminating ground carrying low values. The ore grade can be varied in certain limits in this way, at the same time affecting the volume of gravel and reserves of metal as well.

Mining

Methods applied

Hand operations and mechanised operations are applied in mining. Handworkers extract the gravel by means of pits or by ground-sluicing. Pitting is done in a simple way using craw-bars and showels, buckets being hoisted by hand or by windlass. The workers seek and adhere to rich pay streaks, excavating the richest, lowest layer of the gravel bed only. Underground development of unsupported excavations is extremely limited. Consequently, it is believed, the recovery cannot be higher than 40 per cent or so.

Ground-sluicing is applied where ground is sufficiently inclined and there is enough current water available. The recovery is more satisfactory although some fine gold is undoubtedly lost. The handworkers recover gold by panning, and they sell it to the Mining administration. Assistance is provided to handworkers in tools and arrangements for water supply.

Mechanised mining has been practised in Shanka and Upper Bore placers. Overburden and gravel are excavated by draglines, which feed a washing plant mounted on a pontoon and floating in an artificial water pond. The recovery in this "wet" method is believed to range somewhere between 80 and 90 per cent as some gold is lost by dragline work in muddy water. In addition, unnecessary excavations deep into the bedrock must be made in shallow gravel to allow sufficient depth of water to float the pontoon. A land-based fixed or moveable washing plant might serve better. A higher efficiency and better gold recovery might be anticipated, and consequently lower production costs in "dry" mechanised method.

The machinery is electrically powered. A specially built hydroelectric power plant and a stand-by Diesel power plant are available.

For the future it looks like mechanised "wet" mining will have to be gradually abandoned, and the weight of exploitation will shift more and more to "dry" or semi-mechanised methods and to handwork.

Workable reserves

Geological ore reserves as tabulated in different reserves accounts (Žebre, 1968; Griffith, 1968) are not industrial reserves. The evaluation of industrial reserves, which are exploitable or workable at the profit, has been difficult. The workable reserves depend mainly on the cost of mining. As exploitation is going on in different placers at the same time by different methods and costs, the economy of the whole mining venture interplays the payable tenor limit of individual placers.

The reserves accounts are complicated by not always reliable prospecting results. In addition, some placers have already been partially exploited by handworkers, and no evidence has been left on the excavated volumes.

In order to find out the minimum tenor of the ground to insure a profitable operation, the alternatives of possible extractions and the factors affecting the cost shall be worked out. Once the tenor to break even is known, the boundaries of the workable area of a placer can be delineated and the recoverable reserves calculated. In doing so, the accuracy of reserves estimate must be known.

No accurate evaluation of gold reserves for individual placers of Adola gold field is possible at present. The estimated order of magnitude of total workable reserves indicates that there will be mining going on for years to come, especially if new reserves will be discovered in time.

Estimate of cost and payable tenor limit

Referring to the cost of mining there are unfortunately very few data available to calculate it and to find out the exact value limits of what can be extractable at the profit at present. Žebre (1967) attempted to calculate the working cost per gram of recovered gold. His figures are shown in Table 1 together with some additional parameters. Estimates can be made on this single information from 1965 and 1967.

Table 1. **Working costs per gram of recovered gold and basic parameters**

	Year	Mechanised "wet" mining			Hand-work	Average
		Upper Bore	Shanka	Average		
Cost	1965		2,138			
E$/gram	1967	1,736	2,737	2,204	2,337	2,272
gravel-to-overburden	1965		1 : 0,9			
ratio	1967	1 : 3,5	1 : 1,5	1 : 2,5		
tenor in gravel	1965		1,30			
g/cu.m	1967	2,87	0,90			
tenor overall	1965		0,70			
g/cu.m oall	1967	0,62	0,37			

Considering the price of gold E$ 87,50 per Troy ounce (31,1035 g) and an average fineness of Adola gold 900, the resulting monetary value of one gram produced gold is E$ 2,53. The corresponding payable tenor limits in gravel and overall for two mechanised placers and the calculated average are given in Table 2.

Table 2. **Payable gold tenor limits in Upper Bore and Shanka placers**

	Year	Mechanised "wet" mining			Remark
		Upper Bore	Shanka	Average	
Tenor in gravel g/cu.m	1965		0,85		Calculated from Table 1
	1967	0,69	1,08	0,87	
Tenor overall g/cu.m oall			0,45		
	1967	0,153	0,43	0,25	

It can be seen from Table 1 and 2 that the mechanised operation in Upper Bore was profitable (0,62 > 0,153), meanwhile that in Shanka was worked at a loss (0,37 < 0,43).

Theoretically, the average workable grade in a placer should equal the payable tenor limit. In practice it must be higher for the recovery and its limited accuracy as well as the degree of reliability of the reserves estimate. The margin to be considered depends on the accuracy of data.

However, the minimum workable overall gold tenor for a certain method applied under different local conditions is not the same. The minimum tenor to break even is a variable. Lacking any accurate recent data on the cost of mining, an average 0,25 g/cu.m overall may be regarded as the order of magnitude of the workable tenor limit for the "wet" dragline mining for the time being.

Exploration

General

Sampling of placers by pitting has been most commonly used in the past. Square pits with 1 m side were applied mostly. Banka drill was introduced early but was rarely used. The organisation and supervision of exploration was left to the ability and conscientiousness of prospectors in charge for work.

Individual washing has been used to recover gold up to the present day. Some occasional attempts to introduce sluice-boxes and other mechanical panners failed. Three exploration stages were practised although not quite consistently: "scout prospection" was followed by occasional "preliminary prospection" in rows 1 000 m apart, and finally in "close prospection" the pits were dug in lines 100 m apart with a spacing of 25 m. In designating the lines, provision was made for intermediate lines 50 m apart.

Statistical characteristics of placers

Mathematical statistics were applied to find out the quantitative expression of variability of placers, expressed by the coefficient of variation of the gold tenor of gravel in its original state in grams per cubic meter. The values are given in Table 3 and refer to data obtained either by pitting (P) or Banka drilling (BD). The coefficient of variation of gold tenor was computed for the placers listed in Table 3 either in whole, all data considered, or in some cases for workable areas only. By analogy, the results may be generalized for the whole Adola area.

Table 3. **Variability of gold tenor in gravel**

Placer	Area between lines	Gold tenor in gravel: No. of samples	Mean g/cu.m	Variability V per cent	Remark
Shanka	39—61	105	0,63	92	BD; Workable area mainly
Upper Bore	214—252	125	3,52	102	P; Workable area only
	190—220	102	4,22	108	P
Kelecha	66—90	131	1,28	115	BD; Workable area only
	75—77	43	1,28	118	BD; Part of workable area
	66—90	245	1,01	200	BD
Lower Bore	8—42	167	1,04	98	P
	44—90	179	0,89	109	P
Kajemiti	4—114	314	1,67	150	P
	116—138	60	8,45	140	P
Burri	0—50	231	0,32	195	P

The coefficient of variation reflects primarily the properties of the placer, although it can be affected also by other factors such as sampling method, number and quantity of individual samples etc. The values from Table 3 range between 92 and 200 per cent. Accordingly, the placers belong to groups of very- and most irregular mineralizations (Kreiter, 1968). For workable parts of placers, with erratic and extremely high values reduced, an average value of 110 per cent may be characteristic.

