CLAIM: A New Personal Computer-assisted Simulation Model for Teaching Mineral Exploration Techniques

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Bauchau, C., Jaboyedoff, M. and Vannier, M., 1993, CLAIM: *A new personal computer-assisted simulation model for teaching mineral exploration techniques,* in *Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Duke, J.M., eds., Mineral Deposit Modeling: Geological Association of Canada, Special Paper 40, p. 685-691*

Abstract

Since 1965 the Université de Lausanne and the École des mines de Paris have been jointly developing computer programs for simulation of mineral exploration. The first models were empirical, but with the use of large computers they soon became more complex and realistic. A new model, CLAIM, *written in C language, works on a personal computer using* MS-DOS. *This new teaching method is fast, allows an instant comparison of students' results with the model, and has numerous graphic options.*

CLAIM *simulates a sedimentary copper-bearing district covering an area of 400 km^2. The objective is for students to use geochemical and drilling data and topographic and geological maps to devise an optimum exploration strategy.*

The teacher or manager sets up the "game" using the management program. Access to information is possible with a drilling function that presents complete drill logs. Standard sections simulate the geological setting; displacing the sections along trajectories creates a spatial distribution. Topography is drawn from a base level digitized on a square grid, subsequently eroded and weathered with a lithology-dependent weathering module. Different types of mineralization are simulated by ellipsoidal grade distribution. The mineralization is assigned to a lithologic horizon with defined x-y *coordinates. Finally, geochemically anomalous zones are created from shallow mineralization maps.*

Management programs enable progress of the actual game with budget control, and drilling, assaying and geochemical sampling requests and results. Numerous other developments appear feasible.

Résumé

Depuis 1965, l'Université de Lausanne et l'École des mines de Paris ont travaillé conjointement à la mise au point de logiciels de simulation en exploration minérale. Les premières générations de modèles étaient empiriques, mais grâce à l'utilisation d'ordinateurs puissants ils sont vite devenus plus complexes et plus réalistes. Un nouveau modèle, CLAIM, fonctionne sur ordinateur personnel en utilisant le langage C sous MS-DOS. Cette nouvelle méthode d'enseignement est rapide, elle permet de comparer instantanément les *résultats de l'étudiant avec ceux du modèle, et elle comporte de nombreuses options de représentations en mode graphique.*

CLAIM simule un district minier renfermant des gisements sédimentaires de cuivre et s'étendant sur une aire de 400 km^2. Les étudiants doivent concevoir une stratégie optimale d'exploration à partir des cartes topographiques et géologiques et des données de la géochimie et des forages. Une fonction de forage donne accès à une batterie complète de données de forage. Des coupes géologiques normales présente le contexte géologique; le déplaçant des coupes géologiques le long de trajectoires crée une représentation de la distribution spatiale des entités géologiques. La topographie est dessinée à partir d'un niveau de base numérisé sur un maillage carré, lequel est par la suite érodé et altéré à partir d'un "module d'altération" dont l'action varie selon les lithologies présentes. Différents types de minéralisations sont représentés par la distribution des ellipsoïdes des teneurs. Les étudiants les intègrent au modèle en les assignant à un horizon lithologique au moyen de cordonnées x-y précises. Finalement, des zones d'anomalies géochimiques sont crées à partir de carte de minéralisations correspondant à des niveaux superficiels.

Toutes ces fonctions techniques interagissent avec un programme de gestion qui permet de modifier les résultats en fonction des contraintes budgétaires, des données de forages et des besoins en matière d'essai et d'échantillonnage. De nombreuses autres possibilités sont réalisables.

INTRODUCTION

In 1965, R. Woodtli, a professor at the Université de Lausanne, developed an empirical model for simulation of mineral exploration (Woodtli, 1971). More complex computerized models and programs were subsequently developed in cooperation with H. Pélissonnier and M. Vannier of the École des mines de Paris (Woodtli *et al.*, 1975; Pélissonnier and Woodtli, 1977; Vannier and Woodtli, 1979). The most recent program, CLAIM, written by Vannier, was developed and set up at the Université de Lausanne by the authors and J. Savary. It is presently used by fourth-year students under the supervision of C. Bauchau and M. Maignan (Jaboyedoff *et al.*, 1989a,b). The researchers continue to improve CLAIM and to create new models (Bauchau and Jaboyedoff, 1990).

