FROG: Formalism for Representation of Objects in Geology.

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Abstract

Representation and recognition of geologic objects is a preliminary task to **Reasoning about Geology**. Solving the problem of recognition of geological objects cannot be done by pattern recognition, but by what we will call **structure recognition**, i.e. recognition of a set of distinctive and organized characteristics. The problem is to extract the relevant informations of a geological cross-section, to define the adequate relations between these informations and finally to set up a theory allowing us to describe unambiguously geological objects. FROG provides a set of primitive characteristics and operators allowing to define and to build those structures.

keywords: geology, qualitative reasoning, graph, recognition, formal calculus.

1 Introduction

We present a type of formalism allowing description, representation and recognition of geological objects on geological cross-sections (picking of seismic cross-sections). The analysis of these geological cross-sections is difficult because of a certain amount of defects on geological cross-sections such as non fulfilment and distortions. That is why methods for geometrical recognition are hardly helpful. Therefore, we propose as an alternative to the pattern recognition, a process of **recognition of structure**. We will call **structure** a set of characteristics gathered through relevant relations.

After a geological preliminary presentation, we will present the problems raised by this type of recognition, that will lead us to define the relevant characteristics of geological objects called **pinches-out**. We will then present theory and calculus necessary to the construction of these geological objects. That will lead us to conceive a geological cross-section as a graph which geological objects are subgraphs. Consequently, defining types of geological structures will come down to define specific graphs representing these structures.

2 Some geology.

Geology surveys subsurface formation. The two important classes of geological events are stratigraphical events which are the origin of the formation of sedimentary layers and tectonical events which are the deformations of these layers after their deposit. In this work, we will only analyse stratigraphy. We will survey the formation of geological structures through their **genetic** aspects whatever posterior tectonical deformations may be. Therefore, on a stratiphical point of view, cross-sections on figure 1 must be considered as equivalent.

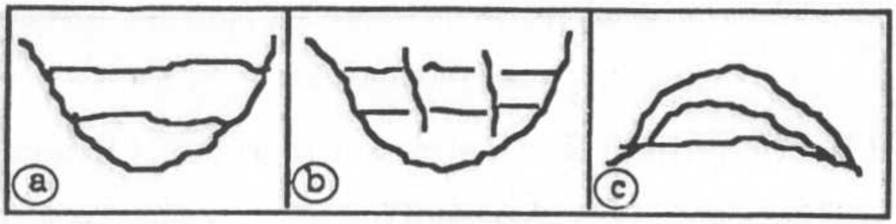

Figure 1: In the three cases, there has been formation of a basin filled by two layers; the second basin has been altered by faults and the third one has undergone a deformation. They both have the same stratigraphical evolution, even if their tectonical evolutions are different.

3 Primitive characteristics of a geological cross-sections: pinches-out

Geological structures are the result of sequences of geological events. In similar conditions, identical sequences of geological events create structures of similar nature. In some cases, geological structures are recognizable by their morphology. However, as previously shown, morphology is not a reliable characteristic of geological structures as such, for it is modified throughout years. Thus, **the process we choose is to deal with the geological structure genesis**.

We will study the main conjonctions of the following stratigraphical events: erosion, erosion and deposit, deposit and non-deposit. As shown on the figure 2, these three groups of events set up a specific relations of horizons[1] among them that we will call **pinches-out**. Pinches-out are not defined