It seems that there is no essential difference in variability of tenor between longitudinal and transversal directions in placers.

Table 4. **Variability of gravel bed thickness**

Placer	Area lines	Thickness of gravel bed: No. of samples	Mean m	Variability V' per cent	Coefficient of correlation r (o < r < 1)	Remark
Shanka	39—61	105	1,21	49	—0,06	in whole
Upper Bore	190—220	102	0,61	66	—0,12	in whole
	214—252	125	0,64	52		worked-out area
Kelecha	66—90	245	0,80	60,4	—0,13	in whole
	66—90	131	0,97	51,6		workable area

The thickness of the gravel bed varies as well, an average being in the order of magnitude of about 1 m. The corresponding coefficient of variation of thickness varies between 50 and 60 per cent. It is given for some cases in Table 4. The eventual interdependence between the thickness and the gold tenor of a placer bed was examined for three cases. The coefficient of correlation shows the linear relationship between the two parameters. An average value of about —0,1 was obtained, proving an extremely weak inverse statistical dependence without any practical significance.

There might be a correspondence between the tenor and the composition, and the size of gravel. No evaluations have been made for these interdependences so far.

The distribution of gold in exploration openings and the variable thickness of gravel bed are shown for a part of Kelecha placer in Figure 2. The irregular distribution of gold is evident. There are always low-grade or even barren zones adjoining rich pay streaks as the concentration of heavy gold in running water was affected by its changing velocity and transporting power, both extremely variable in shallow streams.

The variability of gold values along the placers is shown for Kelecha and Lower Bore in Figure 3, the values being the average tenors in individual exploration lines across the placers. The graph illustrates the character of variability of tenor in Adola placers. The diminishing tendency downstream is evident. In the case of Kelecha there was a probable lateral feeding in the headwaters.

The statistical frequency distributions of tenor for Kajemiti, Lower Bore, Kelecha and Shanka placers are shown in Figure 4. The distribution curves have an assymetrical, right skewed form, peaking lower than

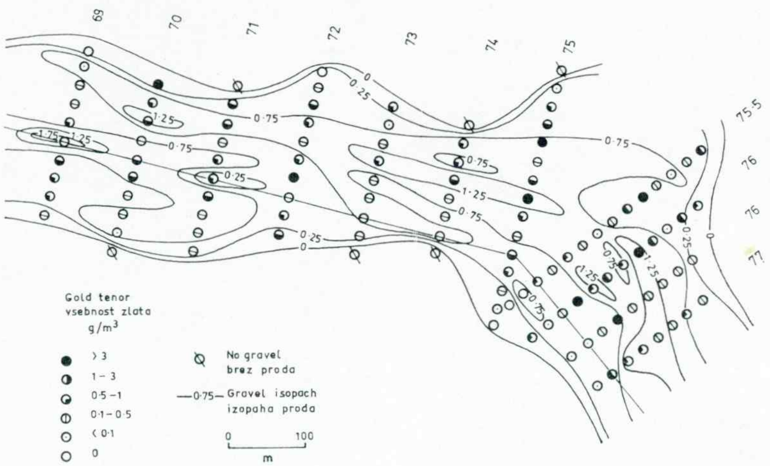

Fig. 2. Detail from Kelecha, showing variability of gold tenor and thickness of gravel bed

Sl. 2 Izpremenljivost vsebnosti zlata in debeline prodne plasti; detajl iz Keleche

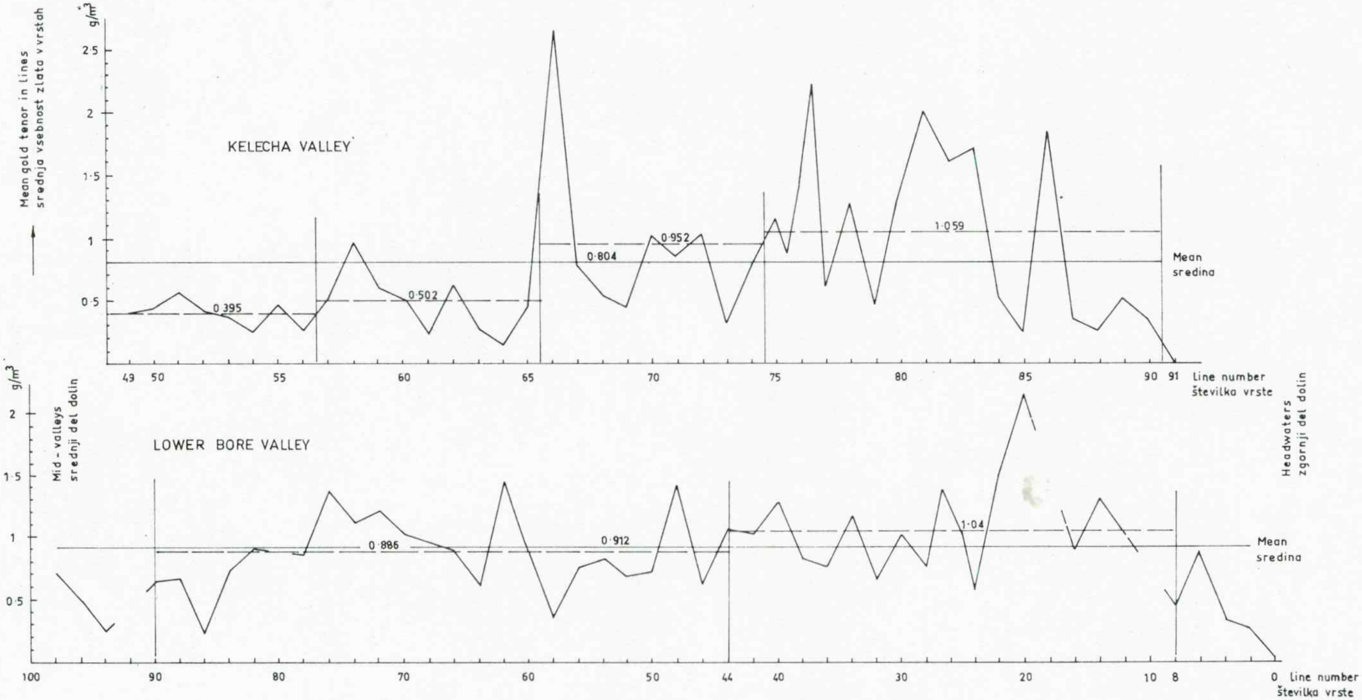

Fig. 3. Distribution of gold tenor (mean values of individual lines) along the placers
Sl. 3. Porazdelitev vsebnosti zlata (srednje vrednosti posamičnih vrst) vzdolž prodišč