After more than 15 years of experience on large computers, Vannier has adapted the new program to C language so that it works on personal computers running on MS-DOS. This offers the advantages of simplicity and graphic packages.

OBJECTIVES

The main objective of CLAIM is to teach students the practical aspects of mineral exploration. Simulation of a complex geological model enables students to become familiar with mineral-exploration situations. Students evaluate the results from real drill holes, geochemical samples, and topographic and geological maps. By doing this, the students use their knowledge of Earth sciences (Fig. 1), and try several exploration strategies.

Although the program is not difficult to apply, experience has shown that supervision by a tutor will allow students to make the most effective use of it.

PRESENTATION OF THE MODEL

The CLAIM 1990 model simulates strongly folded, black-shale-hosted, stratiform copper-cobalt mineralization (Zambia-Shaba-Kupferschiefer type). The modeled district extends over 400 km^2 and contains several copper-cobalt deposits with various characteristics. This type of copper deposit is second in importance to the porphyry type, yielding around 30% of the annual copper production and containing 25% of the proven copper reserves of the Western world. The deposits also account for a significant percentage of cobalt production. This deposit type is particularly important in Africa but exists in other parts of the world as well. The ore deposits range from a few dozen Mt to 250 Mt with grades reaching 5% Cu (H. Pélissonnier, pers. comm., 1980).

CONSTRUCTION OF THE MODEL

The modeling procedures described below are completed by the management program. The model used in the simulation consists of several elements (Fig. 2). The system is based on the systematic use of drill holes specified by x and y coordinates, maximum depth, and type of drill rig. The **drilling function** draws up complete drill logs showing the intersected lithology and possible mineralization. The quality of information depends on the type of rig used (diamond core, percussion, dry core or auger, Fig. 3).

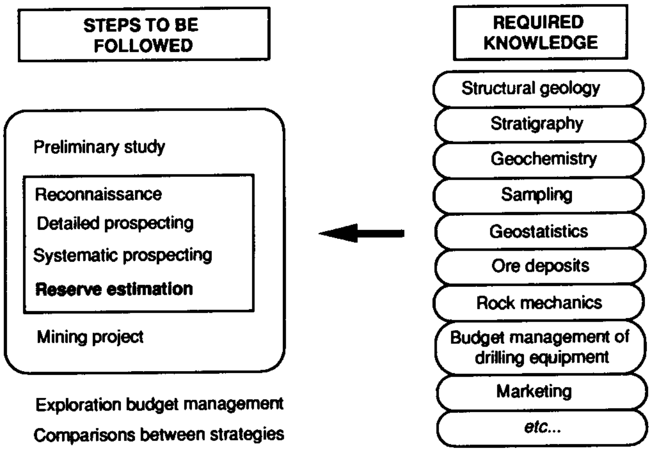

Figure 1. *Interdisciplinary character of the program simulating mineral exploration.*

The **geological setting** is created by one or more standard sections, defined by broken lines and by relations of superposition between such lines and the geological formations they are delimiting (Fig. 4). Their spatial distribution is obtained by displacing the sections along parametric curves, thus defining surfaces that can be either geological strata or faults (Fig. 5). When taking into account the superposition relations, the intersection between a straight line (drill hole) and these surfaces produces an intermediate drill log. Moreover, deflections or undulations can affect each surface, thus simulating features such as stratigraphic wedges. One or more **folding phases** affecting all strata can also be added. As demonstrated, structure plays an important role in this game.

It is necessary to create **topography** on the simulated block of rocks. A surface representing the base level is digitized over a square grid and then eroded and weathered as a function of a weathering module, which is characteristic of each rock type (Fig. 6). Thus a **weathered layer** is generated, the depth of which can easily be modified. Naturally, this is important with respect to the dimensions of the hypogene and supergene mineralization. At this stage, the geological log is ready (Table I).