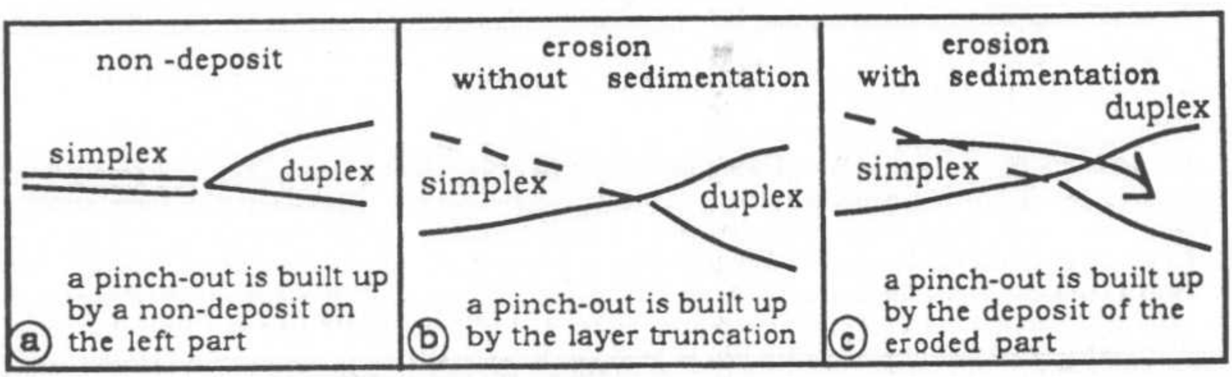

Figure 2: pinches-out formation

by morphological criterious, but by trend and contact of segments criterious Pinches-out, unlike horizons are a piece a reliable information, not sensible to deformations. **The pinch-out is a time invariant of geological structures. Pinches-out are the record of the builds up of geological structures.**

We define here two types of pinches-out:

A left pinch-out (cf. figure 3.b) consists in two "end" extremity points, in a sense of polarity and in a "**beginning**" extremity point, i.e two "in" markers and one "out" marker. The "out" marker is called **simplex** and the "in" markers are called **high and low duplex**.

A right pinch-out (cf. figure 3.a) is made up, in a similar way, of two "beginning" extremity points and one "end" extremity point. So, the simplex is the "in" marker and the duplexes are the "out" markers.

In fact, the high duplex of a pinch-out shows a chronological property more than a spatial one; the high duplex is younger than the low duplex. Identification of low/high duplexes is processed by a mere computation of oriented angles at pinch-out point.

[1] horizons are made of a set of segments. We will call segment (or marker) any curve between two pinches-out. Segments have a polarity. When we are going in the polarity direction, we see, on the left the younger layers, on the right the older layers.

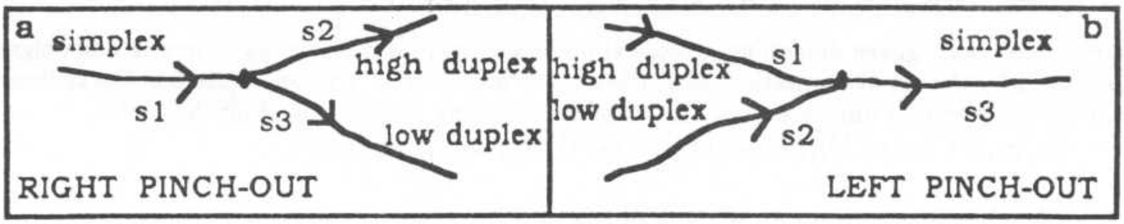

Figure 3: pinches-out

4 Pinches-out Theory.

Pinches-out theory has a specific aim: the representation of any cross-section **on the basis of pinches-out and on the relations among those pinches-out.** Spatial relations among pinches-out such as "next to", "above" are inadequate to describe the relations among pinches-out because these relations are modified as time passes and are not significant of chronological relations among pinches-out. Even, if we

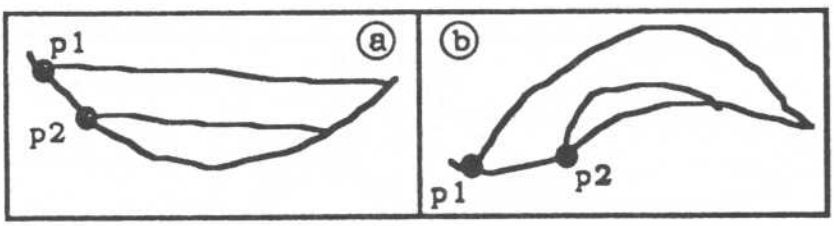

Figure 4: the b. basin represents a deformation of the a. basin at a day posterior to its formation. On figure a, pinch-out p_1 is above pinch-out p_2, and that is no more true on figure b.