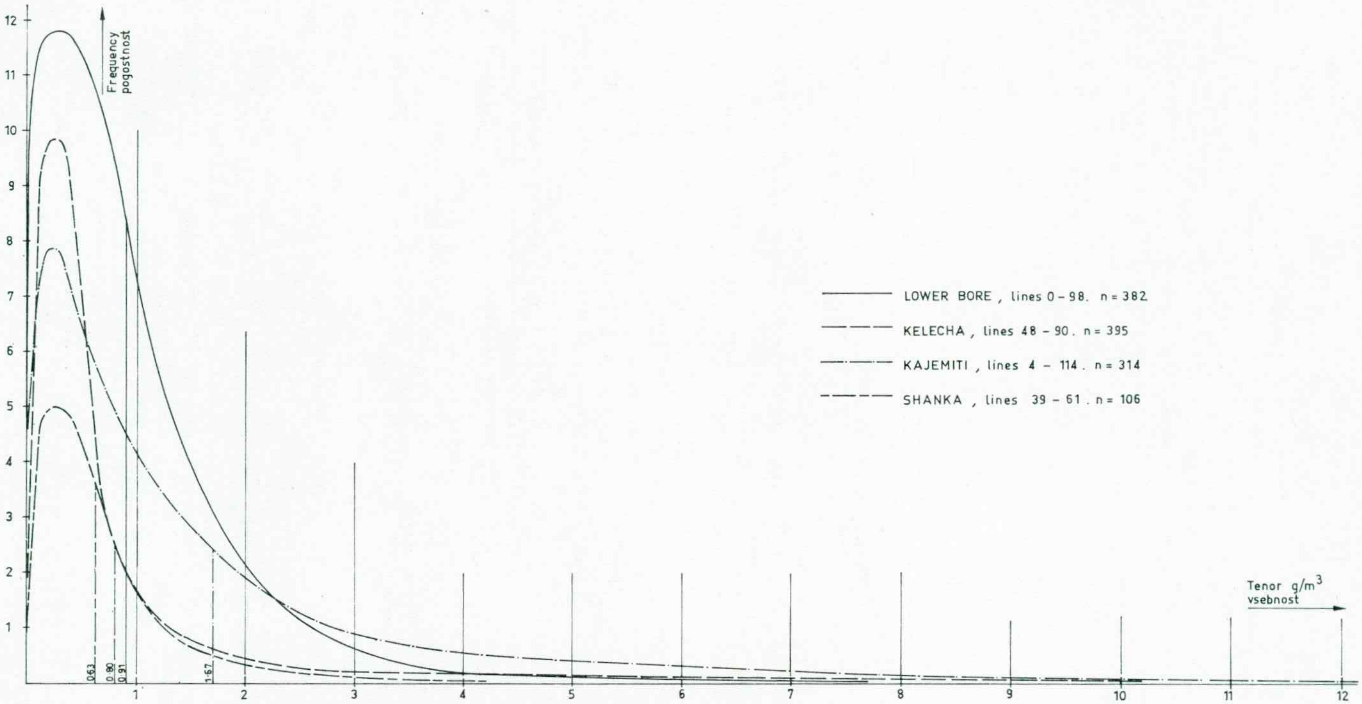

Fig. 4. Frequency distribution of gold tenor in gravel in some placers
Sl. 4. Pogostnost vsebnosti zlata v nekaterih prodiščih

1 g/cu.m. Such a frequency distribution of values is often obtained in mineral exploration. It rarely conforms to normal or Gaussian distribution, thus limiting the direct use of statistical formulas in dependence on the degree of assymetry. Nevertheless, the formulas can serve as approximations to provide rough estimates in search for guidelines in practical exploration.

The average values have been calculated as the arithmetic mean. Although commonly used and easily calculated it is greatly affected by extreme values. Therefore the extreme values must be appropriately reduced in calculations.

Comparison of exploration data and mining results

Errors in mineral exploration are unavoidable. A 100 per cent accuracy of exploration cannot be achieved in practice, and allowances are made for the reliability of reserves accounts.

The recent mining in Adola has rendered possible the comparison of exploration data with those obtained by exploitation. Shanka and Upper Bore placers have been mined so far. The possibility of verifying the reliability of exploration data, however, is limited as factors such as the accuracy of sampling methods and recovery in mining are not exactly known.

The discrepancies between the reserves calculated from the exploration data and those revealed by mining are shown for some cases in Table 5, the geological reserves estimated on an assumed 90 per cent recovery in "wet" dragline mining method. Exploration data were obtained by pitting (P) or Banka drilling (BD), both sampling methods performed in an exploration grid 100 × 25 m.

Table 5. **Discrepancy between the reserves calculated from exploration and mining data**

Placer	Area lines	Reserves of gold in kg calculated A	recovered B	geological C	Discrepancy in per cent $\frac{B}{A} \cdot 100$	$\frac{C}{A} \cdot 100$	Remark
Shanka	1—23	755	795	884	105	117	P and BD
Shanka	39—61	162	215,5	240	133	148	BD
	47—61	82,5	125	139	152	169	BD
Upper Bore	214—252	697	805	895	116	129	P
	234—252	343	364,5	405	106	118	P

The figures reveal a positive discrepancy between 117 and 169 per cent for geological reserves with reference to the exploration data, indicating the order of magnitude only. Nevertheless, there has been more gold mined as shown by exploration. The same sign of error points at a systematic error in both methods of sampling. The discrepancy of about 160 per cent in Banka drilling is very high.

There is no possibility of comparison for handworked placers such as Kajemiti or Demi Denissa because ob unknown and probably extremely low recovery in the applied way of extraction.

Analysis of grid density

The above comparison for the mined-out portions of placers is not sufficient to judge the adequacy of the applied exploration grid. In order to assess its optimum density and the accompanying sampling errors in Adola placers, statistical considerations were applied. It must be pointed out again that the statistical evaluation of an assymetric distribution of values is not but an approximation, and the figures provide for orientation values only.

The principal determinants in the choice of a grid density are the required accuracy, expressed as an allowable error, and the variability of placer. Additional factors to be respected are the size of placer, the sampling method and the economy of exploration as well.

The reserves ready for mining are classified as "measured" reserves. In general, however, an allowable error of $\pm$ 15 to 20 per cent is commonly accepted for the highest category of reserves, regardless the classification. The resulting error of an estimate is the statistical sum of all occurring errors, and shall not be higher than the allowable error.

For the generally low-grade Adola gold placers the allowable error should be in the order of 15 per cent at maximum.

