

PLATFORM BREAK-DOWNLAP PLANES RELATIONSHIP IN PROGRADING CARBONATE PLATFORMS: A TOOL FOR THE RECONSTRUCTION OF BASIN EVOLUTION

Nota dei Soci CARLO DOGLIONI (*) & ALFONSO BOSELLINI (*)

ABSTRACT

The platform break hinge and the downlap hinge are defined as the upper and lower terminations of a clinoform respectively. The platform break plane and the downlap plane are the planes connecting all the platform break hinges and the downlap hinges of a prograding depositional system. The depth of a basin in front of a prograding carbonate platform can be expressed as $X \sin \alpha$ (fig. 1), where X is the length of the clinoform connecting platform break and downlap hinges and α is the angle of the lower slope with the horizontal. Variations of the clinoform length and declivity will consequently define variations of the basin depth. The platform break and downlap planes relationship can be useful in forecasting the depth evolution of a basin: parallel platform break and downlap planes indicate no change in bathymetry; divergent platform break and downlap planes signify an upward deepening of the basin, while a convergent pattern is associated with a shallowing upward basinal succession. In nature these patterns are very common. The resultant geometries are functions of 1) subsidence; 2) carbonate productivity; 3) climate; 4) sediment supply into the basin; 5) sea level changes. As shown by the numerous examples of the Dolomite Region, the combination of these factors produce different prograding geometries of the carbonate platforms.

RIASSUNTO

Le cerniere di *platform break* e *downlap* sono rispettivamente le terminazioni superiore ed inferiore di una clinostratificazione. I piani di *platform break* e di *downlap* sono i piani che intersecano le cerniere di *platform break* e *downlap* di un sistema deposizionale progradante. La profondità di un bacino antistante una piattaforma carbonatica progradante può essere espressa come $X \sin \alpha$

na, dove X è la lunghezza della clinostratificazione che unisce le cerniere di *platform break* e *downlap* e α è l'angolo della clinostratificazione con l'orizzontale. Delle variazioni della lunghezza o dell'inclinazione della clinostratificazione produrranno di conseguenza delle variazioni della profondità del bacino. La relazione tra piani di *platform break* e *downlap* può essere dunque utile nel prevedere l'evoluzione della profondità di un bacino: piani di *platform break* e *downlap* paralleli indicheranno che il bacino ha mantenuto una profondità costante; piani di *platform break* e *downlap* divergenti indicano un approfondimento verso l'alto della serie bacinale, mentre piani convergenti ne indicheranno una diminuzione verso l'alto della profondità. In natura sono molto comuni delle situazioni composite dei tre precedenti principali casi. Queste geometrie sono funzione dei seguenti fattori: 1) subsidenza; 2) produttività carbonatica; 3) clima; 4) apporto clastico nel bacino; 5) oscillazioni eustatiche. La combinazione di questi fattori produce differenti geometrie di progradazione come evidenziato dai numerosi esempi della Regione Dolomitica. Ad esempio la differenza tra le curve descritte dai piani di *platform break* e *downlap* delle piattaforme carbonatiche Ladiniche del Catinaccio e delle Pale di S. Lucano indica una maggior subsidenza sinsedimentaria nella zona delle Pale di S. Lucano, imputabile all'articolata tettonica medio triassica della regione.

KEY WORDS: *Carbonate platforms, platform break, downlap, planes, subsidence, Dolomites.*

INTRODUCTION

This paper presents an interpretation of some internal geometries occurring in prograding carbonate systems and demonstrates how these geometries may be useful in understanding paleo-waterdepth and basin evolution, both in outcrop and in seismic lines. One of the main differences between carbonate and siliciclastic prograding systems lies in the declivities of their slopes: carbonate platforms commonly have slo-

- This paper was presented to the "CNR Alpi" Meeting in Bologna the 19-12-1988 and was supported by a MPI 40% grant (Prof. A. BOSELLINI).

(*) Dipartimento di Scienze Geologiche e Paleontologiche dell'Università, Corso E. I d'Este, 32, I-44100 Ferrara.

pes of 20° to 30° (particularly when the sediment is coarse-grained) which can be easily identified in outcrop. Moreover, the terminations of clinoforms may be quite abrupt as a result of their oblique pattern; in fact, while tangential geometries do occur frequently, clear sinusoidal patterns seem more rare in carbonate rocks. The Dolomites of northern Italy exhibit excellent and well known examples of progradational pattern of carbonate platforms (MOISISOVICS, 1879; LEONARDI, 1967; BOSELLINI & ROSSI, 1974; BOSELLINI, 1984; BOSELLINI & DOGLIONI, 1988); they have served as the field data for the models proposed in this paper.

