INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 21, No. 5, p. 154-160, 2022
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

# The application of geostatistics based model for the phosphate mineral resource estimation in a dry climate region, case of the Bled El Hadba phosphate deposit, NE Algeria

**Sabrina Souadnia*[1], AmelMaou[1], Amel Boudries[2], Fahima Halimi[3]**

[1]*Department of Earth Sciences, Institute of Architecture and Earth Sciences, Ferhat Abbas University, Setif1; Geology Research Laboratory, Annaba, Algeria*

[2]*Department of Agricultural Sciences, Faculty of Sciences, University of Skikda, Geology Research Laboratory, Annaba, Algeria*

[3]*DepartmentDepartment of Geology, Faculty of Earth Sciences, Geology Research Laboratory (GRL), BadjiMokhtar University, Annaba, Algeria*

Article published on November 20, 2022

**Key words:** Phosphate, Drill, PCA, Simulation, Mining resources

**Abstract**

Since many decades, several researchers have been exploring the potential of geostatistics in mineral resource estimation, resulting in numerous works and publications. The Bled El Hadba phosphate deposit, of the Jebel Onk mining basin, NE Algeria is structured in a basal, a principal, and a summit sublayer. A total of 24 core holes were drilled with a mesh size of 400*300m. We analyzed the exploration data with a Principal Component Analysis (PCA). The results of the correlation circles of the loading factors on the chemical elements P2O5, CaO, mgO, SiO2, Fe2O3, CO2, and IR (Insoluble Residue) allowed us, the identification of three main associations: the first association is formed by P2O5 and CaO representing the phosphate material; the second association is that ofmgO and CO2 representing the dolomitic gangue; and the third association is made up of SiO2, Fe2O3 and IR representing the siliceous clay gangue. This study proves that the PCA model can accommodate drilling geological parameters and effectively approximate complex relationships among them. The variography of P2O5 contents allows the construction of a geostatistics model of the distribution of phosphate resources in each of these constituent sublayers. The geostatic simulation provided several possible variants, one of which could be the closest to reality. The latter would allow the most rigorous planning and control of the exploitation. Our approach could be applied in similar deposits with the same deposition conditions throughout the region.

***Corresponding Author:** Sabrina Souadnia ✉ souadnia.s@gmail.com

## Introduction

Sedimentary phosphates represent an important resource for their multiple uses in agriculture and industry. Algeria is like the countries of North Africa, contains large quantities concentrated in the mining basin of Djebel Onk in Tébessa, where five phosphate deposits have been discovered. These deposits contain more than two billion tons of resources. Among these deposits the deposit of Bled El Hadba which is the object of our study. The Bled El Hadba phosphate deposit is located in the Djebel Onk basin, 14 km south-east of Bir-El-Ater, Tébessa (Fig. 1). The geological studies (e.g. Ranchin, 1963; Cielensky & Benchernine, 1987; Prian & Cortiel, 1993; Mezghacheet *et al.*, 2002; 2004) showed that the phosphate bed is composed of three sub-layers: the basal, the principal, and the summit sub-layers. Each of these sub-layers exhibits specific mineralogical and geochemical characteristics. Therefore, it is essential to separately valorize them. The geostatistical estimate by ordinary kriging allows the modeling of a deposit (Kechiched, 2011, Boulemia *et al.*, 2021) but it does not reproduce the "histogram and variogram" characteristics of the variable. It therefore provides a simplified image of the phenomenon studied. Hence the interest of using another approach: the simulation, which makes it possible to consider several variants, has the same statistical and spatial characteristics as reality and therefore optimizes planning and operation, which is the objective of our study. This simulation was performed by sequential Gaussian Simulation Method (SGS) of the phosphate resources of each of the three sub-layers. The obtained results were provided in the present work.

## Materials and methods

*Geological Setting*

The Bled El Hadba phosphate deposit is a sedimentary deposit. The beds age ranges from Thanetian to Quaternary. The phosphate bed is of Upper Thanetian age (Fig. 1). This layer is subdivided into three sublayers: the basal, the principal, and the summit sub-layers. The phosphate layer is about 30 m thick. Its exploration was carried out by many exploration campaigns. In total 720 samples were taken from the 24 drillings.

