Water Inflow Patterns in Zambian Mines

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ABSTRACT

An analysis of pumping figures suggests that there are two distinct styles of water inflow patterns in Zambia's mines.

Carbonate hosted orebodies (Kabwe and Nampundwe) display a characteristic seasonal variation in water inflow with peak pumping showing a short time lag with respect to the rainfall pattern. Aquifer characteristics are controlled by secondary, weathering enhanced, near surface phenomena.

Non-carbonate hosted orebodies such as those of the Copperbelt (Konkola and Nkana) occur in successions of highly variable lithology and consequently there are stacked aquifers of variable character. Inflow of water does not display seasonal variation. The major factors affecting the amount of inflow are the structural setting, the geometry of the orebody and the local lithostratigraphy. Thus the Konkola orebodies which occur in a saddle shaped open ended basin result in what is probably the wettest mine in the world, pumping some 376,000 cubic metres of water a day.

INTRODUCTION

There are a total of eight major base metal mining centres currently operational in Zambia. Six of these occur on the Copperbelt, the remaining two (Kabwe and Nampundwe) lie further to the south and in markedly different geological settings. To compare the influence of host rock geology and structural setting on water inflows, data from the Kabwe and Nampundwe

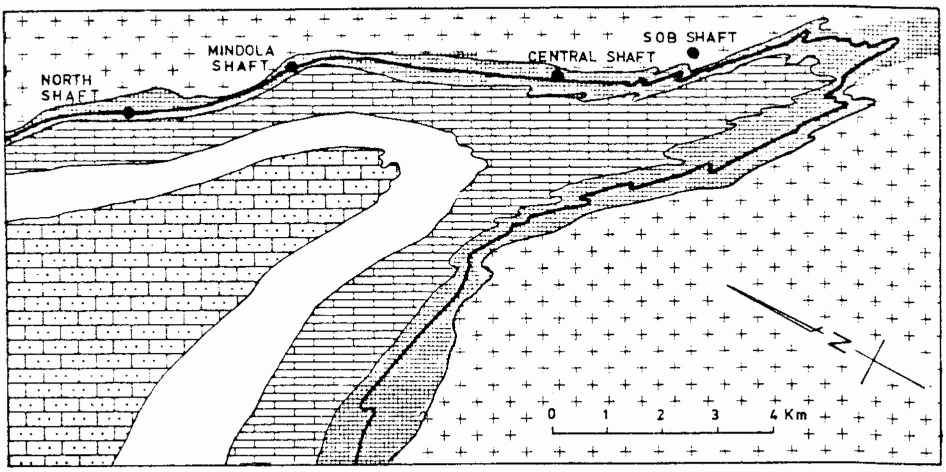

Figure 1b Simplified geological map of the Nkana Mining Area

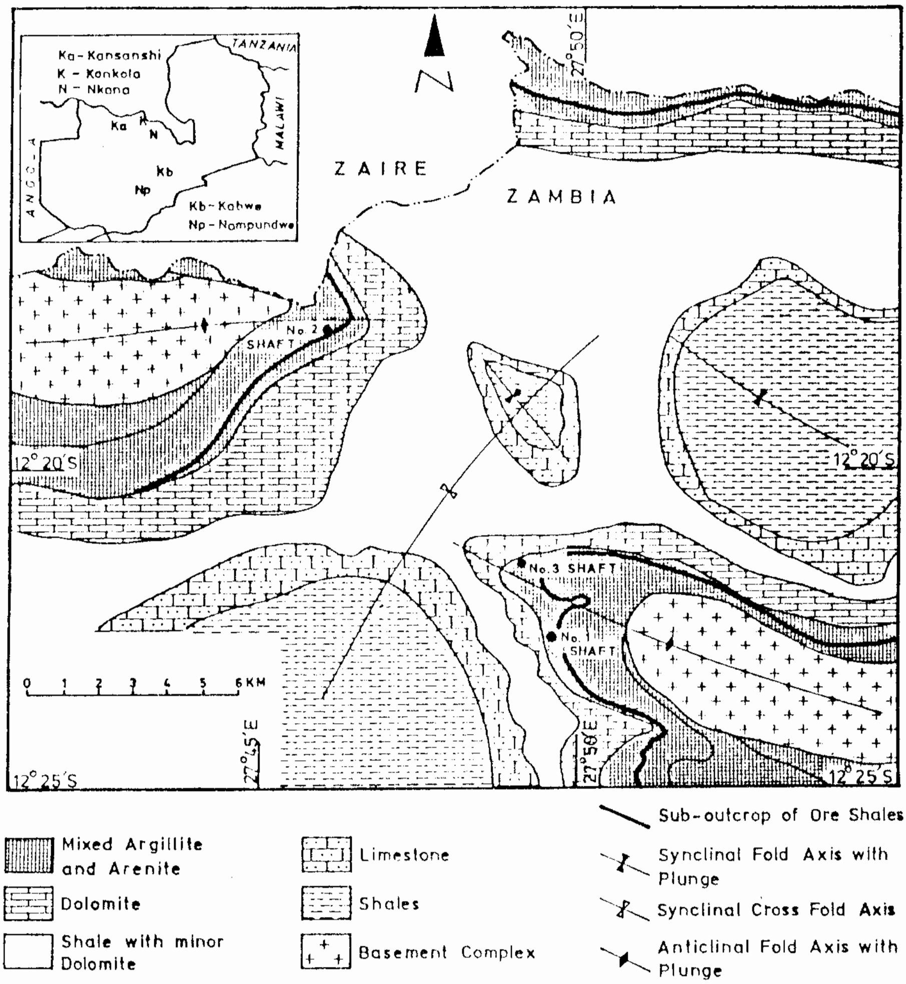

Figure 1a Simplified geological map of the Konkola Mining Area

mines were contrasted with data from the Konkola and Nkana mines, the latter two having broadly similar geology but differing structural settings.

After a brief review of the geology, the rainfall and pumping data for each mine area are analysed using time series analysis (1) and cross correlation programs (2). Time series analysis was used to detect any periodicity in the rainfall and pumping figures. Since both of data sets are expected to display a time dependant variation, cross correlation is used to compare both time series and test for significance.

Unsupported mining methods are employed at all of the mines studied therefore to ensure safe mining active dewatering policies are employed at each of the mines. Pumping figures were used as a measure of water inflows instead of measured borehole inflow volumes. This is because pumping figures are more regularly monitored and also include casual inflows from joints etc. which can yield significant volumes of water.

GEOLOGICAL SETTINGS

COPPERBELT OREBODIES