PLATFORM BREAK AND DOWNLAP HINGES AND PLANES: DEFINITIONS

We define the *platform break hinge* as the line of inflexion between horizontal platform-top sediments and the inclined slope or talus sediments. The *downlap hinge* is the line where the toe of a prograding clinoform flattens out into the horizontal basin facies (fig. 1). The *platform break plane* is here defined as the diachronous plane which tie all the platform break hinges; similarly the *downlap plane* is the diachronous plane intersecting all the downlap hinges (fig. 2). It is therefore necessary to differentiate the downlap surface (VAIL *et al.*, 1977; VAIL, 1987) from the downlap plane, which in

fact is not a depositional surface but simply the result of a facies change. In fact the downlap plane could coincide with the downlap surface if the adjacent basin was starved and basinal sedimentation negligible. In other words, downlap plane and downlap surface, are two distinct features which have to be considered separately. We believe that the first one can be recognized both in seismic sections and outcrops, while the second is much more difficult to identify unequivocally. While unconformities have not time lines crossing them, the planes which we are dealing with are heterochronous ideal "surfaces" which are cut by time lines: that is the reason why we prefer the word plane rather surface because it is a feature which has never been a true surface.

PLATFORM BREAK - DOWNLAP PLANES RELATIONSHIPS

The relationship between platform break plane and downlap plane can be used to understand the depth evolution of a basin. The depth of a basin adjacent to a platform can be inferred from the length and declivity of the platform-margin clinoforms (fig. 1): i.e. $d = X \sin \alpha$, where d is the depth of the basin, X is the length of the slope and α is the angle of the lower slope with respect to the horizontal. This is also true for concave or tangential shapes of the clino-

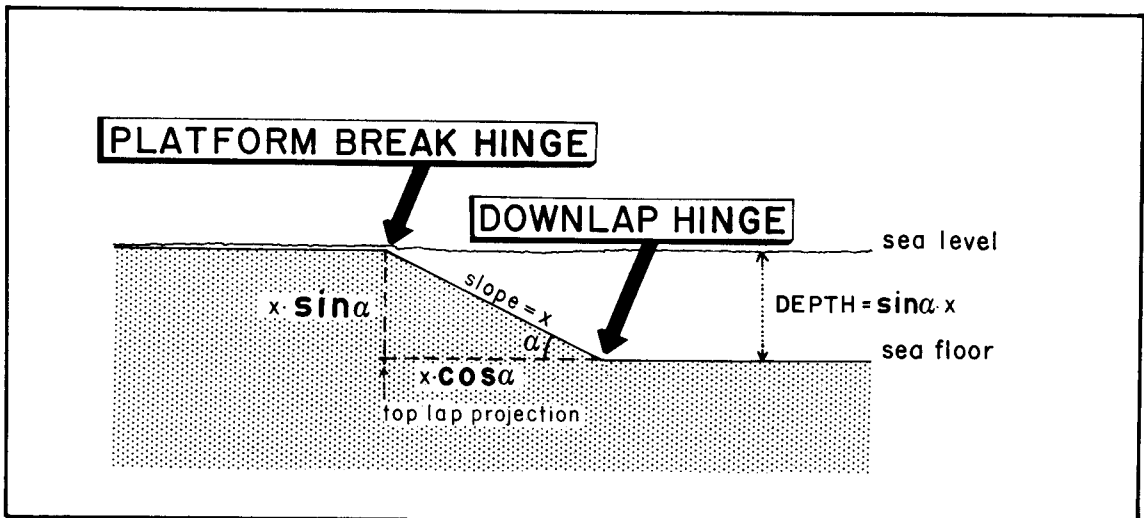


Fig. 1 - Platform break and downlap hinges are the points where stratification changes from horizontal to inclined and from inclined to horizontal. The sea depth is a function of the length of the slope (X) connecting the platform with the basin, and of the angle of the lower slope with the horizontal (α). Thus $X \sin \alpha$ is almost equal to the depth of the basin and $X \cos \alpha$ is the distance between the platform break projection and the downlap hinge.