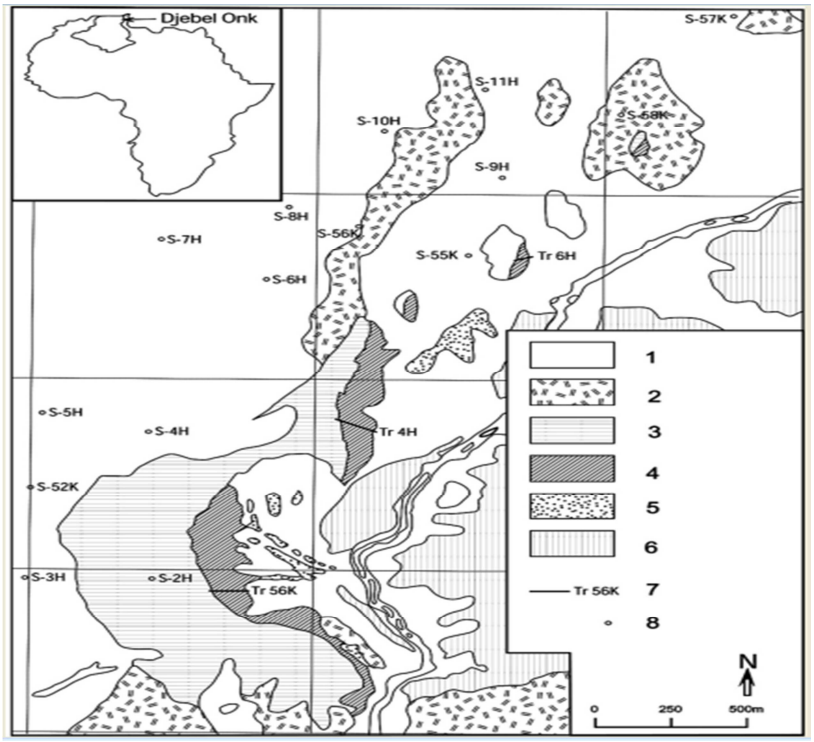


**Fig. 1.** Geologic location map of the study area 1: Alluvial deposit, 2: deposit composed of fallen limestones, quartz, sands and clays, 3: Limestones with silex of Ypresian age, 4: phosphate layer of Thanetian age, 5: schistosed marls and clays of Lower Thanetian age, 6: limestones and marls of Montian age, 7: trench, 8: well (EREM, 1987).

*Used methods*

*Methods of multivariate data analysis*

The principal component analysis PCA is a method of multivariate data processing. The principal of this method is described by many authors (Lebart *et al.*, 1979; Benzecrit *et al.*, 1980; Volle, 1981). It is commonly used in the earth sciences field (Mezghache, 1989). It is a factorial method that allows constructing factors considered as new independent variables or not correlated statistically and facilitating the study between the initial variables. The main objective is to extract, in a condensate form, the largest amount possible of information contained in the data. Be it connected to the relationships between variables or individuals. The main steps for a PCA are:

- The calculation the correlation matrix and search of load factors.
- Plotting interpretation of correlations circles.
- And finally probably mapping individual's factors.

*Geostatistical methods*

Geostatistics or regionalized variables theory aims to study the random functions. (Matheron, 1965-1970) introduced the regionalized variables notion to quantify a random phenomenon showing a spatial variability structure. The geostatistical modeling was already studied in a number of geological research works (Goovaerts, 1997; Deutsch, 2002; Leuangthong *et al.*, 2004; Daniel Khan *et al.*, 2008; Cabello, 2009). In our work, the geostatistical method used is the Sequential Gaussian simulation method SGS.

*Sequential Gaussian Simulation- SGS*

The simulation aims to generate by adequate algorithms multiple realizations of the random function Z(x). By construction, these constructions are all equiprobable and have the same statistical and spatial characteristics that the reality z(x).

Two main geostatistical simulations: Gaussian and non-Gaussian. In our work, the simulation was carried out by means of a Gaussian method: the Sequential Gaussian Simulation SGS. It is applied on the observations following a Gaussian law. If the distribution is not Gaussian, a transformation of the variable into a Gaussian variable Y is necessary. This is an anamorphosis.