In the last stage, one defines **mineralization** (grade, paragenesis). Each mineralized zone is simulated by several ellipsoidal mineralized bodies with functions determining the metal grade at a point *(x,y,z)* (Vannier and Woodtli, 1979):

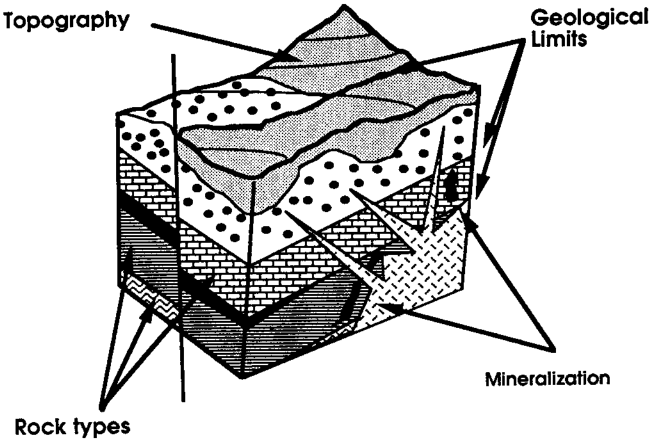

Figure 2. *The basic elements in a general model.*

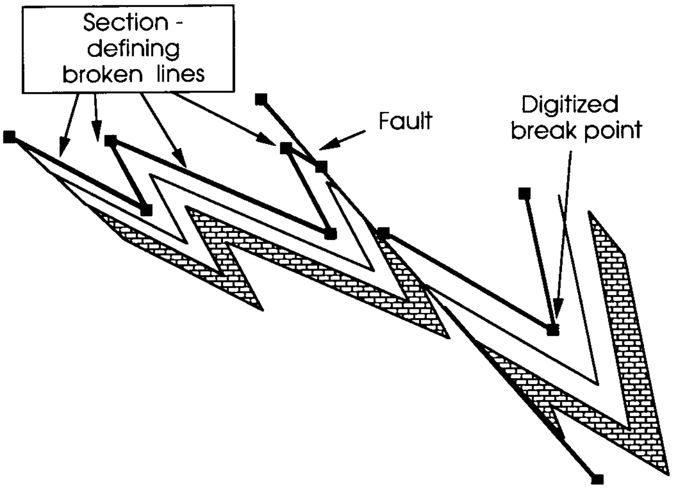

Figure 4. *Digitization of a section; the breaks of each line are stored.*

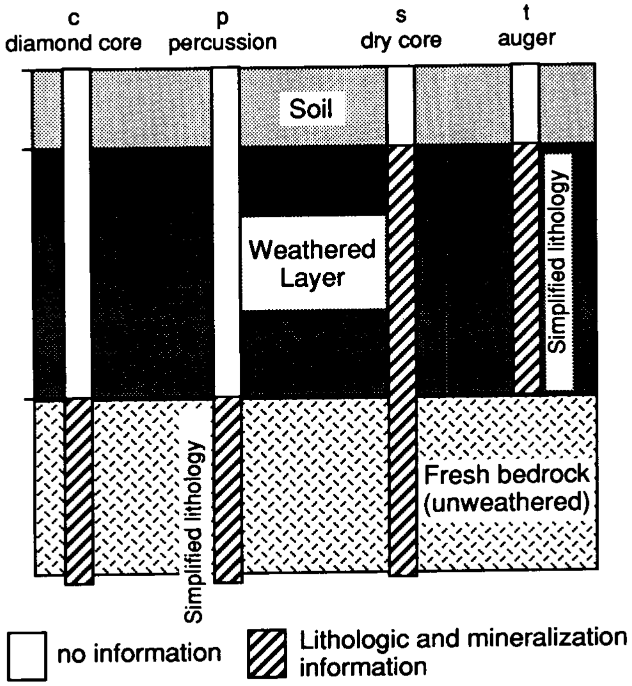

Figure 3. *Type of information given by the various categories of drill rigs.*

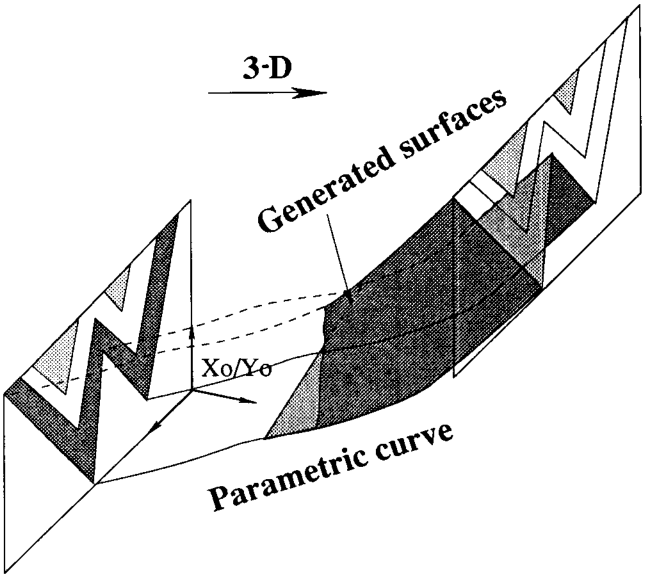

Figure 5. *Simulation principle of a geologic volume by translation of a standard section (Fig. 4).*