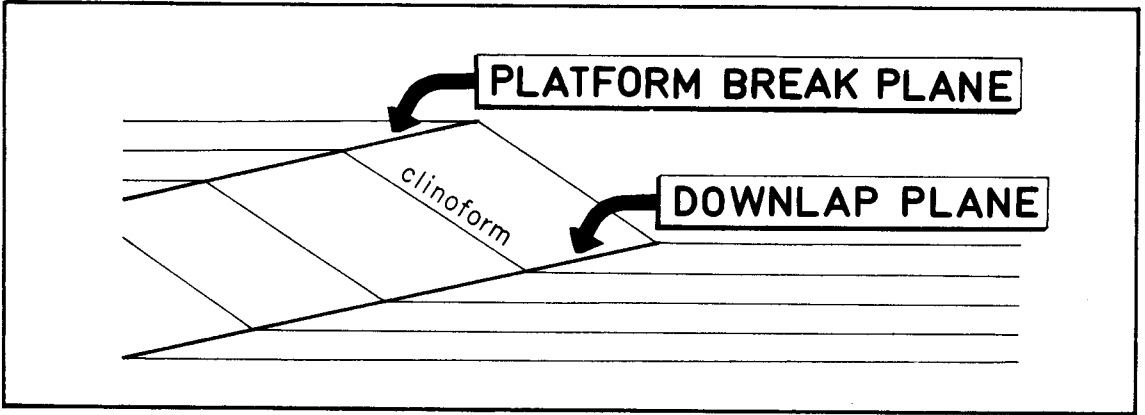


Fig. 2 - Platform break plane and downlap plane are the ideal planes intersecting respectively all the platform break hinges and all the downlap hinges in a progradational system.

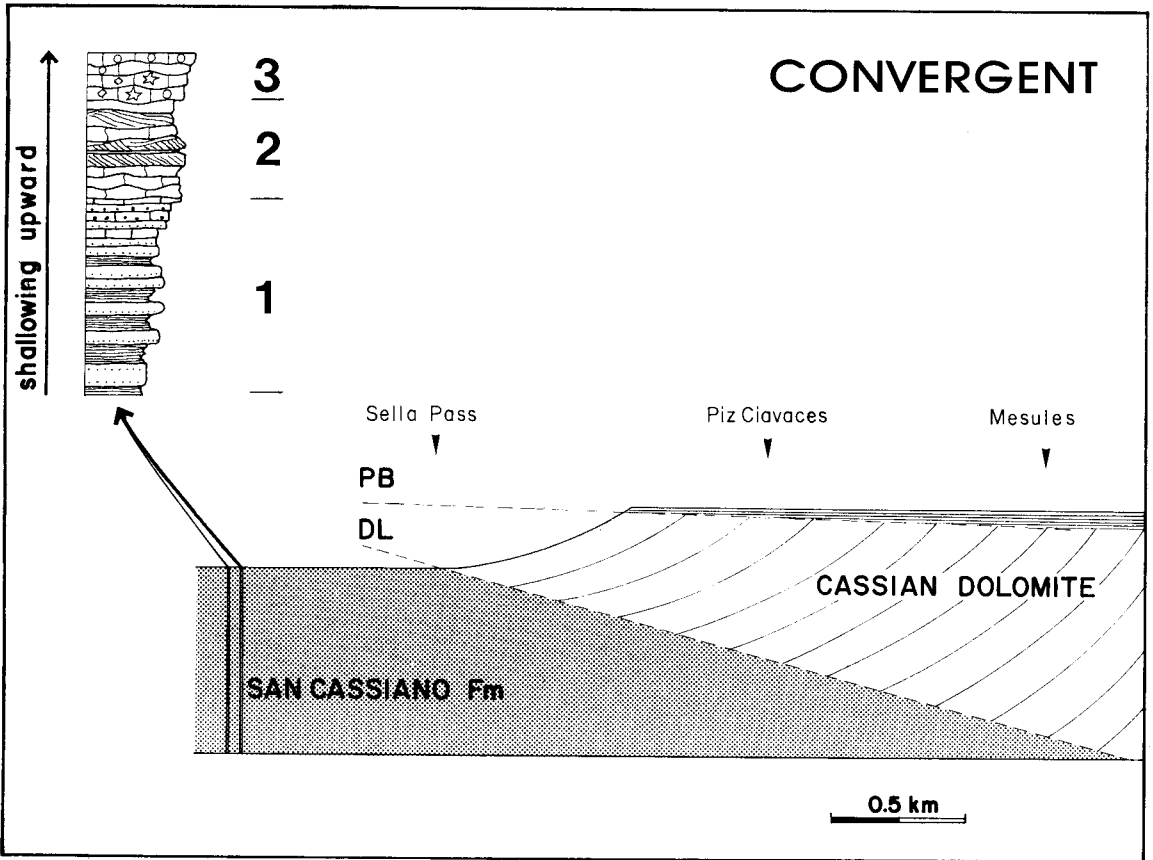


Fig. 3 - Reconstruction of the western margin of the Sella Carnian carbonate platform (Upper Cassian Dolomite). It is an example of convergent platform break plane (PB) and downlap plane (DL); the coeval basin (San Cassiano Formation) consequently shows a shallowing upward sequence (1, graded calcarenites and breccias alternating with shale and mudstone; 2, nodular and wavy bedded limestones with traction-current structures; 3, wavy bedded calcarenites).

forms. For sake of simplicity, we can therefore assume rectilinear clinoforms because tangential or sinusoidal clinoforms do not change the parameters of $\sin\alpha$ and $\cos\alpha$: it suffices to connect the platform break hinge and the downlap hinge with a straight line (averaged slope) which gives the length X ; the angle of this straight line with the horizontal is α .