* The steps of this simulation method are (Kedzierski, 2007):

- Choosing a grid node and defining a search sphere in the case of the isotropic phenomenon or a search ellipsoid in the case of anisotropy;

-Kriging a value to this point Zo (x);

-Constructing a Gaussian law from the kriging estimate and the variance estimate at a node;

-Drawing a random value from this distribution;

-Adding the simulated value to the available values list.

**Results and discussion**

*Multivariate data analysis PCA*

The core samples were analyzed for the chemical elements $P_2O_5$, CaO, mgO, $SiO_2$, $Fe_2O_3$, $CO_2$ and IR.

The simple correlation matrix (Table. 1) was computed on the geochemical data of the core samples taken from the principal sub-layer. This matrix shows that:

- $P_2O_5$ is positively correlated with CaO, negatively with $CO_2$, RI, mgO, $SiO_2$;
- $CO_2$ is positively correlated with mgO, negatively with Fe2O3 and CaO;
- IR is positively correlated with $Fe_2O_3$ and mgO is negatively correlated with $SiO_2$;

-mgO is negatively correlated with CaO and mgO;

- $Fe_2O_3$ is positively correlated with $SiO_2$ and CaO is negatively correlated with $SiO_2$.

**Table 1.** Correlation matrix of chemical elements.

| | $P_2O_5$ | $CO_2$ | RI | MgO | $Fe_2O_3$ | CaO | $SiO_2$ |
|---|---|---|---|---|---|---|---|
| $P_2O_5$ | 1,00 | | | | | | |
| $CO_2$ | -0,75* | 1,00 | | | | | |
| RI | -0,17* | -0,12 | 1,00 | | | | |
| MgO | -0,79* | 0,88* | -0,07 | 1,00 | | | |
| $Fe_2O_3$ | 0,01 | -0,23* | 0,71* | -0,18* | 1,00 | | |
| CaO | 0,40* | -0,42* | -0,31* | -0,50* | -0,13 | 1,00 | |
| $SiO_2$ | -0,16* | -0,14 | 0,98* | -0,09 | 0,73* | -0,28* | 1,00 |

*: significant correlations

From the correlation simple linear matrix (Table 1), the load factors were computed (Table 2). This table indicates that 90.44% of data is provided by the first

three factors: 41.98% of data is provided by the load factor F1, 39.56% by the factor F2 and 8.9% by the factor F3.

These computed load factors aim to plot the correlations circles (Fig. 2). The graphical correlations-representation circles of the relationships loads factors/chemical elements allowed to determine the major associations (Fig. 2):

- The first association is formed by $P_2O_5$ and CaO: it is positively correlated with the factor F2 and negatively with the factor F1. It represents the phosphate matter;
- The second association is that of mgO and $CO_2$: it is marked by a positive correlation with the factors F1 and F2. It represents the dolomitic gangue;
- The third association is constituted of $SiO_2$. $Fe_2O_3$and IR (insoluble residue): $SiO_2$ and IR are marked by a positive correlation with the factor F1 and a negative correlation with the factor F2. It represents the clayey-siliceous gangue.

**Table 2.** The load factors of chemical elements.

| | F1 | F2 | F3 |
|---|---|---|---|
| Variance (%) | 41,98 | 39,56 | 8,90 |
| $P_2O_5$ | -0,88 | 0,12 | -0,31 |
| $CO_2$ | 0,92 | 0,19 | 0,12 |
| RI | 0,06 | -0,96 | 0,04 |
| MgO | 0,95 | 0,12 | 0,07 |
| $Fe_2O_3$ | -0,13 | -0,85 | 0,13 |
| CaO | -0,63 | 0,34 | 0,69 |
| $SiO_2$ | 0,03 | -0,97 | 0,07 |