cannot trust morphological attributes of horizons, it is impossible to ignore them. As far as horizons are concerned, we will only bear in mind the property to link or **to connect** pinches-out. That property will be called **connection of pinches-out**. Therefore, a connection of pinches-out will be a path between two pinches-out caracterized by its type. Types of relations among pinches-out called **label**, define the relation between simplexes and duplexes of each pinch-out. Therefore, on figure 5, we can see (thick line) a connection of pinches-out of label ls, called thereafter because the path from p_1 to p_2 joins the segment **Low** $-$ *duplex* of the p_1 pinch-out to the segment **S***implex* of the p_2 pinch-out. The surveys of types of possible junctions between two pinches-out, bearing in mind the types of "in" ou "out" segments, shows 9 possible configurations (cf. Annex A). Connections of pinches-out will be, throughout the work,

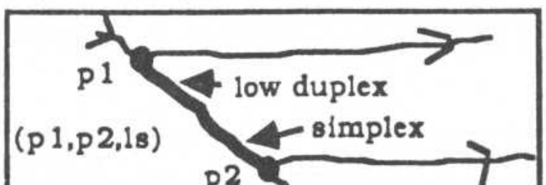

Figure 5: connection of pinches-out of low duplex-simplex notated ls.Formally, a **connection of pinches-out** will be notated: $(beginningpinch - out, endpinch - out, label)$.

very important for they are the synthesis of proximity and chronological informations. A connection of pinches-out as a **path** from one pinch-out to the other describes necesseraly the distance between two pinches-out. Note that the path itself may be interrupted by fault offsets or lack of picking. A connection of pinches-out, through its label, shows directly chronological information.

5 Defining models of geological objects.

We now have a language describing geological objects on a cross-section: an object is unambiguously represented by the set of connections of pinches-out which form it. Thus,on figure 6.a, the sedimentary basin is described in a unique way by the set of the following connections of pinches-out:

$(p_1, p_6, bb), (p_3, p_5, bb), (p_1, p_6, hh), (p_3, p_5, hh), (p_1, p_3, ls), (p_5, p_6, sl)$.

5.1 Geological structures: a graph

This description allows to raise the following postulate established in FROG that **geological structures can be represented by a graph, excluding all kind of morphological information.**
The vertexes of the graph are the pinches-out: $p_1, p_2, p_3, p_4, p_5, p_6$. Consequently, edges are represented by what we call connections of **elementary pinches-out** [2] :

$(p_1, p_2, lh), (p_2, p_3, ss), (p_3, p_4, ls), (p_4, p_5, hl), (p_5, p_6, sl), (p_1, p_6, hh), (p_3, p_5, hh)$

The following connections of pinches-out deducted through transitivity will be added to the edges:

$(p_1, p_5, bb), (p_1, p_6, bb), (p_3, p_5, bb), (p_3, p_6, bb), (p_2, p_4, ss), (p_4, p_5, lh), (p_4, p_6, hl), (p_2, p_6, sl), (p_2, p_5, sl), (p_1, p_4,$

Therefore, a connection of pinches-out is defined as a graph path. A geological cross-section must

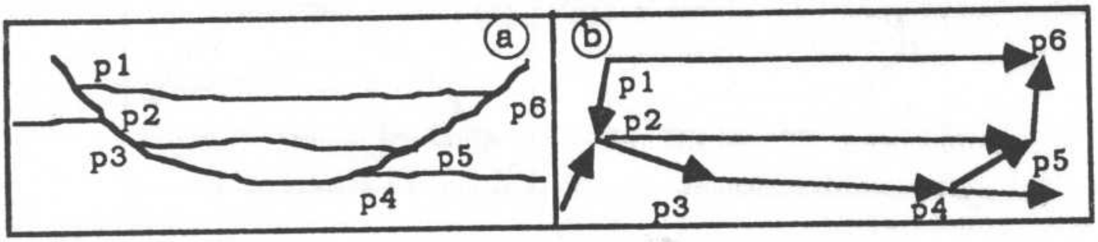

Figure 6: sedimentary basin

then be considered as a graph and the geological structures as a sub-graph of the former one. **Defining models of geological structures consists in defining specific graphs.** Building geological structures consists in applying operators on graph elements to create sub-graphs true to the definitions of the structures.