The geology of the Copperbelt has been discussed in detail in a number of publications (3,4). The orebodies occur in the Lower Roan Group of metasediments which overlie granites and other rocks of the Basement Complex.

A stratagraphic correlation between Konkola and Nkana (approximately 70kms apart) is shown in Table 1, included on this are the major water bearing horizons. Due to the paucity of age dating and fossils this correlation is based mainly on lithological similarities. The best estimate for the age of ore horizon is 1055My (5).

The major structural feature of the region is the SE to NW trending Kafue Anticline. It is in the folded Lower Roan sediments draped around this anticline that the major Copperbelt orebodies are sited. The rocks of the Lower Roan have been subjected to three tectono-thermal events. The result of these deformation events has been a tightening of depositional basins with concomitant folding and associated jointing, minor normal faulting and thrusting.

Series	Group	KONKOLA Formational Name	KONKOLA Lithological Description	KONKOLA Aquifer Zone	NKANA Formational Name	NKANA Lithological Description	NKANA Aquifer Zone
KUNDELUNGU	LOWER KUNDELUNGU	KAKONTWE LIMESTONE	Limestone, dolomite		KAKONTWE LIMESTONE	Black to grey limestone	Unencountered to date
			Tillite		TILLITE	Tilloids and shales	
MINE	MWASHIA	MWASHIA SHALES	Dolomitic siltstones and shales in places massive dolomite			Limestone and dolomite with thin shale interbeds	
			Conglomerate			Argillite, dolomitic argillite and sandstone Minor conglomerates	
	UPPER ROAN	UPPER ROAN DOLOMITE	Dolomite with interbedded sandstone and shale		ULTRA FOR WATER	Argillite, dolomitic argillite, dolomite	
					FOR WATER	Shale with grit Dolomite	Lithological (mainly car.)
	LOWER ROAN	SHALE WITH GRIT	Siltstone with grit bands		HANGINGWALL FORMATION	Dolomite argillite sequence Upper quartzite	and structurally controlled
		HANGINGWALL AQUIFER	Massive dolomite Interbedded siltstone sandstone and dolomite			Near water sediments Hangingwall quartzite	Structurally controlled
		HANGINGWALL QUARTZITE	Quartzite with argillite bands	Aquiclude	ORE FORMATION	Hangingwall argillites Orebody member	
		ORE SHALE	Siltstone with carbonate	Aquiclude			
		FOOTWALL AQUIFER	Footwall conglomerate Footwall sandstone Porous conglomerate	Fracture controlled	FOOTWALL FORMATION	Footwall conglomerate Footwall sandstone Lower conglomerate	Fracture controlled
		FOOTWALL QUARTZITE	Argillaceous sandstone Quartzite with conglomerate bands	Aquiclude		Basal sandstone	
		PEBBLE CONGLOMERATE	Lower porous conglomerate Quartzite conglomerate	Mainly fracture controlled		Basal quartzite	
		BOULDER CONGLOMERATE	Coarse boulder conglomerate			Basal conglomerate	
BASEMENT		COMPLEX	Shists, quartzites, gneisses and granites				