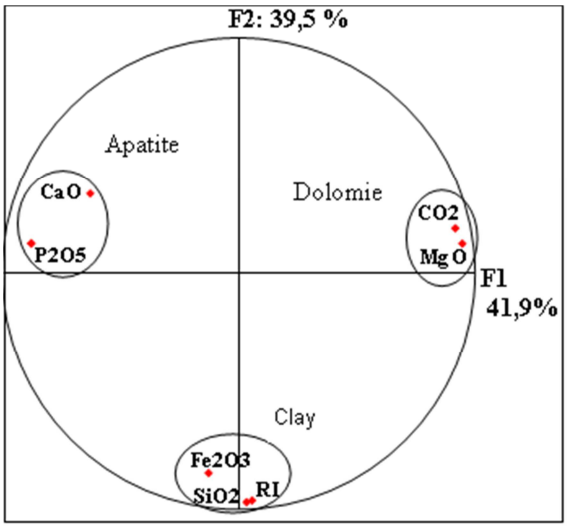


**Fig. 2.** Correlation circles on the contents of chemical elements.

*Geostatistical simulation*

The considered regionalized variable is the $P_2O_5$ content. The geostatistical study and the Sequential Gaussian Simulation method were carried out by means of the Petrel software in the three phosphate sub-layers.

*Variography in the three phosphate sub-layers*

The directional experimental variograms of the $P_2O_5$ contents in the three phosphate sub-layers were computed and adjusted (Table 3 and Fig. 3). The variography results indicate the presence of an isotropic structure; i.e. all the variograms practically exhibit the same ranges. These results were used for the simulation.

**Table 3.** Variograghy results in the three layers - Bled El Hadba deposit.

| | Directional variograms the major axis | | | | Directional variograms the minor axis | | | |
|---|---|---|---|---|---|---|---|---|
| Designation | a (m) | $C_0$ (% ²) | C (% ²) | Modèle | a (m) | $C_0$ (% ²) | C (% ²) | Model |
| Summit sublayer | 1700 | 0.01 | 1.99 | Spherical | 1700 | 0.013 | 1.022 | Spherical |
| Principal sublayer | 1500 | 0 | 1.08 | Spherical | 1500 | 0.250 | 0.850 | Spherical |
| Basal sublayer | 1500 | 0 | 1.19 | Spherical | 1500 | 0 | 1.200 | Spherical |

*Geostatistical simulation in the three phosphate sub-layers*

The simulation by the sequential Gaussian method - SSG - was done in 3D. The different sub-layers, which are three in number, have been simulated. It made it possible to obtain four variants A, B, C and D for each sub-layer. Anisotropy has been taken into account in this simulation.

The maps of the three simulated sub-layers (Fig. 4) show that it is the variants of the main sub-layer which are the richest in phosphate with contents greater than 12%. On the other hand, the two other sub-layers basal and summit are relatively low potential areas. It should be noted that the summit sub-layers contain low potential sectors.

This is explained by the change of facies in the lateral plane. Simulation by the SGS method made it possible to obtain variants of the distribution of P2O5 resources in the three sub-layers One of them is the closest to reality.