The reserves of gold are calculated of the average tenor and thickness of the gold-bearing gravel. The mathematical mean (Ma) as a statistical measure is calculated with an error (p), which depends on the degree of variability (V) and the number of cases (n). It is expressed as a percentage of the arithmetic mean as shown in the known formulae

$$p = \frac{f\,V}{\sqrt{n}} \quad \text{and} \quad n = \left(\frac{f\,V}{p}\right)^2$$

The greater the number of samples, or the denser the grid, the smaller the error and the greater the variability, the greater the error. Factor (f) refers to the probability of error. In rough use of the formula it can be accepted to equal 1. The error determines the accuracy of the arithmetic mean Ma $\pm$ fp.

Theoretical relationship between error (p) and number of samples (n) is shown in Figure 5 for various coefficients of variability. It can be seen that by increasing the number of samples the values of error do not diminish proportionally.

The above formula does not consider the disposition of sampling points in a placer. However, a regular grid pattern with uniformly spaced openings is required to provide correct information on the whole placer. The formula is also independent on the size of the placer. Introducing the unit area for sampling point (F_0), defined as part of the total area (F) of a

Table 6. **Errors pertaining to the arithmetic mean tenor of gold in gravel in dependence on grid density**

Placer	Area lines	Spacing m	Total area $10^3 \times$ sq.m	Unit area sq.m	No. of samples n	Ma g/cu.m	Vav per cent	$p_1$av	Remark
Shanka	39—61	25	211	2040	105	0,63	92	8,94	workable area mainly
		50		4080	52		87,2	12,05	
		100		8160	26			ND	
		200		16320	13			ND	
Kelecha	66—90	25	310,5	2370	131	1,28	115	10,1	workable area
	66—90	25	533	2200	245	1,01	200	13,3	in whole
Upper Bore	214—252	25	314	2500	125	3,52	102	9,1	worked-out area
	190—220	25	247	2420	102	4,22	108	10,7	in whole
Lower Bore	8—42	25	433,5	2590	167	1,04	98	7,6	in whole
		50		5180	83		98,7	10,7	
		100		10360	46		94,8	14,7	
		200		20720	21		92,5	20,2	
	44—90	25	465	2600	179	0,89	109	8,2	in whole
		50		5200	90		107	11,3	
		100		10400	45		106	16,1	
		200		20800	23		102	21,6	
Kajemiti	4—114	25	787	2500	314	1,67	150	8,5	in whole
		50		5000	157		142	11,4	
		100		10000	78		147	16,6	
		200		20000	39		140	22,3	
	116—138	25	150	2506	60	8,45	140	18,5*	in whole
Burri	0—50	25	600	2500	231	0,32	195	12,8	in whole

ND not determined; * exceptional, erratic value

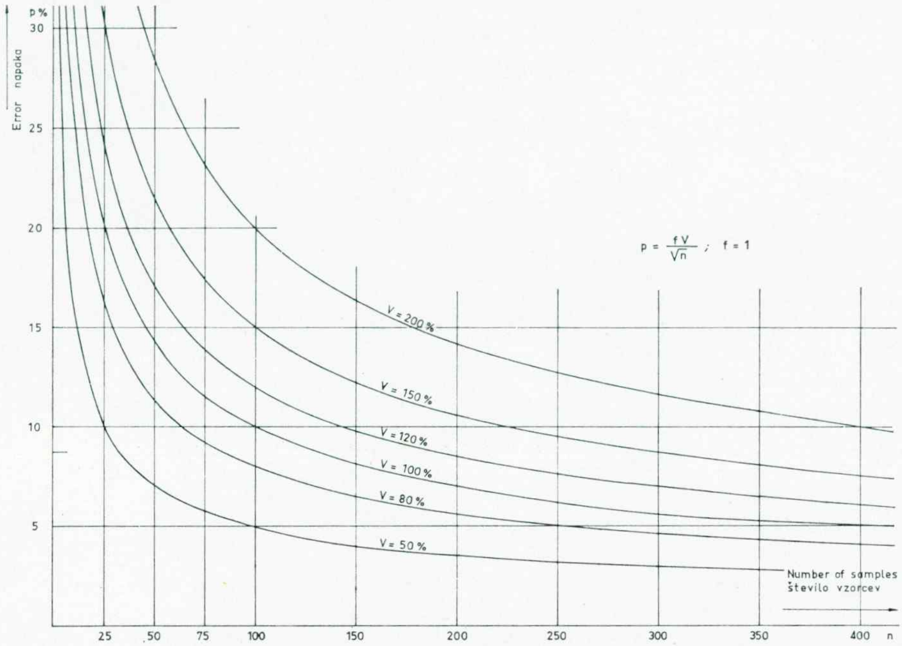

Fig. 5. Relationship between error of the mean and number of samples for different values of coefficient of variation

Sl. 5. Odvisnost napake sredine od števila vzorcev za različne vrednosti koeficienta variacije

placer $F_0 = \frac{F}{n}$, the above formula is expressed as $p = V \sqrt{\frac{F_0}{F}}$ and the unit area $F_0 = \frac{p^2}{V^2} F$.

If the allowable error is known the unit area can be calculated, determining the density of the exploration grid. For the same error the unit areas are in linear relationship with the total areas. The larger the placer, the fewer openings are required for the same error, and the more economical the exploration.

The unit area for a rectangular 100 × 25 m grid commonly used hitherto in Adola is 2 500 sq.m. The errors pertaining to the arithmetic mean tenor in gravel for this and larger unit areas were calculated for several of the explored Adola placers by omitting the appropriate number of data, considering spacings 25, 50, 100 and 200 m in lines 100 m apart. The average values of errors were calculated of 2, 4 and 8 tests correspondingly. The values are shown in Table 6 together with other data.

The relationship between the standard error of the arithmetic mean tenor (p_1) and the spacing, or the unit area, is given in Table 8. The figures are approximate average values, preference being given to the results from workable areas.

Table 7. **Errors pertaining to the arithmetic mean thickness of gravel bed**

Placer	Area lines	Spacing m	Unit area sq.m	No. of samples n	Ma′ m	V′av per	$p_2$av cent	Remark
Shanka	39—61	25	2040	105	1.21	49	4,75	in whole
Kelecha	66—90	25	2200	245	0.80	60,4	3,85	in whole
	66—90	25	2370	131	0.97	51,6	4,50	workable area only
Upper Bore	190—220	25	2420	102	0.61	66	6,56	in whole
	214—252	25	2500	125	0.64	52	4,61	worked-out area

Similarly, the error of the mean thickness of the gravel bed has been calculated for several cases. It is given in Table 7.

The order of magnitude of the standard error of the mean thickness (p_2) for a unit area of about 2 500 sq.m, or a spacing of 25 m, would be about 4,8 per cent. Supposing that the relationship between this error and the grid density is in a similar functional depedence as that for the tenor, the approximate corresponding values are tentatively given in Table 8. The relationships are shown also graphically in Figure 6.