Table 1 Stratigraphic correlation between Konkola and Nkana (modified after 7, 9)

Konkola mining area

The geology of the Konkola mining area is shown in Figure 1a. The mine has three shafts only two of which (Nos. 1 and 3) are currently operational. The structure of the area is dominated by a series of cross cutting synclines and anticlines resulting in the ore formation having a saddle shape.

There are three main aquifers zones which are actively dewatered during mining, problems associated with this have been previously discussed (6). Two of the aquifers lie below the ore horizon and one above (see Table 1). The lower aquifer zone straddles the Pebble Conglomerate/Footwall Quartzite contact zone. The upper 40-50m of the Pebble Conglomerate is usually very coarse, frequently highly weathered and particularly in the 3 Shaft area is strongly fissured. The Footwall Quartzite immediately overlying this zone is highly jointed. Elsewhere water inflows in the Footwall Quartzite is controlled by joints and leached veins. In the past breakthroughs into open fissures have yielded initial surges of up to 60,000m^3/d (7). The approximate inflow from this aquifer zone was 144,000m^3/d or 39% of the total mine inflow.

The Footwall Aquifer comprises coarse grained sandstone and conglomerate lithologies all of which have a high porosity and high permeability aided by the strong jointing associated with these lithologies. Up to 10,000m^3/d of uncontrollable water can be intersected in one development end (7). The Footwall Aquifer accounts for 129,000m^3/d or 33% of the total mine inflow.

The most important aquifer overlying the ore horizon is the Hangingwall Aquifer, the upper part of which is frequently highly weathered and within which most water is encountered. The similarity of stable isotope data (8) from Upper Roan Dolomite and Hangingwall Aquifer waters suggests that these aquifers are probably interconnected. However, the aquifers do have a slightly different chemistry and perched aquifers within the Upper Roan are common, both features implying the degree of interconnection is far from perfect. The Hangingwall Aquifer (including the Upper Roan) accounts for 98,000m3/d or 26% of the total mine inflow.

Nkana mining area

The major structural feature in the Nkana mining area is the northwest plunging Nkana Syncline, see Figure 1b. This structure is in fact a tightly folded synclinorium with second order folds displaying sheared out limbs and associated fracturing and minor thrusting. The Basement/Lower Roan contact acted as a plane of decollement during deformation resulting in the neighbouring rocks being sheared and refoliated.

The mine has four major aquifer zones (9), one in the footwall and three in the hangingwall. The Footwall Aquifer is related to zones of fissuring and leaching, which can yield up to 900m^3/d. Minor amounts of water are made along the Basement Complex/Lower Roan contact. Footwall Aquifer water accounts for approximately 22% of total mine inflow (10).

The lowermost hangingwall aquifer is the Near Water aquifer, see Table 1. At Mindola water inflows are controlled by tensional fissures, fault zones and the degree of leaching particularly of the more carbonate rich horizons. At Central Shaft, water volumes in excess of 2,000m^3/d and at temperatures of 43°C occurred in the Near Water Sediments. At the South Orebody flows of 1,000m^3/d have been intersected mainly in the leached crests of anticlines.