Consider first a platform with climbing progradation (BOSELLINI, 1984) and a nearly horizontal platform break plane; this is the toplap case (MITCHUM *et al.*, 1977; VAIL, 1987). The length of the clinoforms decreases and consequently the basin is shallowing upward. This relationship is present in several Carnian platforms of the Dolomites. In this case platform break and downlap planes are convergent (fig. 3).

In another example, a platform showing climbing progradation, with contemporaneous vertical aggradation, is characterized by increasing length of clinoforms and the basin becomes progressively deeper upward. In this case, platform break and downlap planes are divergent (figs. 4 & 5, B). A good example is represented by the Ladinian buildup of the Pale

di San Lucano – Civetta mountains where it is possible to demonstrate a deepening upward in the corresponding basinal Livinallongo Formation (BOSELLINI & FERRI, 1980). Consequently, climbing progradation is not an indication of shallowing upward of the basin: it is only the interrelation between platform break and downlap planes, i.e. the clinoforms length variations which indicates whether the basin is shallowing or deepening upward.

In fact, if climbing progradation occurs at the same rate as climbing of the platform break plane, so that a constant clinoforms length is maintained, platform break and downlap planes remain parallel, but inclined, signifying constant water depth in the basin (fig. 2). Tabular progradation, where platform break and downlap planes are almost parallel but horizontal also constant length of the clinoforms results and the basin will consequently maintain more or less the same depth (fig. 5, A).

In case of “descending” progradation, the length of the clinoforms increases (BOSELLINI, 1984) as a consequence of the basin deepening upward. The platform break plane may range

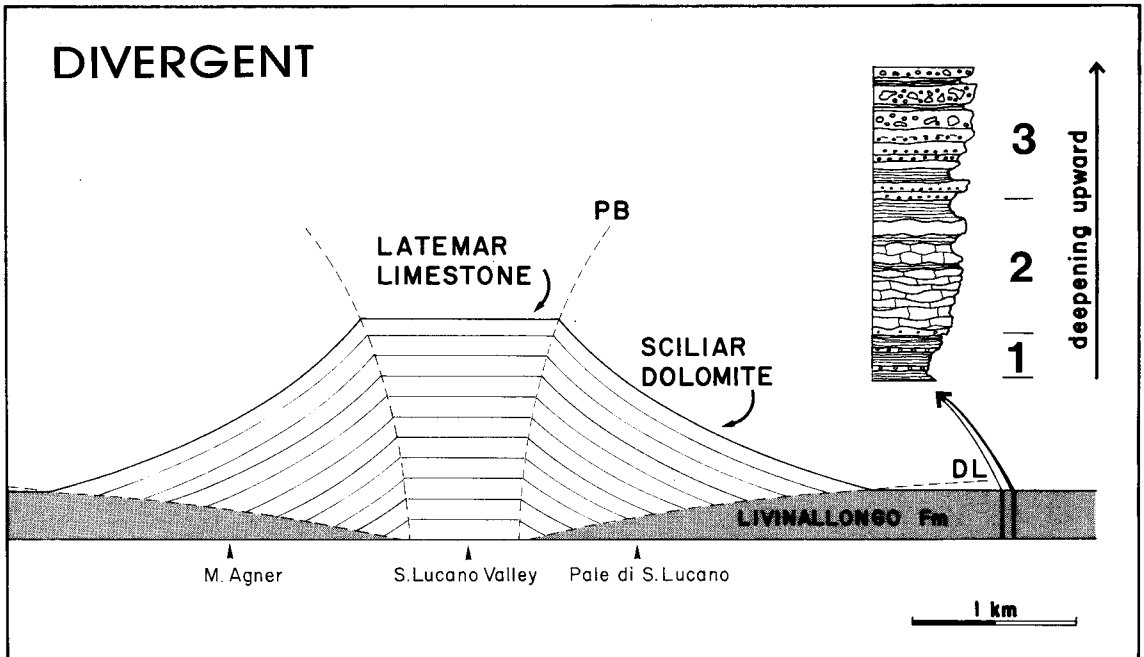


Fig. 4 - Reconstruction of the Ladinian Pale di San Lucano platform; NNW is at the right. Example of divergent platform break plane (PB) and downlap plane (DL). Note that the basinal Livinallongo Formation shows a deepening upward sequence (1, black, laminated siliceous mudstone, starved basin; 2, nodular limestone; 3, graded calcarenites organized in small thickening-coarsening upward sequences). The Sciliar Dolomite is represented by megabreccias of the slope and the Latemar Limestone is consisting of peritidal back-reef sediments.