Table 8. **Relationship between standard errors of the arithmetic mean p_1 and p_2 and grid density**

Spacing in lines 100 m apart m	Unit area sq.m	Order of magnitude of standard error in per cent: of mean tenor p_1	of mean thickness p_2
10	1000	6	3
25	2500	8,7	4,8
50	5000	11,5	6,4
100	10000	15,8	8,8
200	20000	21	11,7

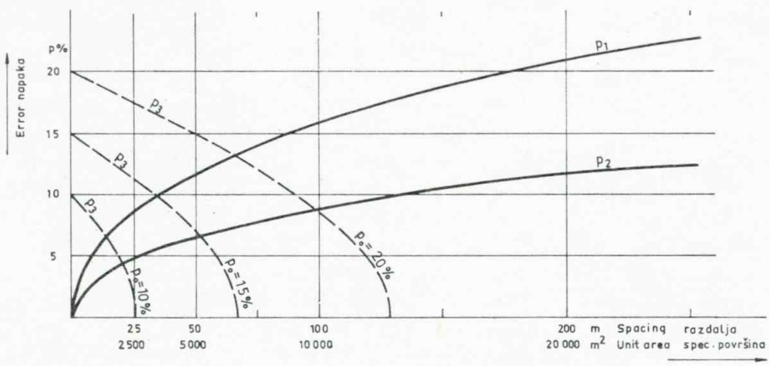

Fig. 6. Relationship between errors p_1, p_2 and p_3 and spacing or unit area
Sl. 6. Odvisnost napak p_1, p_2 in p_3 od razdalje oziroma specifične površine

The accuracy of reserves estimate is influenced by additional errors in sampling operations and measurements, which can be embraced together as the technical error (p_3). Errors are random and systematic. Random errors may occur in measuring volume, thickness and distance, weighing the gold, determining areas from the maps etc. (measuring error p_m). In a sufficiently high number of cases random errors cancel out as they have alternate signs. Systematic errors may influence the results considerably more. In conditions of Adola exploration they can arise from the following sources:

(a) Problematic determination of volume of excavated gravel because of swelling (swell error p_s),

(b) Uncertainity of volume of recovered Banka samples (volume error p_v),

(c) Technical shortcommings in sampling because of inaccurate and poor performance of labour (operation error p_w),

(d) Losses of gold in panning (panning error p_p),

(e) Confusion in evidence of samples, loss or even theft of gold (care error p_c),

(f) Errors in calculations (calculation error p_{cc}).

However, the possible sources of errors are objective and subjective in nature. Means shall be found how to reduce or eliminate them.

Since the figures of reserves are calculated by multiplication and addition of not related values with errors pertaining to them, the resulting error (p_o) is obtained by addition of squares of partial errors

$$p_o^2 = p_1^2 + p_2^2 + p_3^2 \text{ and } p_3 = \sqrt{p_o^2 - p_1^2 - p_2^2}$$

Introducing the guide-values from Table 8 for three cases of allowable error (p_o) 10, 15 and 20 per cent, the corresponding values of technical error (p_3) are shown in Figure 6.

The relationship between the resulting error (p_o) and the unit area or spacing is better illustrated for four cases of technical error (p_3) 5, 10, 15 and 20 per cent in Figure 7. The values are given also in Table 9.

Table 9. **Relationship between resulting error p_o and grid density**

Spacing in lines 100 m apart m	Unit area sq.m	Resulting error p_o in per cent for p_3: 5	10	15	20 per cent
0	0	5	10	15	20
25	2500	11	14	18	22
50	5000	14	16,5	20	24
100	10000	19	21	23,5	27
200	20000	24,5	26	28	31

A general conclusion can be made, however, that in Adola conditions with an estimated margin of technical error ± 10 per cent the unit area must be kept at about 2 500 sq.m per sampling point, if an approximate

± 10 to 15 per cent degree of reliability of reserves estimate shall be expected. Provided the margin of technical error will be lowered by improved quality of work, the unit area might be enlarged to 5 000 sq.m, especially in large placers.

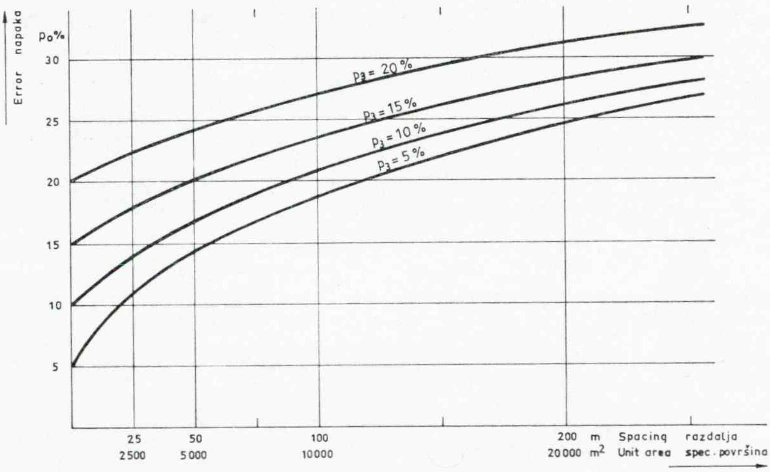

Fig. 7. Relationship between resulting error p_0 and spacing or unit area
Sl. 7. Odvisnost končne napake p_0 od razdalje oziroma specifične površine

From the point of view of variability of placers there is no need to adhere to the introduced 1 : 4 rectangular exploration grid as the anisotropy in placers is not strong. A 50 × 50 m square grid would be well applicable. Even better would be a rhomboid grid with lines 50 m apart and spacing 50 m, the diagonal 100 m in the longitudinal direction of the placer as shown in Figure 8. It could have also a uniform spacing of 54 m between pits, the lines 47 m apart in this case.

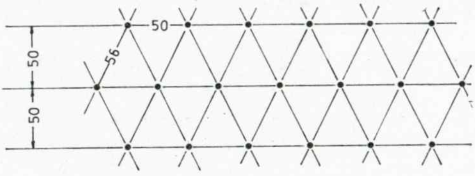

Fig. 8. Proposed rhomboid grid
Sl. 8. Predlagana romboidna mreža

Exploration in rows, however, has certain advantages in hard-passable bush country.

In deciding on the grid density the total area of a placer is to be considered, and the necessary number of samples approximately established. It may be increased or reduced, depending on how the probable errors would be influenced.

Sampling

Pitting and Banka drilling as sampling methods differ essentially in the quantity of produced samples. In Banka drilling, the obtained core is already a direct partial sample of the placer. In pitting, the relatively large intermediate samples have to be first reduced to partial samples, introducing so an additional reduction error (p_r), which, in turn, is part of the technical error. As Banka sampling is burdened with errors too there is no clear advantage in reliability for one or another of the methods. Anyhow, in groundwater-logged and swampy ground Banka drilling is the only applicable method. Both methods require good organization and supervision.

There is a loss of gold in washing the gravel as well, this being another source of error. The weighing of gold on sensitive analytical balance can be performed accurately.