5.2 Building the structures.

The three groups of structures (sequences, associations of sequences of 1st and 2nd order) that we are going to define are represented on figure 7. Building these structures consists in manipulating a graph and extracting *interesting* sub-graphs. For this purpose, we will use two operators: an **association operator** and a **correlation operator**. The role of those operators will be specified with the definition of these structures. [3]

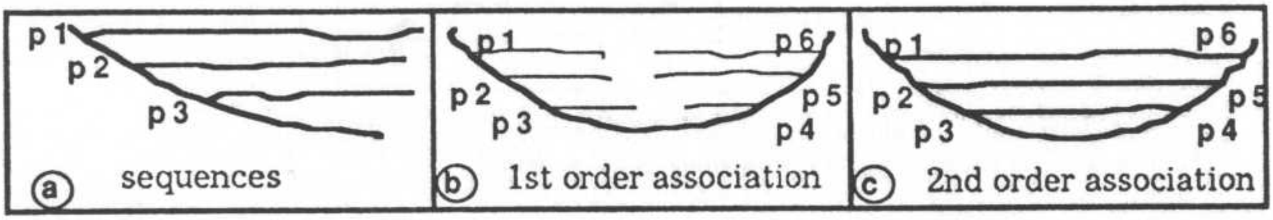

Figure 7: Three examples of structures types.

[2] Connections of elementary pinches-out are connections of pinches-out such as there is no pinch-out between the two "extremity" pinches-out.

[3] The properties of those operators are presented in [5].

5.3 Sequences

Throughout time, sequences show a succession of geological events of the same type (cf. Annex B). Thus, a **left half-basin** created by a succession of sedimentary deposit events in similar conditions, is made of a succession of connections of label ls pinches-out. A geological cross-section will be made of as much left half-basins as they are related components, if we consider that the sub-graph [4] of the cross-section includes label ls edges only. Formally, it will be defined as following:
$(ls_1 \bigoplus \ldots \bigoplus ls_n)$ is a left half-basin iff $\forall ls_i, ls_{i+1} ls_i = (p_m, p_n, ls), ls_{i+1} = (p_n, p_p, ls)$
The association operator notated $\bigoplus$, as indicated by its name, associates connections of pinches-out in the paths. Formally, it allows to build a *set* of connections of pinches-out that describe a geological structure. In the example on figure 7.a, the left half-basin is made of 3 connections of pinches-out of label ls: $(p_1, p_2, ls) \bigoplus (p_2, p_3, ls) \bigoplus (p_1, p_3, ls)$
Therefore, sequences can be defined as showed in annex B.

5.4 Associations of sequences of 1st order

The associations of sequences of 1st order establish a first level of symmetry in geological structures. The correlation operator gathers these symmetrical parts. This operation 's aim is to keep pinches-out associated by a symmetrical relation of connection and to eliminate the others. The associations of sequences are therefore represented (cf. Annex C).

5.5 Associations of sequences of 2nd order.

Objects of 1st order are gathered into objects of 2nd order by applying again the correlation operator. Graphically, it consists in passing from figures 8.a1, 8.b1, 8.c1 to figures 8.a2, 8.b2, 8.c2. In the case of figure 8.a, we correlate the outer pinches-out (p_1, p_4) of the 2 connections of pinches-out; in the case of the figure8.b, the inner pinches-out (p_2, p_3) are correlated; both correlations are used in the case 8.c. That is to link (p_1, p_2, ls) to (p_3, p_4, sl) through (p_1, p_4, hh) and (p_2, p_3, hh).