In terms of rock volume the Far Water aquifer is potentially the most important aquifer at Nkana. Largest inflows of water occur in the more dolomitic and gritty lithologies where flows

Nampundwe mining area

The Nampundwe orebodies occur within the Cheta Dolomite Formation which is considered to be of Upper Roan age (14) and is thus broadly comparable with the host dolomites of the Kabwe ores. Two orebodies are currently mined, both are stratabound and occur along a strike length of about 1.1km. The orebodies are separated from each other by a poorly mineralized zone which varies in thickness from 1 to 50m. Mineralization comprises, pyrite and chalcopyrite with lesser amounts of pyrrhotite. Weathering has resulted in the upper 70m of the orebody being highly oxidized and the development of a highly porous gossan outcrop.

The mine is situated on the northwestern limb of a large synclinal structure which plunges to the North West. Dips vary from 70° to near vertical but are considerably reduced in the hinge zones of the folds which are frequently highly fractured.

As at Kabwe the dolomitic host rock is the major aquifer of the region. Water flow within the aquifer is controlled by joints (notably in drag fold areas), fissures and particularly the weathered zone that overlies the sulphide orebody. Recharge is considered to be dominated by direct infiltration after precipitation with the gossan acting as a sponge like reservoir.

	KONKOLA	NKANA	KABWE	NAMPUNDWE
PUMPING FIGURES (m^3/d)				
Mean	376,400	44,100	54,100	4,690
Min	300,300	36,800	31,800	1,760
Max	420,400	51,500	100,200	7,440
S.D (as % of Mean)	24,600 (6.5)	2,870 (6.5)	15,600 (29)	1,050 (22)
AUTOCORRELATION				
Rainfall	0.430	0.408	0.450	0.370
(S.D)	(0.096)	(0.086)	(0.086)	(0.086)
Pumping figures	-0.020	0.016	0.271	0.176
(S.D)	(0.096)	(0.086)	(0.086)	(0.086)
CROSSCORRELATION Rainfall vs Pumping [Ten year period P] (t valve)				
P	-0.146 (-0.95)	0.035 (0.38)	0.013 (0.14)	0.111 (1.21)
P + 1lag	0.106 (0.68)	0.043 (0.47)	0.379 (4.43)	0.158 (1.72)
P + 2lags	0.156 (0.99)	0.046 (0.50)	0.546 (7.01)	0.222 (2.42)
P + 3lags	-0.114 (-0.72)	0.061 (0.66)	0.486 (5.97)	0.053 (0.57)

$t_{(0.05/2;39)} = 2.02$ $\qquad t_{(0.05/2;119)} = 1.98$

Table 2 Basic Rainfall and Water Inflow Statistics for selected Mines of up to 5,000m^3/d from individual boreholes have been recorded. The apparent lithological control of water inflow seems to be overprinted by a structural control since even high yielding lithologies contain 'barren' zones. This is particularly well seen in the highly folded Central and South Orebodies. The temperature of water intersected during drilling can be as high as 43°C which causes ventilation problems. The water temperature is certainly due to the high geothermal gradient in the region (11). A total of 33% of the mine water inflow is derived from the Far Water Aquifer.

The Ultra Far Water Aquifer accounts for only 1% of the total mine inflow of water. This is due to the geometry of the mining area which means that dewatering of this aquifer is only necessary at deeper mining levels. Dewatering holes are long (300m) therefore few have so far been drilled, consequently knowledge of this aquifer is limited.

NON COPPERBELT OREBODIES

Kabwe mining area

The only working mine in the area is Kabwe Mine which was formerly known as Broken Hill Mine. The geology of the area has been described by (12,13). The ore deposits occur within a northwesteward striking belt of dolomitic rocks flanked by metamorphosed argillites. Lack of exposure and the massive poorly bedded nature of the dolomite has prohibited a detailed understanding of the stratigraphy and structure of the area. The age of the host dolomite is uncertain but it is probably equivalent to the Upper Roan Group of the Copperbelt (13). The mineralization has been dated at 712my and is considered to be roughly coeval with sedimentation (12).

The ore occurs as massive sulphide pipe-like bodies which plunge to the ENE at angles ranging from 30° to almost vertical. The orebodies have massive sulphide cores with an outer aureole of oxidized ore. Frequently this outer zone is vuggy and fissured, indeed a cavity associated with the No. 8 orebody contains dolomite crystals of up to a metre in size.