P i t t i n g. Pitting is a slow process applicable in dry, well-standing ground. Round pits are prefered, the diameter being in the order of 0,7 m. Working at a piece-rate system, the diggers automatically keep the diameter at the minimum.

The unit volume of gravel *in situ* in a 0,7 m diameter pit measures 0,384 cu.m, and about 0,48 cu.m when loosened, its weight nearing a ton. Such a quantity is to large to be washed by panning as is the established practice in Adola. For application of sluice-boxes about 4 cu.m of water would be required per unit volume, a requirement not easily met in mainly dry Adola valleys. In addition, by treating the whole quantity of excavated gravel, the errors in volume as well as losses in handling, transport and washing the gravel are unavoidable. So, the samples must be reduced. In the past, at Adola, the quantity washed in pitting was 0,1 cu.m, or sometimes even 10 random bateas of gravel (about 0,07 cu.m each) were washed only.

The minimum required volume (weight) of one partial sample depends on factors variable within the limits of a placer. The low tenor and very irregular distribution of minute gold grains, together with highly changing size of gravel, would require large samples. On the other hand, the weight of partial samples shall be kept as low as possible from the point of view of economy.

The reduced sample shall represent as closely as possible the tenor of the excavated gravel from the pit. The intermediate sample cannot be worked down as in treatment of samples of primary deposits, and there are no formulae for determining the reliable sample quantity of gold-bearing placers. It is important to keep the granulometric composition of reduced samples as unchanged as possible by having the material completely mixed up. However, the reduction error is lower, the larger the reduced sample and the higher the number of partial samples. Hawing this in mind, the excavated gravel shall not be reduced too much, especially in coarse gravel.

The following procedure has been adopted recently in reducing the intermediate samples. The excavated gravel is piled up on a clean ground, thoroughly mixed up and flattened on a 15 cm high wooden cross to get it quartered. A channel is made from the periphery to the center of each quarter to fill a standard unit of measurement. It is a trough-like wooden box 15,3 cm high, measuring 60 $\times$ 30 cm at the top and 60 $\times$ 20 cm at the bottom, its volume being 0,023 cu.m. The gravel in the box is well compacted. Mainly for the sake of easier calculating, and additional sample is taken to have 5 boxfuls as one partial sample, totalling 0.1 cu.m of gravel in a compacted state and weighing about 200 kg.

The volume of samples is problematic because of the swelling of gravel in loose condition. The gain in volume may be the source of a dangerous error. It is measured by the ratio of volume of loose gravel against undisturbed volume (swell factor). Several tests gave values ranging between 1,05 and 1,4. Swell factor varies considerably for different sizes of gravel, which range between that of coarse sand and boulders of several decimeters in diameter. However, an average value of 1,25 has been assumed for Adola gravel, this being, of course, a rough general approximation.

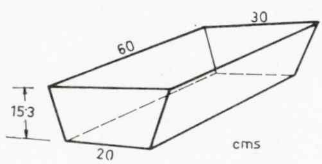

Fig. 9. Dimensions of standard unit of measurement
Sl. 9. Dimenzije standardne merske enote

The dimensions of the standard box (Fig. 9) were established on the assumption that the loose gravel can be compacted to about half of its original undisturbed volume. Thus the volume of compacted gravel in one box would correspond to 0,02 cu. m of undisturbed gravel. It depends also on how well and diligently the compacting and tamping has been done.

Tests were carried out to check the reduction error for the described procedure. The quantity of gold was determined in single boxfuls and a series of 4 boxfuls for which the mean deviation from the arithmetic mean was calculated as given in Table 10.

A roughly calculated average mean deviation of gold tenor in gravel for series of 4 boxfuls (totalling 0,08 cu.m) is in the order of magnitude of 10 per cent. In terms of the average gold tenor of placers, this means a possible reduction error (p_r) of:

$\pm$ 17 per cent for a placer displaying an average gold tenor of 0,6 g/cu.m
$\pm$ 10 per cent for a placer displaying an average gold tenor of 1 g/cu.m
$\pm$ 5 per cent for a placer displaying an average gold tenor of 2 g/cu.m
$\pm$ 3,3 per cent for a placer displaying an average gold tenor of 3 g/cu.m

The error will be even smaller because 5 boxfuls instead of 4 are used in reducing the intermediate samples. It may be expected to cancel out since the probability of deviations in either direction is equally great.

Table 10. **Mean deviation from the arithmetic mean of gold tenor for series of unit boxes**

Placer	Pit No.	No. of series of 4 boxfuls n	No. of boxfuls N	Gold quantity as average of n series g	Mean deviation per one series g	Mean deviation expressed in g/cu.m
Kelecha	35/100N	8	32	0,040	0,0205	0,20
	35/125N	7	28	0,0094	0,0042	0,05
	39/0	4	16	0,0172	0,0038	0,05
	40/25S	4	16	0,0132	0,0037	0,05
	40/50S	$3\frac{1}{2}$	14	0,0429	0,0164	0,20
	40/25N	4	16	0,0077	0,0022	0,03
	40/100N	3	12	0,0073	0,0016	0,02
	40/125N	2	8	0,0061	0,0005	0,01
Ababido	1/0	6	24	0,0183	0,0036	0,04
	2/150W	7	28	0,0621	0,0347	0,40
	2/175W	4	16	0,0175	0,0087	0,11
Burri	0/250W	4	16	0,0355	0,0072	0,09
	0/275W	2	8	0,050	0,010	0,12
		Average		0,0252	0,009	0,10

The same might be expected, however, for the swell error. Under unfavourable conditions the errors may accumulate to a significant systematic error. It is believed that most discrepancies in the past were closely connected with errors in reduction and swelling.

About 10 cm of bedrock is excavated in the pits. In has been a common practice in Adola to wash 1 batea of bedrock only (about 0,007 cu.m). An additional error originates in this way.

B a n k a   h a n d   d r i l l i n g. Banka drilling is a quick, clean and cheap method if properly executed. It is simple to operate and easy to transport. On the other hand it is not applicable in very coarse gravel and may not be sufficiently accurate because of relatively small volume of core. The evaluation of the data is liable to errors because of uncertain volumes of recovered samples. The general view prevails that banka drilling in placers yields lower results than pitting, and this was proved also in the past for Adola.

$6^{1}/_{2}$ inch Banka hand drills have been used in Adola exploration. The method applied recently is basically similar to that suggested by G r i f f i t h (1960). In clayey overburden a spiral auger is used. On reaching the gravel, casing is lowered and the depth of overburden noted. The casing is hammered down through the gravel into the bedrock for about 25 cm. The total length of casing is measured, and after pulling it out, the thickness of the penetrated bedrock is established and deducted from the total length to obtain the thickness of gravel indirectly. A 100 per cent core recovery is (theoretically) assured in this way, and the problematic consideration of swelling of the loosened gravel avoided.

The casing is emptied and the entire quantity of gravel washed as one sample. About 10 cm of bedrock is washed together with the gravel.