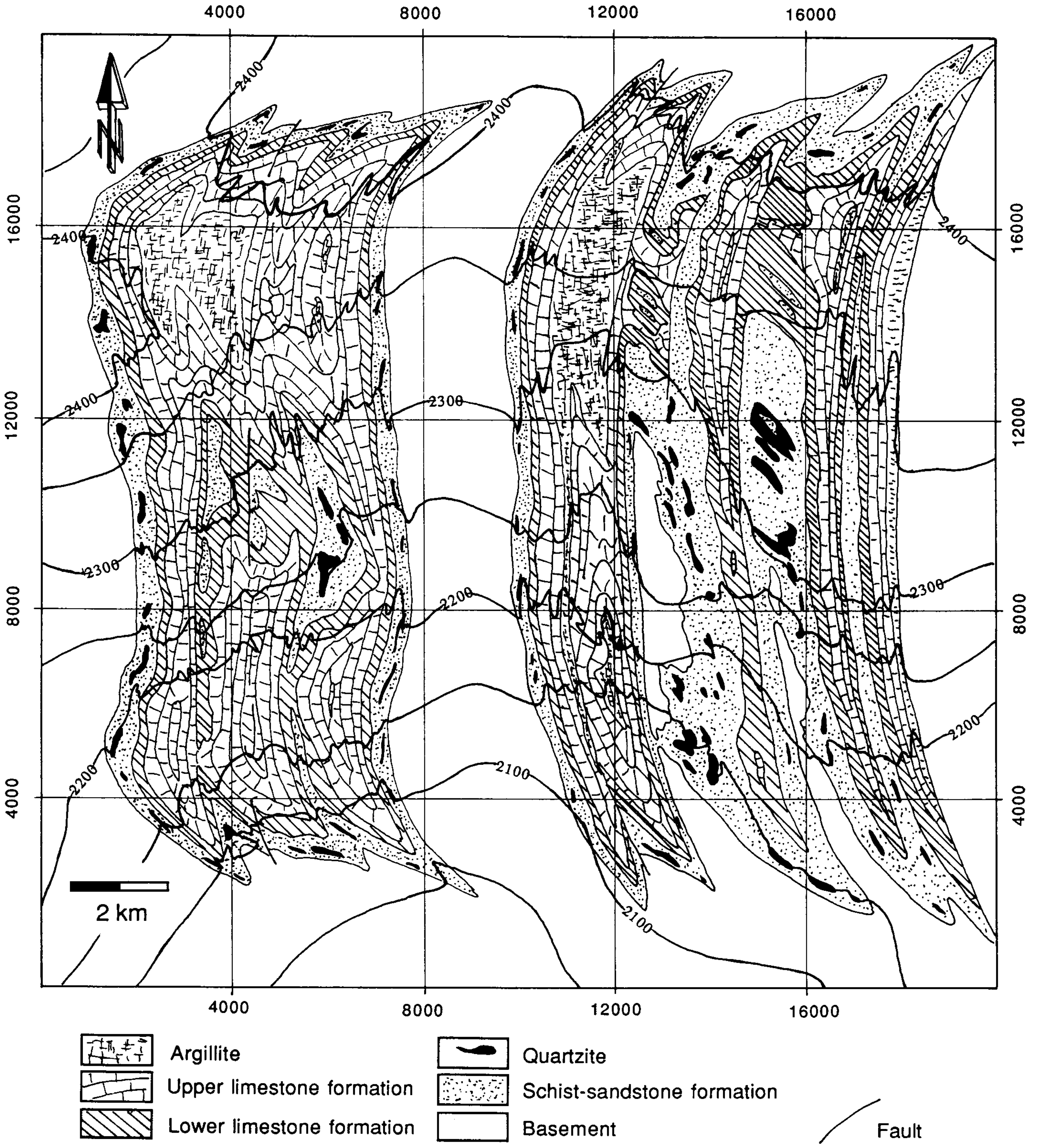

Figure 6. *CLAIM: a general geological and topographic map (contour interval 50 m). Notice the influence of geology upon the surface morphology.*

$$T(x,y,z) = \Sigma T_i\, f_i[(x - x_i)^2,(y - y_i)^2,(z - z_i)^2]$$

where x_i, y_i and z_i are the coordinates of the centres of the ellipsoids; T_i is the grade determined at x_i, y_i and z_i; and $f_i()$ is a function decreasing with the distance to the centre [see also T(x,y) used for geochemistry].

The location of the bodies in space is obtained by assigning them to a lithologic horizon and to a curvilinear trajectory.

Files required to create the model must therefore include the following information: geological sections and superposition relations of strata; names of rocks and their weathering modules; parageneses of mineralization (sulphurized and oxidized); and location and shape of the actual mineralization.

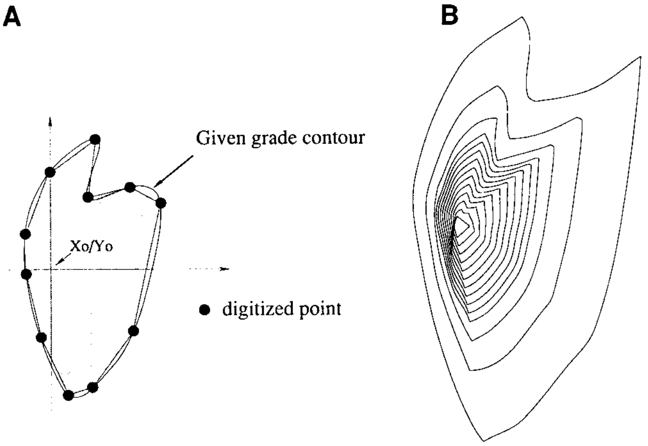

Figure 7. (**A**) *Example of digitization of a geochemical anomaly's grade contour with a maximum grade in* (x_0,y_0). (**B**) *Contouring of the anomalous zone produced by the* T(x,y) *function.*

DEFINING GEOCHEMISTRY

Soil geochemistry can be added to make the simulation more realistic. Interpretation of 5000-10,000 sample analyses will allow the students to use statistical, geostatistical and other methods.

The anomalous zones are located on a map showing mineralization intersected within the upper 30 m of the surface derived from the model described above. Grade contours are then defined with respect to topography and geology, and the position (x_0,y_0) of maximum grade (T_0) is identified by means of a function

$$T(x,y) = K/(A + D_n)$$

where

$$D = [(x_0 - x)^2 + (y_0 - y)^2]^{0.5}$$

and K and A are functions of the anomaly's shape, the direction $[(x,y)-(x_0,y_0)]$, and T_0. The anomaly's shape is propagated from the maximum grade zone. Geometrically it is comparable to a cone, of which the section is a defined grade contour, the vertex is the maximum grade, and the generating line is the T( ) function (Fig. 7). The anomalous zone is defined by the sum of several geochemical T(x,y) functions. To reduce calculation time, a circular limit of influence is attributed to each anomalous zone. A background noise factor is added to the previously described normal T(x,y) function values. Finally, the geochem-

Table I

Drill log from a diamond-drill hole that intersected copper mineralization with little cobalt; copper and cobalt analysis of the drill core from the black shale layer.