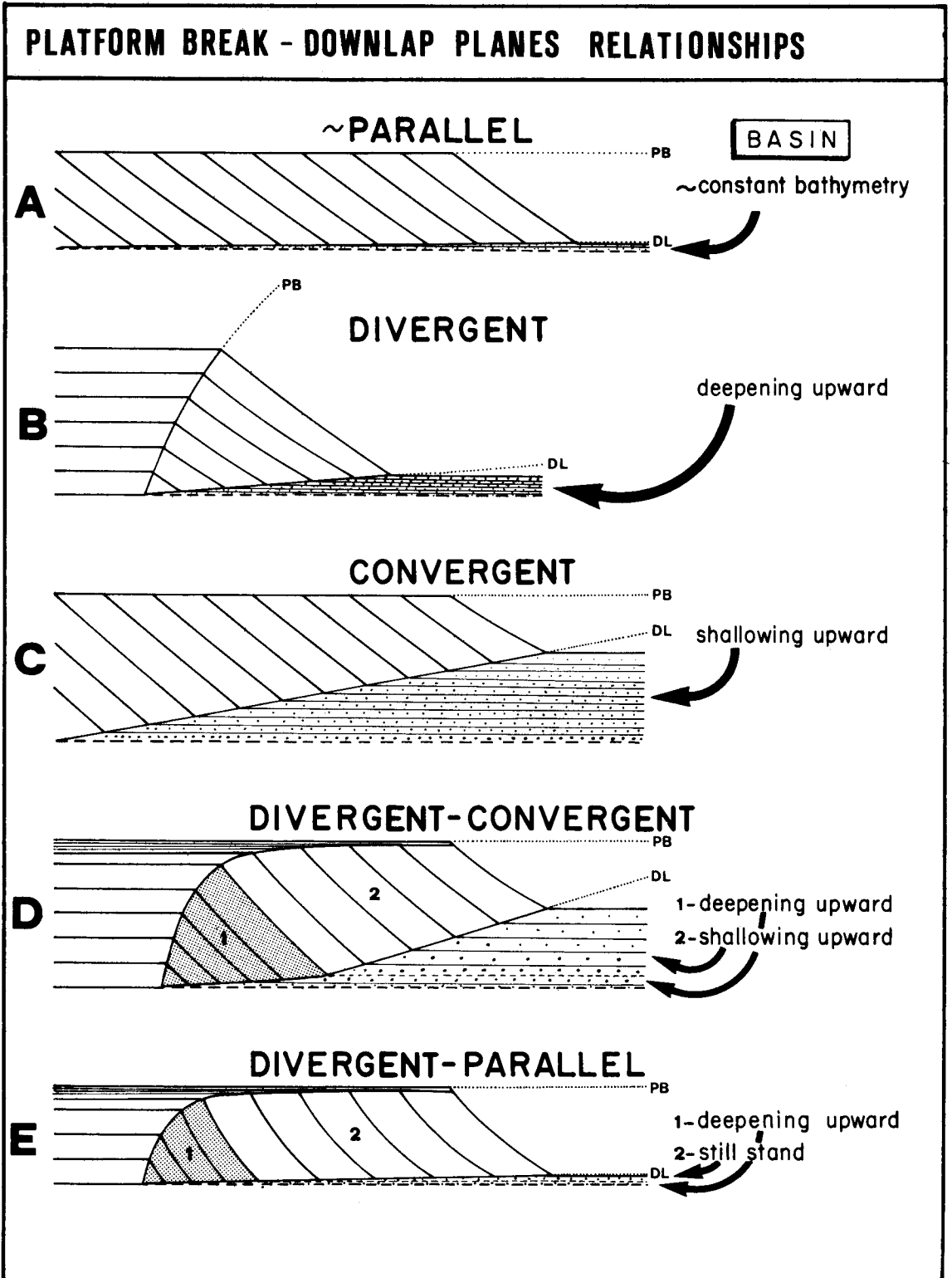


Fig. 5 - Different platform break-downlap planes relationships in progradational systems produce different evolution of the basin: A, parallel - constant bathymetry; B, divergent - deepening upward; C, convergent - shallowing upward; D, divergent-convergent - deepening and later shallowing upward; E, divergent-parallel - deepening and later still stand. PB, platform break plane; DL, downlap plane.