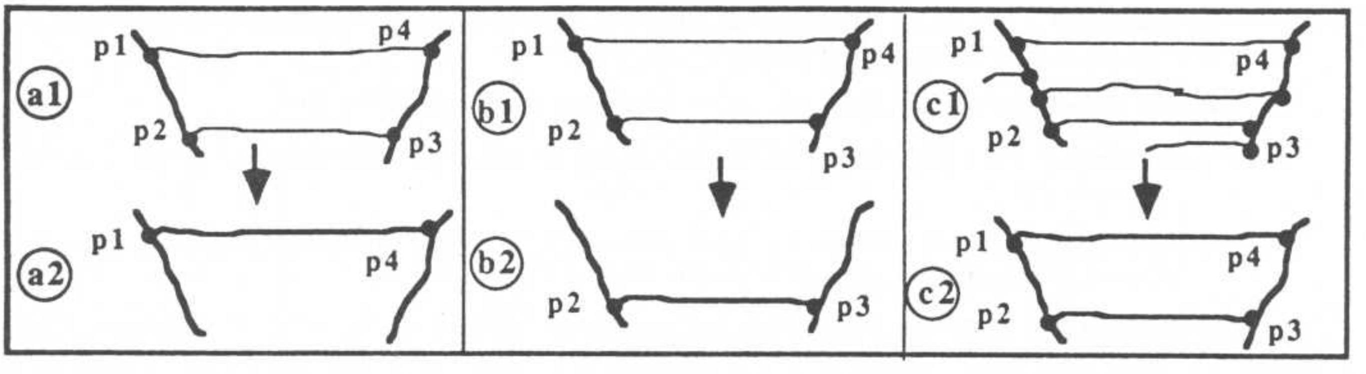

Figure 8: correlation operator.

Formally, the result of correlation operator correlation is:
$\{(p_1, p_2, ls)\} \bigoplus \{(p_3, p_4, sl)\} \bigoplus \{(p_1, p_4, hh)\} \bigoplus \{(p_2, p_3, hh)\}$ The correlation operator has a selection and filtering function on set of connections of pinches-out associated by $\bigoplus$. It keeps the couples of connections of correlated pinches-out and eliminates the others. Therefore, we can define the following sequences associations of 2nd order (cf. Annex D).

6 Implementation and Further works.

FROG has been implemented in the GROG program [4]. GROG analyses geological cross-sections, detect incoherencies, recognizes geological structures, and at last provides a complete description of a cross-section called topo-chronology. GROG is written in ADA and OPS5 [3] and works on MICROVAX-GPX

[4] Generation and Representation of Objects in Geology.

(VMS). The extension of FROG formalism to the recognition of tectonical structures, and to geological structures in 3D is presently under study.

7 Conclusion

The representation of geological objects obtained by FROG provides a very concise expression compared to a numerical expression of similar phenomenous. This method, compared to those of pattern recognition is easier in the sense that ambiguities or inherent uncertainties in these methods have disapeared. That result is not due to pure chance or to the use of data processing tricks. The system analysed through the image we have, is deterministic. Among the amount of traces let by geological phenomenous, we must take into account those providing a coherent **explanation** of physical phenomenous which have occured. The relevant characteristics (pinches-out) of this system, the relations they imply (connections of pinches-out) explain the analysed system, that is to say the formation of sedimentary layers, for they show **sufficient and necessary** informations about geometry and chronology.
This process can be considered as a qualitative reasoning process for it describes a physical system through qualitative characteristics. These characterisitics are not derivatives or order of magnitude, but characteristics adapted to geological problems: connections of pinches-out. This process of *recognition of structures* allows, in some cases, to give an interesting alternative to *pattern recognition*.