Since the diameter of Banka casing is small the recovered volume of gravel per meter is about 0,018 cu.m, and its weight about 36 kg only. The calculation of tenor per cubic meter of gravel is a sensitive operation, depending heavily on the volume gathered inside the casing, which, in turn, is affected by the size of gravel and the sharpness of the cutting edge of the casing shoe. In other words, the diameter of casing to calculate with is a variable quantity which may be the source of a systematic error. Griffith (1960) suggests the use of the external diameter ∅ 165 mm. Internal diameter ∅ 136 mm was used in recent calculations by the author (1970), the choice based mainly on the past results and coarse gravel, but a wide —21 per cent margin of possible error was taken into account. Looking at the section of the cutting-shoe of the casing shown in Figure 10, it is evident that some gravel under the cutting edge will be pushed aside, especially when it is coarse. Cobbles and boulders may even partly or completely block the entrance, bringing up little or no sample at all.

The conclusion is, that in only very fine-grained material, and with a sharp bevelled edge of the cutting shoe, the external diameter shall be used in calculations. The coarser the material the smaller the diameter to be

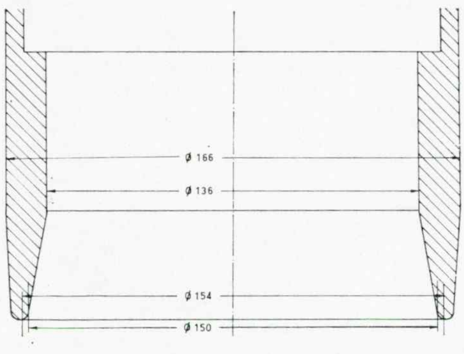

Fig. 10. Section of 6 ½ inch Banka casing shoe

Sl. 10. Prerez »čevlja« 6 ½ colskih Banka obložnih cevi

used. No corresponding tests have been made to date. As long as this is not done the median diameter ∅ 150 mm and specific volume 17,7 cu.dm/m might be the best dimension to be considered.

Specific volumes for Banka casing diameters and the differences of volume in per cent with reference to the internal diameter ∅ 136 mm are given in Table 11.

Comparing the quantity of one Banka partial sample (about 36 kg/m) with that in pitting (about 200 kg), the question arises how representative are both samples? There is no reduction in Banka sampling. Samples of regular cylinder form are cut across the gravel bed regulary, and this may be advantageous if compared with a constant volume of partial samp-

Table 11. **Data on specific casing volume in Banka hand drilling**

Diameter ⌀ mm	Theoretical specific casing volume cu. dm per meter	Difference per cent	Remark
136	14,52	0	internal ⌀
150	17,66	21,6	
154	18,62	28,2	
160	20,00	38	
165	21,40	47,5	external ⌀

les in pitting, regardless of the thickness of gravel. The representativeness of Banka samples is theoretically perfect. In practice this is valid for fine-grained material and less for coarse gravel.

Sampling by pitting and Banka drilling is schematically illustrated in Figure 11, with errors listed for both methods. The statistical sum of the reduction error (p_r) plus swell error (p_s) in pitting is confronted with a volume error (p_v) in Banka drilling, the rest of the errors approximately equal in both methods. The sum of both errors in pitting might be expected to range about 10 per cent in average. They are random and may even cancel out. The volume error in Banka sampling is difficult to assess. It may be believed that in average its effect would not be essentially different from the combined effect of both errors in pitting. This question could be answered, at least partially, by a series of comparison experiments.

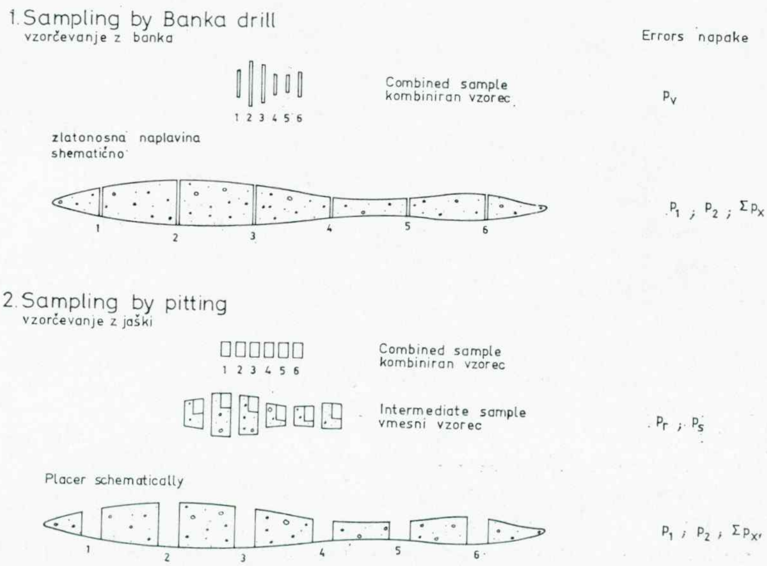

Fig. 11. Schematic illustration of sampling by Banka drilling and pitting
Sl. 11. Shematski prikaz vzorčevanja z napravo Banka in jaški

H a n d w a s h i n g o f g o l d. Gold is recovered from gravel by hand-panning on wooden bateas. Some fine gold may be lost in panning by unskilled panners, or when muddy water is used for washing. Due to the shortage of water this might be quite often the case. The average recowery in panning is not known, but evidence exists that losses do occur and contribute to errors.

Hand panning in Adola is a long established practice, which would be difficult to replace by sluice-boxes, rockers or mechanical pans. Although the capacity of these devices is higher it is questionable if the recovery would be better. Careful handwashing on bateas may yield the best possible recovery if clear water is used, at least comparable to that of mechanical washing plant used in "wet" mining.

Costs and performance

The errors in sampling can be reduced by increasing the number of samples. A balance must be found between the necessary accuracy and the economy of exploration, although in low-grade deposits the expense should not be always the decisive factor.

In hand pitting, a crew of two workers dig one pit. Performance and costs in the recent exploration campaign are given in Table 12.

Table 12. **Performance and specific costs in pitting**

Placer	Total depth m	No. of pits n	Average depth m	Performance per cal. day Efficiency m/man	Progress m/pit	Cost per meter net* E$	gross E$
Kelecha	329,20	68	4,84	0,51	1,02	3,71	5,93
Burri	3470,60	255	13,62	0,51	1,02	3,69	4,65
Lower Bore	2768,90	221	12,55	0,53	1,06	3,40	3,88
Ababido	1500,25	187	8,01	0,50	1,00	3,30	4,60
Total	8068,95						
Average			9,75	0,51	1,02	3,53	4,765

* labour only

The average efficiency in pitting is 0,51 m per man per calendar day, and the average progress 1,02 m per pit correspondingly. A monthly average of 31 m was achieved per pit or a crew of two. A piece-rate system of payment was introduced. It seems difficult to raise this efficiency much more under the existing conditions, but progress can be increased by digging more pits at the same time.