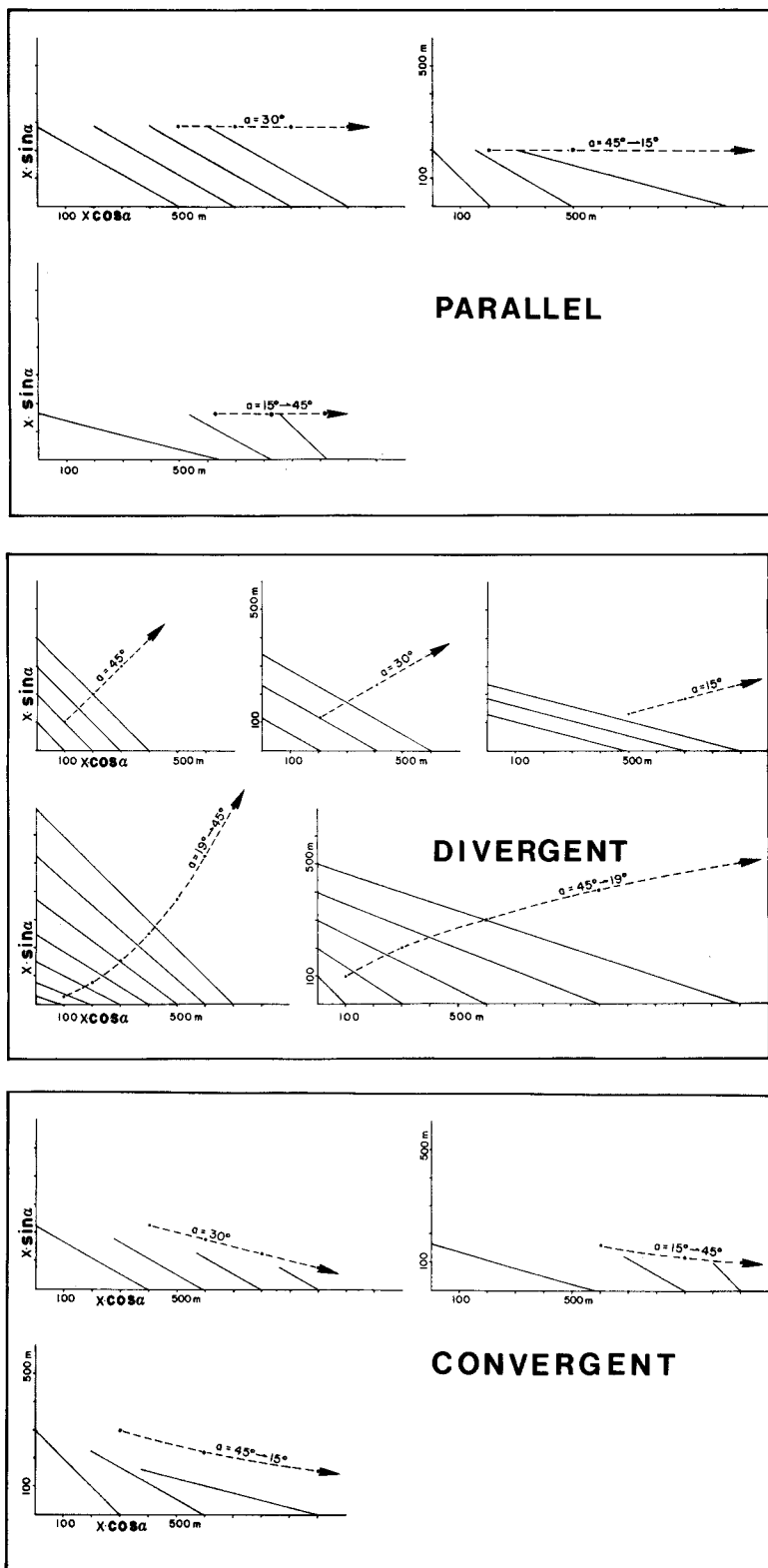


Fig. 6 - In fig. 1 the depth of a basin adjacent to a prograding carbonate platform is shown to be $X \sin \alpha$. In this diagram, we plot the $X \sin \alpha$ against $X \cos \alpha$ variations in the parallel, divergent and convergent cases of the platform break-downlap relationships. With constant angle α the result is a straight line. With variable α , the $X \sin \alpha$ - $X \cos \alpha$ relationship will give an arc in the divergent and convergent cases. The broken lines are horizontal with constant $X \sin \alpha$ (constant depth of the basin, parallel case); whereas they rise in the divergent case (deepening upward) or they decrease in the convergent case (shallowing upward). Consequently composite evolutions show combinations of the former elements. Note that the increasing of $X \sin \alpha$ values is corresponding to a relative sea level rise. Please note as example the divergent case: the straight line predicts a constant growth of the basin depth, while the first arc is still indicating a deepening of the basin but with higher aggradation of the platform with respect to a low sediment supply into the basin.

from subvertical, inclined to horizontal (toplap) while the downlap plane is inclined toward the basin. The two planes thus diverge basinwards.