Level (m)	**Material encountered**
(2060)	(Start)
2060-2059	Soil
2059-2040	Weathered layer
2040-2031	Black shale
2031-1990	Argillaceous sandstone
1990-1981	Sandy shale
(1981)	(Termination)

	Mineralization		
Level (m)	**Cu** (%)	**Co** (%)	**Paragenesis**
2039	1.82	0.33	Malachite, chalcocite, cuprite, native copper, carrollite
2038	2.34	0.37	Malachite, chalcocite, cuprite, native copper, carrollite
2037	2.75	0.38	Malachite, chalcocite, cuprite, native copper, carrollite
2036	3.40	0.41	Malachite, chalcocite, cuprite, native copper, carrollite
2035	4.10	0.45	Malachite, chalcocite, cuprite, native copper
2034	4.52	0.46	Malachite, chalcocite, cuprite, native copper
2033	4.71	0.46	Malachite, chalcocite, cuprite, native copper
2032	5.11	0.48	Malachite, chalcocite, cuprite, native copper
2031	5.10	0.47	Malachite, chalcocite, cuprite, native copper

Note: Drill XXX; rig C; team X; (x,y) = 7745, 2990 m; required depth = 80 m.

ical sum of T(x,y) functions and background noise is weighted as a function of the lithology in which samples are collected.

PRODUCTION OF DOCUMENTS

Using the drilling function, one can draw geological, topographic and mineralization maps. These documents are produced on a plotter by contouring programs. The students use geological and topographic maps as a base for the exercise. However, to draw maps at a scale of 1:25,000, a minor manual intervention is still required. The latest model, at a scale of 1:50,000, is done completely by computer.

Geological cross sections and detailed topographic and geological maps can be produced with the same drilling function. A screen image and a hard copy (Fig. 8) can be obtained. Graphic applications are designed for teachers, for demonstrations and for the development of new models.

THE GAME AND GAME MANAGEMENT

After examination of their documents, students (working in teams of two or three) will be able to request collection and analysis of geochemical samples, specify drill holes (Fig. 3), request geological maps, and pay for such expenses from their allocated budget. In turn, they receive analytical and lithostratigraphic results, operating costs, and their budget balance. A special program manages the credits, carries out the students' requests according to the technical data of the various drill rigs, and calculates and debits the costs. The game is divided into 10-12 drilling periods and three geochemical sampling periods, one period corresponding to one computer run and simulating roughly one month of fieldwork. At the end of the game, teams present a final report.

The game progresses as follows:

1. On a floppy disk, the students produce files

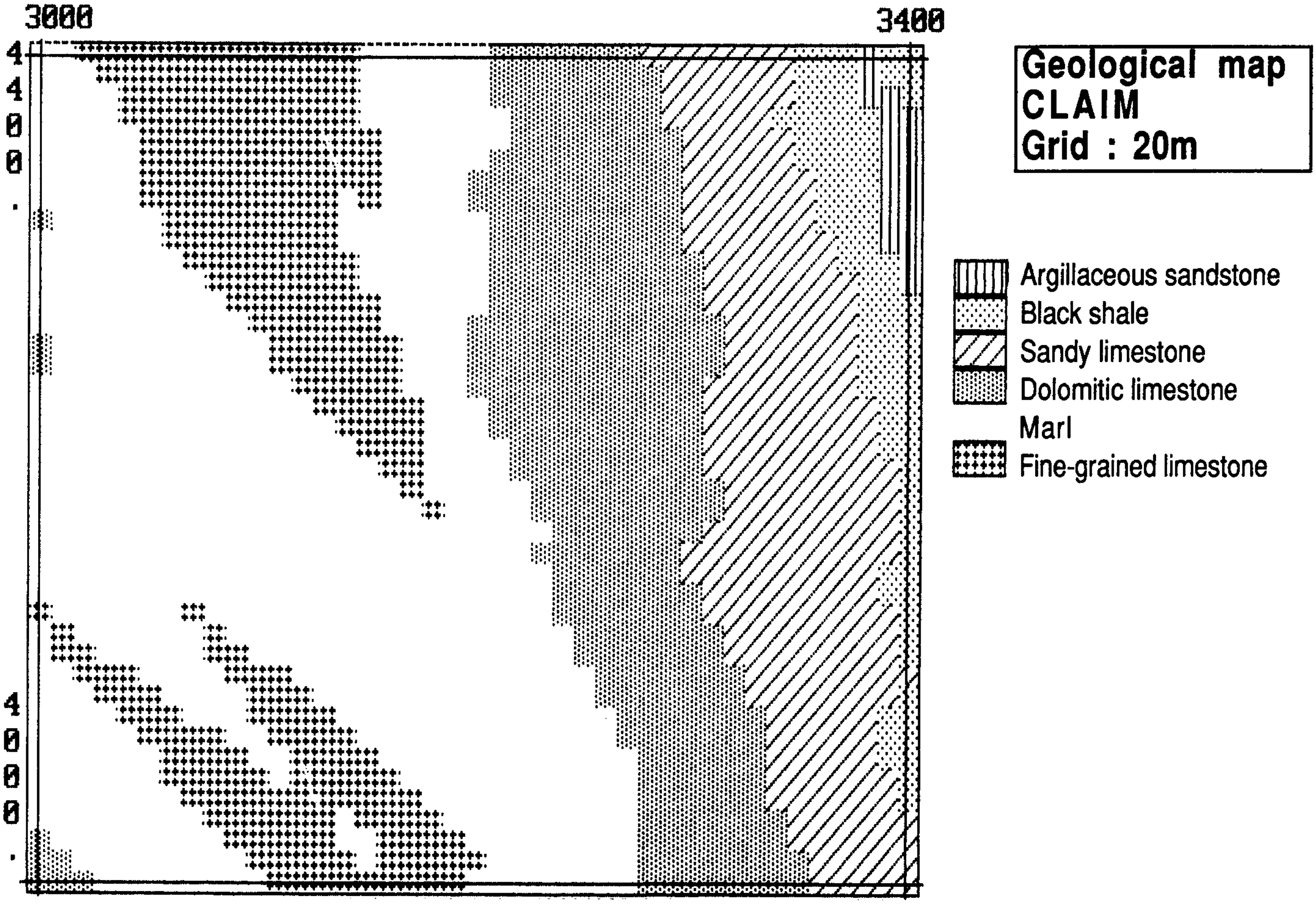

Figure 8. *Printout of a detailed geological map.*

requesting funds, drilling contracts, geochemical samples and detailed geological maps.

2. The game leader submits these files to the management program, which stores credits and costs. Drill holes are also stored because these can be deepened later.

3. The game leader gives the students back a file containing expenses, the budget balance, the results of the geochemical samples, the description of the drill holes (lithology and mineralization) in the form of drill logs (Table I), and the detailed geological maps.

4. The students interpret the data, adjust their strategy to the interpreted results, and prepare new requests for work.

CONCLUSIONS AND FUTURE PROSPECTS

Mineral exploration is a series of long and expensive operations with uncertain outcome. It may take years and millions of dollars to obtain conclusive results. For these reasons, it is almost impossible to teach this discipline directly in the field. Simulation enables students to gain experience in a short time (four weeks to four months) and on a limited budget. They will be able to handle scientific, technical, strategic and financial aspects of exploration. If they work intelligently, they will find one or more mineralized bodies at the end of the exercise. Their results can be compared with the model, enabling the teacher to assess the difference between their conclusions and "reality," something that is almost impossible to do in real life.

The main contribution of the new CLAIM model is to teach students to make quick moves; this is possible if the program has been correctly set up. The teacher can quickly identify the errors and shortcomings of the students. The game can be easily used anywhere in the world where one personal computer per team is available.

Since these programs have been adapted for personal computers, new prospects are opening within and outside the higher education field. First, new models may be created rapidly. For a given type of deposit, one can test various exploration strategies, keeping in mind that the accuracy of modeling depends on the degree of theoretical knowledge of that type of deposit. Applications to hydrogeology and structural geology will be considered in the future. Last, but not least, this game is (and should become more and more in the future) a remarkable teaching tool for students from developing countries, as already demonstrated by the Simulated Mineral Exploration Workshop, which has been held each spring at the École des mines de Paris since 1972.

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