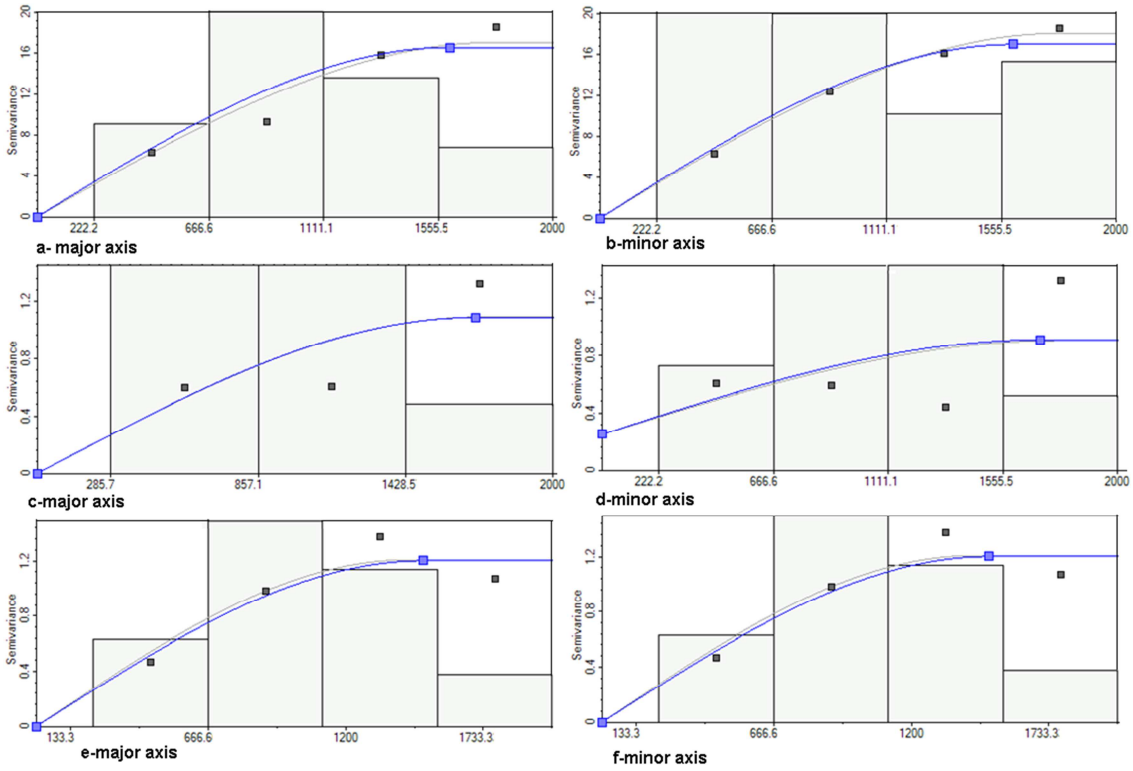


**Fig. 3.** Calculation and adjustment of variograms in the three sub-layers: a-b: summitsub-layer, c-d: Principal sub-layer, e-f: Basal sub-layer

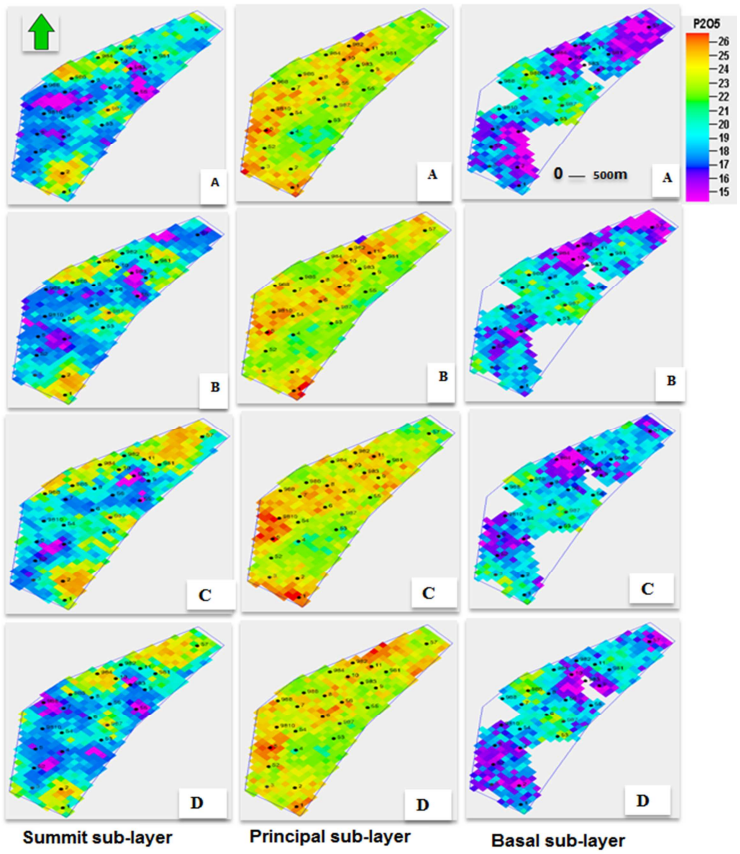


**Fig. 4.** Map of the results of the geostatistical simulation of the variable $P_2O_5$ in the three sub-layers. Four variants were simulated A, B, C and D.

**Conclusion**

The bearing horison of the phosphate mineralisation is formed of a layer of Upper Thanetian age. It has an average thickness of 30 m. This layer outcrops in the eastern part of the deposit and dips north-west under the Ypresian limestones and the Miocene sediments. The phosphate layer is made up of the superposition of three sub-layerss: summit sub-layer, principal sub-layer and basal sub-layer.

The principal component analysis PCA of data revealed the existence of three chemical associations that represent the phosphate matter, the dolomitic gangue and the clayey gangue. It also allowed for the computing of correlations between the different elements, thereby indicating that $P_2O_5$ is positively correlated with CaO, negatively with $CO_2$, IR,mgO and $SiO_2$. The geostatistical study and the simulation were carried out on the regionalized variable $P_2O_5$. The directional experimental variograms of the $P_2O_5$ contents in the three phosphate sub-layers were computed and adjusted.