Platforms showing a non-linear evolution are common in the Dolomites. The Catinaccio platform is one of the best examples. The platform break plane, which is very steep during the first growth stages (which indicates strong vertical aggradation) becomes progressively less inclined, assuming an almost horizontal configuration (which indicates strong progradation). Platform break and downlap planes first diverge and then become parallel or converge (fig. 5, D & E). The above relationships mean that the lower part of the basinal section accumulated in a rapidly deepening basin, while the upper part was deposited either in a basin of constant depth or in one which shallowed upwards. As is well known, these geometries are functions of sediment supply, sea-level changes (VAIL *et al.*, 1977; KENDALL & SCHLAGER, 1981; HAO *et al.*, 1987; BICE, 1988), tectonism (subsidence or uplift, BICE, 1988), climate (VAIL, 1987; VAN WAGONER *et al.*, 1987) and carbonate productivity (WILSON, 1975; KENDALL & SCHLAGER, 1981). Horizontal platform-break planes (toplap) are due to phases of relative sea-level still-stand, whereas aggradational patterns with steep platform-break planes are generated by a relative sea level rise (BOSELLINI, 1984). The evolution of the composite examples shown in fig. 5 (D, E) might be explained in terms of such relative sea-level changes. The first aggradational phase could be related to the steepest part of the cycle (eustatic rise) of the sea (highstand for instance of a 3th order cycle), or to a major tectonic subsidence. The following horizontal platform break plane (toplap phase) could reflect the last phase of the highstand just before the eustatic curve would begin to fall again, or it could be related to a lower subsidence rate. The inclination of the downlap plane is function of the sediment supply into the basin. With negligible basinal sediment supply (for instance in a starved basin) we have essentially an horizontal downlap plane; in contrast, high rates of basinal sediment supply will generate a steep downlap plane. If localized tectonics is the main control of the relative sea level changes, different geometries may characterize neighbouring carbonate platforms or even different margins of the same platform. In the Dolomites, horizontal and parallel platform break and downlap planes, e.g. around the Catinaccio platform (BOSELLINI & DOGLIONI, 1988) occur at the same time as di-

vergent platform break and downlap planes in a neighbouring platform (the Pale di San Lucano, fig. 4). These two platforms obviously grew in areas with different subsidence rates, related to Triassic strike-slip tectonics that disrupted the Dolomites particularly during Ladinian time (DOGLIONI, 1984; DOGLIONI, 1987). The mentioned examples are representative of the four end members of platform break — downlap planes relationships: parallel, divergent, convergent, composite. Other combinations probably occur, including retrograding systems (if any). The simple conclusion is that divergent platform break and downlap planes record a deepening of the basin whereas convergent planes will be associated with shallowing basins. The spatial pattern of these two geometric discontinuities may be an important tool in understanding and predicting the evolution of carbonate platform-basin systems. Estimation of the basin water-depth in carbonate systems can be very accurate because the platform break can be assumed to be close to sea-level. In some instances this model might also possibly be applied to clastic prograding systems (e.g. deltaic systems) to estimate the water-depth evolution of a basin. In fig. 6 a graphic expression of possible variations is presented. The accuracy of the procedure will be governed by the degree to which post-depositional compaction has modified the original geometries (DEVANEY *et al.*, 1986; DOGLIONI & GOLDHAMMER, 1988) and will probably be related to the thickness of compactable basinal sediment below the carbonate platform.

If we can predict the depth evolution of a basin from the $X \sin \alpha$ variations in a carbonate platform, where X is the length of the clinoform and α is its lower angle with the horizontal, we could apply the reverse analysis from the known evolution of a basin: e.g. if the basin shows a deepening upward succession, the platform should be characterized by a divergent pattern of platform break and downlap planes, while conversely a basin characterized by a shallowing upward sequence should have an adjacent platform displaying a convergent pattern, if syn-sedimentary tectonics are absent between the two systems.

This technique is proposed as a tool in basin analysis: e.g. it might allow us, in absence of lithological data, to identify situations on seismic sections in which basinal source rocks might have developed, or to generate more accurate facies models for the carbonate platform margins involved.

ACKNOWLEDGEMENTS:

Thanks to D. BERNOULLI and an anonymous referee for the critical reading of the paper. We also thank A.W. BALLY, P. BRACK, R. CATALANO, G. EBERLI, R.K. GOLDHAMMER, E. MUTTI, C. NERI, F. RICCI LUCCHI, P. VAIL and J.L. WILSON for interesting discussions around this topic.