8 References

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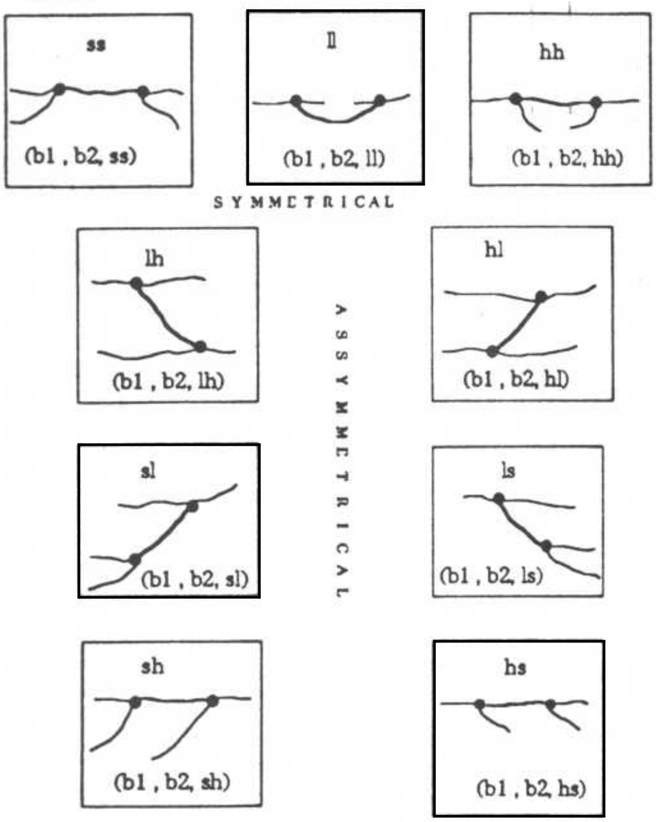
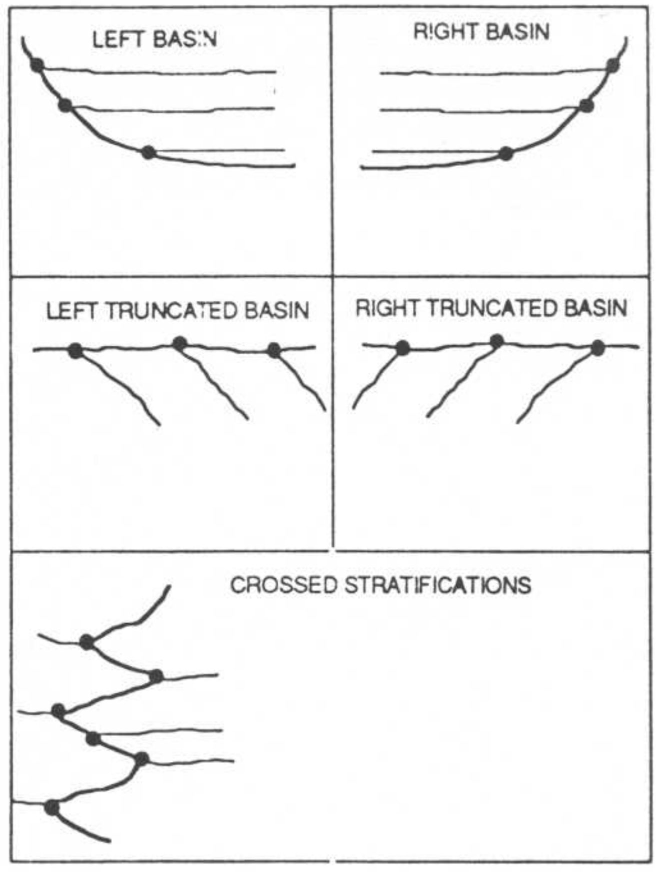
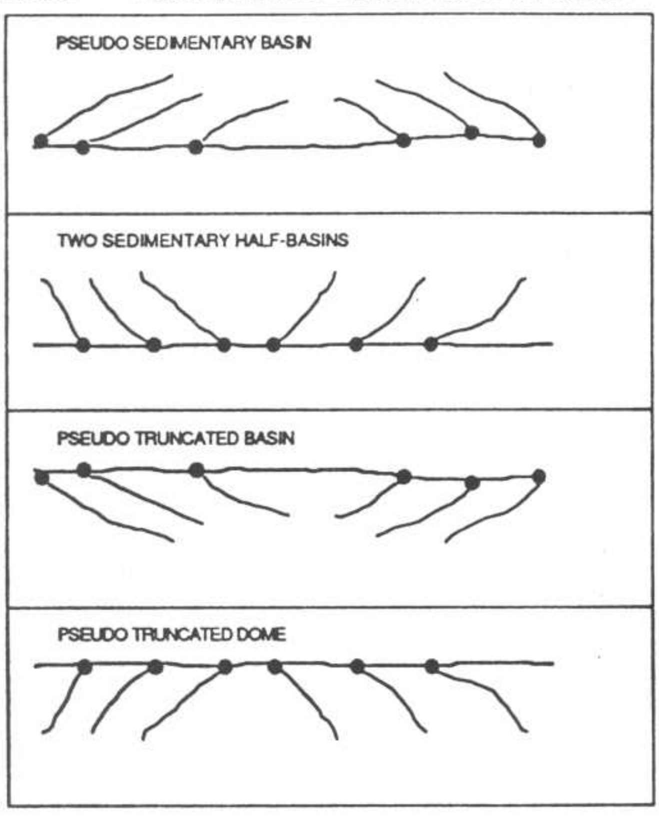
annex: A CONNECTION OF PINCHES-OUT



ANNEX B SEQUENCES



ANNEX C ASSOCIATIONS OF SEQUENCES OF 1ST ORDER



annex D ASSOCIATION OF SEQUENCES OF 2nd ORDER