The dolomitic host rock to the orebodies is the major aquifer in the region. Water flow within the aquifer is controlled by surface weathering enhanced fissures which decrease in frequency below 80m, joints and the fissures in the immediate vicinity of the orebodies. Recharge to the aquifer is by direct infiltration, seepage from dambos and possibly from lateral inflow from the surrounding argillaceous sediments.

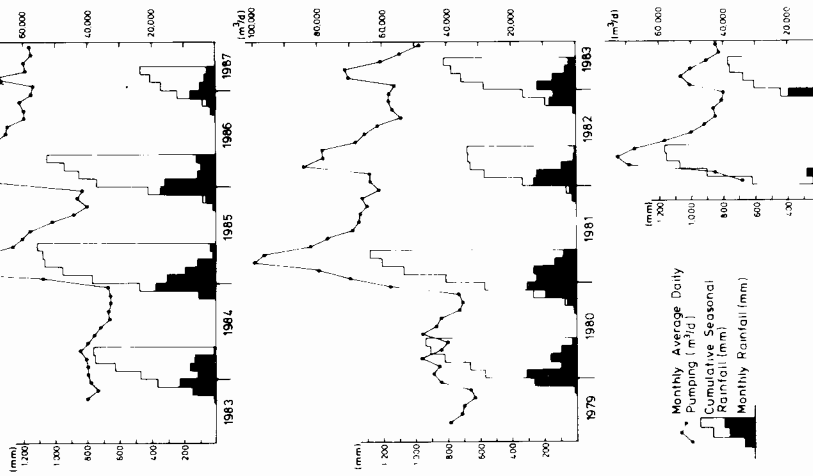

Figure 2b Rainfall and mine pumping data for Kabwe

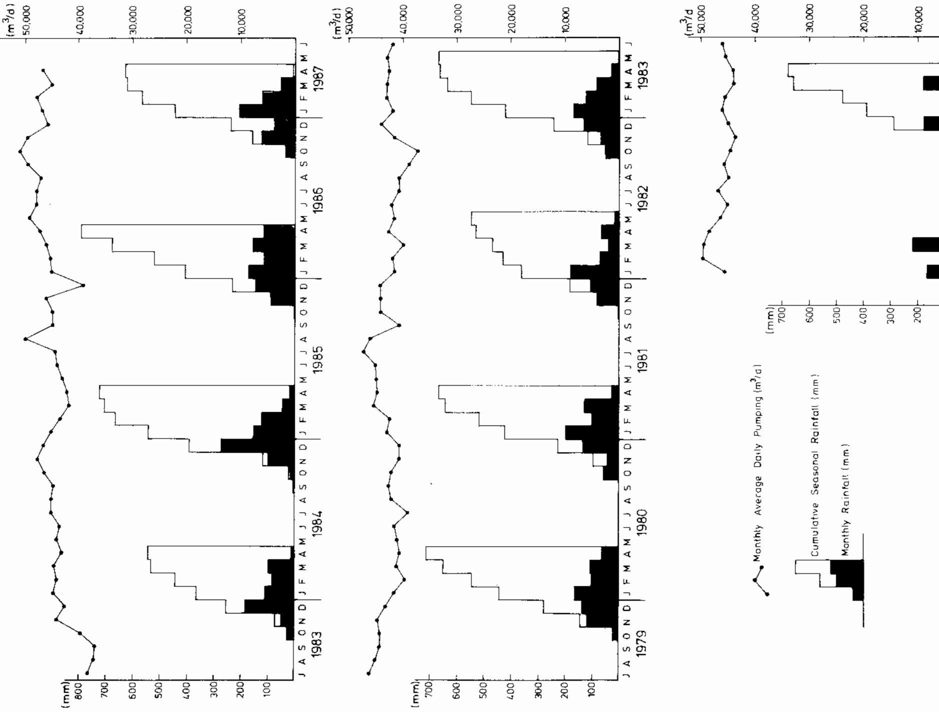

Figure 2a Rainfall and mine pumping data for Nkana

b. the orebodies are situated on anticlinal structures and consequently there is much tensional joining and fissuring which aids interconnection within and between water bearing horizons. c. the area around the mine is generally flat lying, this in conjuction with the low dips over much of the region, means a large sub outcrop of the aquifers is made available for recharge. The Nkana Basin is smaller than the Konkola Basin and would thus have a lower storage capacity and potential recharge area than the Konkola Basin. The steeper dips of the region also serve to decrease the area available to direct recharge by precipitation. In addition the Nkana orebody lies in a synclinal structure and consequently is less affected by tensional jointing.