Manoscritto consegnato il 30 dicembre 1988

Testo accettato per la stampa il 20 febbraio 1989

Ultime bozze restituite il 9 maggio 1989

REFERENCES

- BICE (1988) - *Synthetic stratigraphy of carbonate platform and basin systems*. *Geology*, **16**, 703-706.
- BLENDINGER W. (1986) - *Isolated stationary carbonate platforms: the Middle Triassic (Ladinian) of the Marمولادا area, Dolomites, Italy*. *Sedimentology*, **33**, 159-183.
- BOSELLINI A. (1984) - *Progradation geometries of carbonate platforms: examples from the Triassic of the Dolomites (Northern Italy)*. *Sedimentology*, **31**, 1-24.
- BOSELLINI A. & DOGLIONI C. (1988) - *American Association of Petroleum Geologists. Field Trip n. 6 in the Dolomites*. Guide Book, Amer. Ass. Petrol. Geol., Mediterranean Basins Conference, Nice, 1-45.
- BOSELLINI A. & FERRI R. (1980) - *La Formazione di Livinallongo (Buchenstein) nella Valle di S. Lucano (Ladinico inferiore, Dolomiti Bellunesi)*. *Ann. Univ. Ferrara, Sc. Geol. Paleont.*, **IX**, **6**, 63-89.
- BOSELLINI A. & ROSSI D. (1974) - *Triassic carbonate buildups of the Dolomites, Northern Italy*. *Soc. of Econ. Paleont. and Mineral. sp. publ.*, **18**, 209-233.
- DEVANEY K.A., WILKINSON H.B. & VAN DER VOO R. (1986) - *Deposition and compaction of carbonate clinothems: The Silurian Pipe Creek Junior complex of east-central Indiana*. *Geol. Soc. Amer. Bull.*, **97**, **11**, 1367-1381.
- DOGLIONI C. (1984) - *Tettonica triassica transpressiva nelle Dolomiti*. *Giorn. Geol.*, **46/2**, 47-60.
- DOGLIONI C. (1987) - *Tectonics of the Dolomites (Southern Alps - Northern Italy)*. *Journ. Struct. Geol.*, **9**, **2**, 181-193.
- DOGLIONI C. & GOLDHAMMER R.K. (1988) - *Compaction-induced subsidence in the margin of a carbonate platform*. *Basin Research*, **4**.
- HAQ B.U., HARDENBOL J. & VAIL P.R. (1987) - *Chronology of fluctuating sea levels since the Triassic (250 million years ago to present)*. *Science*, **235**, 1156-1167.
- KENDALL C.G.St.G. & SCHLAGER W. (1981) - *Carbonates and relative changes in sea level*. *Marine Geol.*, **44**, 181-212.
- LEONARDI P. et al. (1967) - *Le Dolomiti. Geologia dei monti tra Isarco e Piave*. Vols. 1-2, 1-1019, Manfrini Ed., Rovereto.
- MITCHUM R.M.Jr., VAIL P.R. & THOMPSON S. III (1977) - *Seismic Stratigraphy and Global Changes of Sea-Level, Part 2: The Depositional Sequence as a Basic Unit for Stratigraphic Analysis*. In: *Seismic Stratigraphy - applications to Hydrocarbon exploration* (Ed. by C.E. Payton), *Mem. Amer. Ass. Petrol. Geol.*, **26**, 53-62.
- MOJSISOVICS E.V. (1879) - *Die Dolomit riffe von Sudtirol und Venetien. Beitrage zur Bildungsgeschichte der Alpen*. Holder, Wien, 1-522.
- VAIL P.R. (1987) - *Seismic stratigraphy interpretation procedure*. *Amer. Ass. Petr. Geol., Atlas of Seismic Stratigraphy, studies*, **27**, **1**, 1-10.
- VAIL P.R., MITCHUM R.M.Jr. & THOMPSON S.III (1977) - *Seismic stratigraphy and global changes of sea level. Part 4: Global cycles of relative changes of sea level*. In: *Seismic Stratigraphy - applications to hydrocarbon exploration*, (Ed. by C.E. Payton), *Mem. Amer. Ass. Petr. Geol.*, **26**, 83-97.
- VAN WAGONER J.C., MITCHUM R.M.Jr., POSAMENTIER H.W. & VAIL P.R. (1987) - *Key definitions of sequence Stratigraphy*. *Amer. Ass. Petr. Geol., Atlas of Seismic stratigraphy, studies*, **27**, **1**, 1-15.
- WILSON J.L. (1975) - *Carbonate facies in geologic History*. Springer-Verlag, 1-471, New York.