The results reveal the existence of an isotropic structure. The maps simulated by the SGS method allowed determining the most potential sectors in the three sub-layers.

**References**

**Benzekri JP, Coll.** 1980. L'analyse de données. Dunod, 2eme ed. Paris 2, 632p.

**Boulemia S, Hadji R, Hamimed M.** 2021. Depositional environment of phosphorites in a semiarid climate region, case of El Kouif area (Algerian–Tunisian border). Carbonates and Evaporites **36,** 53. Doi.org/10.1007/s13146-021-00719-4

**Cabello P, Falivene O, López Blanco M, Howell J, Arbués P, Ramos E.** 2009. Modelling facies belt distribution in fan deltas coupling sequence stratigraphy and geostatistics. The Eocene Sant Llorenç del Munt example (Ebro foreland basin, NE Spain). Marine and Petroleum Geology DOI:10.1016/j.marpetgeo.2009.08.009

**Cielensky S, Benchernine N.** 1987. Travaux de prospection et d'évaluation des phosphates dans la région de Bir El Ater. Rapport interne, EREM, 80p.

**Daniel Kh, Clayton V, Deutsch V.** 2008. Solved Problems in Geostatistics resources , vol **15, no. 2,** p. 119-127.

**Deutsch CV.** 2002. Geostatistical Reservoir Modeling, Oxford University Press 376p

**E.RE.M.** 1985-1987. Travaux de prospection et d'évaluation des phosphates dans de Bir El Ater. Rapport EREM, 2 tomes: géologie, 50p. Prospection d'évaluation, 53p

**Goovaerts P.** 1997. Geostatistics for Natural resources Evaluation, New York: Oxford University Press 483p.

**Kechiched R.** 2011. Typologie géochimique et géostatistique des minerais de phosphates du gisement de Bled El Hadba- Djebel On (Algérie Orientale) Mém. de magister. Université Badj Mokhtar. Annaba. 164 p.

**Kedzierski P.** 2007. Révisions de géostatistiques, Résumé publié sur internet 7p.

**Lebart L, Morineau A, Fenelon JP.** 1979. Traitements de données statistiques, méthodes et programmes. Edit. Dunod. Paris 510 p.

**Leuangthong O, Jason A, mcLennan, Clayton V, Deutsch CV.** 2004. Minimum Acceptance Criteria for Geostatistical Realizations (Citations: 9). Nonrenewable Resources , vol **13, no. 3,** 131-141, 2004.

**Matheron G.** 1965. Les Variables Régionalise´es et leur Estimation. Masson, Paris 305p.

**Matheron G.** 1970. The Theory of Regionalized Variables and its Applications.Les Cahiers du Centre de Morphologie Mathématique, Vol. 5, Ecole des Mines de Paris, Fontainebleau 212p.

**Mezghache H, Hani A.** 2002. Typologie chimique des phosphates du gisement de Djemi-Djema, bassin de Djebel Onk (Algérie orientale). Géologie Méditerranéenne. Tome XXVII n° 1/2, 2000, pp 95-106.

**Mezghache H, Toubal A, Bouima T.** 2004. Typology of phosphate ores of the Djebel Onk Mining Basin (Eastern Algeria). Phosphorus Research Bulletin **15,** 5-20. Online ISSN: 1882-2363, Print ISSN: 0918-4783.

**Mezghache H.** 1989. Cartographique automatique et interpretation geostatistique d'une campagne de prospection geochimique sur sol-application à la zone mercurille Nord Numidique (Algerie). Thèse de Doctorat-Nouvelle; CNRS-CRPG-INPL. Nancy - France 175 p.

**Prian GP, Cortiel PH.** 1993. Etude de développement du gisement de phosphate de Djebel Onk (Algérie). Rapport d'expertise géologique, B.R.G.M. France 288p.

**Ranchin G.** 1963. The sedimentary phosphates of lime in Djebel Onk's region (Algeria), S.E.R.M. (Société d'Exploration et de Recherche Minière) Paris, France pp. 85.

**Volle M.** 1981. Analyse de données. Econo-mica, Paris 317 p.