In Banka hand drilling, an equal specific efficiency per man can be achieved in the best case. The progress, however, is much better than in pitting. A short account of performance and costs in Banka hand drilling is given in Table 13.

Table 13. **Performance and specific costs in Banka hand drilling**

Placer	Total depth m	No. of boreholes n	Average depth m	Performance per cal. day: Efficiency m/man	Performance per cal. day: Progress m/drill	Cost per meter: net E$	Cost per meter: gross E$
Wollabo	150,55	41	3,67	0,16	2,56	9	9,5
Awata terraces	131,35	27	4,86	0,26	4,35	9,50	10,15
Kelecha — average	973,42	432	4,57	0,42	6,30	6,58	8,30
best results	(517,80)			(0,57)	(8,60)	(4,32)	(5,92)
Average			4,40	0,28	4,4	8,4	9,3

The collective nature of work under a concentrated supervision and favourable field conditions made it possible to achieve a speed up to 8 times higher than in pitting. In Kelecha, for instance, two or three drills operated simultaneously in tandem, the workers changing continuously in order to reduce breaks in progress. The efficiency was stimulated by a collective bonus system. A crew of 14 drilled 8 m per 8 hours shift, all working phases included. Comparing with the efficiencies of less than 2 m per drill per 8 hours shift achieved in Adola previously, this was about 4 times higher.

The relative comparison of average costs and efficiency per man as well as progress per sampling point is given for both methods in Table 14.

Table 14. **Comparison of specific costs and efficiency of pitting and Banka hand drilling**

Operation	Performance per cal. day: Efficiency m/man	Performance per cal. day: Progress m/sampling point	Specific cost: net E$	Specific cost: gross E$	Progress-to-cost ratio
Pitting — average	1	1	1	1	1
Banka drilling — average	0,55	4,3	2,37	1,95	2,25
best results	(1,12)	(8,4)	(1,22)	(1,24)	(4,3)

As cost is concerned, digging two pits would correspond approximately to operating one Banka drill, the progress in Banka twice that of pitting at least. The advantage in speed of Banka drilling over pitting is evident. Considering the better representativeness of Banka samples and approximately equal average reliability of both methods, Banka sampling is the superior method, especially in favourable conditions and when time is the decisive factor. On the other hand, linking the accuracy with the cost, the number of pits for the same money is twice that of Banka operation, favourably influencing the reliability but loosing time.

Conclusions

In sampling Adola placers by pitting or Banka drilling an average ± 15 per cent reliability of reserves estimate can be expected in general for a unit area in exploration grid of about 2500 sq.m, provided the sampling operations are carried out carefully.

Banka hand drilling, if properly executed, is generally advantageous over pitting in terms of economic efficiency. Its accuracy depends on the size of gravel and may, however, compete with that obtained by sampling in pitting. Some experiments would be needed to check it. Until further data are available the median diameter of casing shall be considered. Banka method is not applicable in very coarse gravel.

A square grid 50 × 50 m or a rhomboid one 100 × 50 m should be used wherever possible.

In the past, exploration in Adola seems to have been suffering mainly from systematic negative errors attributed to swelling in pitting, and incorrect execution of coring in Banka drilling. The applied unit area of about 2500 sq.m per sampling point was appropriate. As the reliability of data, the gold tenor values are slightly underestimated in average.

In an evaluation attempt such as this, certain assumptions have been made. Hence, no mathematically precise results can be produced, and prescriptions cannot be laid down as how to eliminate the errors. There are many objective and subjective factors involved, some of them hardly controllable in Adola.

Statistična ocena raziskav zlatonosnih naplavin na območju Adole (Južna Etiopija)

Milan Hamrla

V državnem rudniku Adola, okrog 500 km južno od Addis Ababe, pridobivajo zlato iz proda, ki so ga nanesle reke verjetno v pluvialu kvartarja. Doline z zlatonosnimi naplavinami so danes povečini suhe. Prvotna nahajališča zlata so v bližini, vendar niso raziskana. Naplavine leže na predkambrijskih skladih, prekrite pa so z glino. Debelini zlatonosnega proda in prekrivke sta v razmerju 1 : 1 do 1 : 20. Povprečna vsebnost zlata v produ je 1 do 2 g/m^3. Zlato pridobivajo ročno in mehanično.

Koeficient variacije vsebnosti zlata v produ se menja med 90 in 200 % za različna nahajališča, za območja naplavin, ki so primerna za izkoriščanje, pa je v povprečku okrog 110 %. Tudi debelina prodne plasti se menja; povprečna vrednost ustreznega koeficienta variacije je 55 %. Zelo slaba inverzna odvisnost vsebnosti zlata in debeline prodne plasti je brez praktičnega pomena.

Naplavine vzorčujejo z jaški ali pa z vrtalno napravo Banka. Kot je pokazalo rudarjenje, so rezultati preteklega raziskovalnega dela podani z negativno sistematsko napako; v resnici so bile pridobljene količine zlata vedno nekoliko večje od izračunanih.

Navadno vzorčujejo po mreži 100 $\times$ 25 m, ki ji utsreza specifična površina 2500 m^2. Rezerve računajo iz povprečne vsebnosti zlata v kubičnem metru proda v prvotnem, zbitem stanju in povprečne debeline prodne plasti. Oba parametra sta kot aritmetična sredina določena z napakama (p_1,p_2), ki rasteta, če je mreža redkejša in specifična površina večja, oziroma število vzorcev manjše. Točnost vzorčevanja je odvisna še od drugih napak, ki jih označimo skupno kot tehnično napako (p_3). Pri jaških sta to predvsem napaki zaradi povečanja volumna izkopanega proda (p_s) in njegovega reduciranja (p_r), pri Banka napravi pa volumska napaka (p_v) zaradi negotovega volumna pridobljenega vzorca v odvisnosti od debeline proda. Vse te napake je številčno težko zajeti, ker so odvisne v glavnem od izredno hitro spremenljive granulacije proda. Tehnično napako ocenjujemo v povprečku z 10 do 15 %.

Končna napaka določitve rezerv zlata v relativno siromašnih adolskih naplavinah ne bi smela biti dosti večja od $\pm$ 15 %. Iz grobega računa statistične vsote napak sledi, da tej zahtevi ustreza vzorčevanje v mreži s specifično površino okrog 2500 m^2 pri sedanjem načinu in točnosti izvedbe. Doslej uporabljena mreža je torej pravilna. Če bi bilo vzorčevanje izvedeno precizneje, bi bilo mogoče mrežo razširiti.

Primerjava učinkovitosti vzorčevanja z jaški in napravo Banka pokaže, da je ta bistveno hitrejša, vendar še enkrat dražja v povprečku. Gre ji prednost. V debelem produ pa njena točnost ni zanesljiva, kar bi bilo treba dognati s poskusi.

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