The non seasonal nature of the pumping figures from both Copperbelt mines reflects the size of basins and surface area available for recharge compared with the low transmissivities particularly between aquifers.

Perhaps the most surprising feature of the data is that it is NOT the carbonate horizons which are the greatest source of water but the highly porous and vuggy Footwall Aquifer (as at Konkola) or even the highly fractured quartizitic or argillaceous horizons. Indeed carbonate seems to be more important where it forms a relatively small (but highly soluble) percentage of a rock and its dissolution would considerably enhances porosity.

The lower inflow figures for Kabwe and Nampundwe are undoubtedly due partly to the smaller size of these mines and the presence of only one aquifer. Even though this aquifer is of carbonate composition it does display a strong seasonal variation of water inflow pattern unlike the Copperbelt examples. This reflects not so much the structural setting of the orebodies but the importance of weathering enhanced transmissivity which results in enlargement of joints and fractures and the formation of fissures. Such features are particularly important at Kabwe where they are the major control on water inflow. They are fortunately confined to the upper 80m of bedrock, (presumably below this depth the acid groundwaters which aided their formation were neutralized.)

At Nampundwe a similar process was active but in this case acidic groundwaters produced during oxidation of the sulphide orebody resulted in a marked increase in porosity and storage capacity rather than transmissivity. This may explain why although there is a significant relationship between rainfall and water inflow at Nampundwe it is not as strong as at Kabwe.

The uncharacteristicly poor aquifer potential for the Upper Roan on the Copperbelt and the lithostratigraphic equivalents at Kabwe and Nampundwe is almost certainly due to their having being metamorphosed at least once. This has effectively obliterated any primary porosity. Storage capacity and transmissivity are therefore a function mainly of secondary (weathering) induced actions, features generally confined to the near surface part of the aquifer.

REFERENCES

1. Box, G.E.P. and Jenkins, G.M. Time series Analysis: forecasting and control. Holden Day, (1970).
2. Davis, J.C. Statistics and data analysis in geology. p550, Wiley, New York (1972).
3. Mendelsohn, F. The Geology of the Northern Rhodesian Copperbelt, p525, Macdonald, London (1961).
4. Fleischer, V.D., Garlick, W.G. and Haldane, R. Geology of the Zambian Copperbelt. In Handbook of strata bound and stratiform ore deposits (Ed.K.H.Wolf), Elsevier, Amsterdam, (1976).
5. Cahen, L. and Snelling, N.J. The geochronology and evolution of Africa. Clarendon Press, Oxford, (1984)
6. Rijken, J.H.A. and Clutten, J.M. The water problem in relation to mining at Konkola division, Nchanga Consolidated Copper Mines Limited. Geologie en Mijnbouw, V. 51, p399-408, (1972).
7. The Konkola water problem. Unpubl.Rep.ZCCM Ltd. (1982).
8. Sweeney, M., Turner, P. and Vaughan, D. J. Stable isotope and geochemical study of the role of early diagenesis in ore formation, Konkola Basin, Zambian Copperbelt. Econ.Geol. V.81, p.1938 1852 (1986).
9. A geological guide to Nkana Division. Unpub.ZCCM Ltd. Rep.
10. Nkana Mining Area (M.L.3/2) Biennial Geological Report for the period 1st April 1984 to 31st March 1986.
11. Chapman, D.S. Thermal regime of the Luanshya Mine, Republic of Zambia. Geoexploration V21, p265-281 (1983).
12. Whyte, W.J. Geology of the Broken Hill Mine, Zambia. In "Symposium on lead zinc deposits in Africa" Association of African Geological Surveys, Tunis Meeting. (1966).
13. Kortman, C.R. The geology of Zambian Broken Hill Mine, Kabwe. Geologie en Mijnbouw, V51, p347 357, (1972).
14. Simpson, J.G. The geology of the Mwembeshi River Area. Report No. 11, Geol.Surv.Zambia, (1962).