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The evolution of potholes in granite bedrock, W Spain

Marek W. Lorenc[a], Pedro Muñoz Barco[b], Julio Saavedra[c]

[a]*Polish Academy of Sciences, Institute of Geological Sciences, ul. Podwale 75, 50-449 Wroclaw, Poland*
[b]*Agencia de Medio Ambiente, Junta de Extremadura, 06800 Mérida, Spain*
[c]*Instituto de Reursos Naturales (CSIC), Apartado 257, 37071 Salamanca, Spain*

Abstract

Spectacular bed forms, eroded by flood flows, are a feature of the bare rock terraces and channels of some rivers cut into granitic rock in the districts of Salamanca, Cáceres and Badajoz, W Spain. The bed forms comprise a range of pothole types which individually represent various stages in the evolution of mature potholes. Pothole evolution reflects the hydrodynamics of the erosion, by high velocity flood flows, of bedrock. They evolve in time and in concert with the evolution of the landscape. Initial shallow depressions deepen gradually into cylindrical forms as vertical erosion increases. As time passes, lateral erosion increases and leads to wider cylindrical forms which evolve into asymmetrical and bulbous forms. Second-order scouring leads to the development of minor decorative potholes, tunnels and niche caves in the large, mature potholes. Data on pothole geometry should complement the findings of other geomorphological studies on individual rivers and on regions.

1. Introduction

The abundance, morphology and evolution of erosional features, e.g, potholes, developed in river beds may provide a measure of the progress of regional erosion with time. To test this possibility, a comparative study of erosional forms was undertaken at four different sites where potholes and related features are well developed in granite bedrock in the Cáceres, Badajoz and Salamanca Provinces, W Spain.

The first of the four sites is located in the wide valley of the Salor River close to Cáceres in central Extremadura (Fig. 1). Erosional forms occur on a flat river granite terrace scattered with large granite boulders. Nemec et al. (1982) carried out an early study in this area.

The second site is the river Tormes in the vicinity of Puente del Congosto in the southeastern part of Salamanca Province (Fig. 1). The main river channel is flanked by one river terrace narrowing eastwards towards the Roman bridge in Puente del

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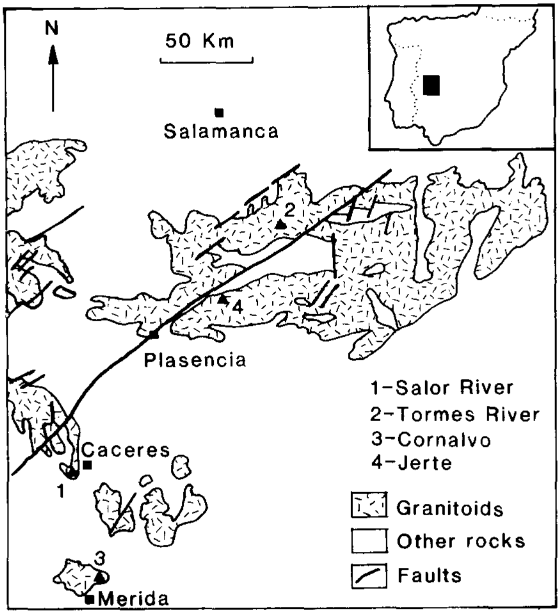

Fig. 1. Sketch map showing the locations of the places mentioned in the text. The distribution of granitic rocks is based on Corretgé (1983).

Congosto. Erosional forms in Spanish granitoids were first described here (Lorenc and Saavedra, 1980).

The third site lies in the valley of the Arroyo de las Muelas which flows through the southern part of the Cornalvo National Park and which is a tributary of the Guadiana River (referred to as Cornalvo below). The site is in the province of Badajoz, 18 km northeast of Merida (Fig. 1). The deep winding river channel has two narrow terraces with granite boulders scattered about. The location of potholes on both terraces indicates that water levels can vary over up to 8 metres.

The last site is at a place called "Garganta del Infierno" on a tributary of the Jerte River about 35 km northeast of Plasencia (Fig. 1). In this case (referred to as Jerte below), the river valley is a deep (40–50 m) V-shaped valley lacking terraces.

2. Pothole evolution

Irregularities and obstacles on bedrock create disturbances, flow separations and local areas of increased static pressure in turbulent flows. These, combined with the influences of varying channel morphologies, are the principal causes for the development of the potholes on the river terraces and channel floors (Allen, 1971; Jackson, 1977; Baker, 1978; Lorenc and Saavedra, 1980; Nemec et al., 1982).

Where flow separations occur, the direction of flow is locally reversed. The resulting eddies are transformed into vertical hydraulic vortices and the scouring of a depression begins. Where the flow is of low velocity, scouring is concentrated on

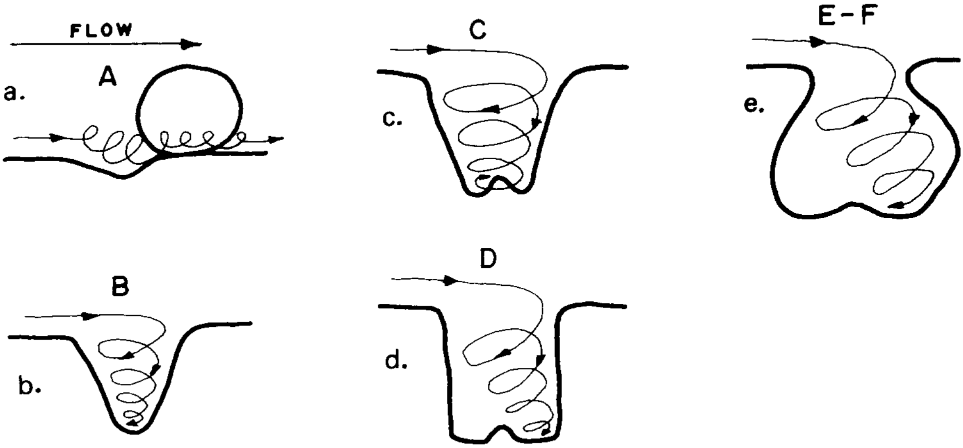

Fig. 2. The evolving morphology of a typical pothole with time (see text).

the upstream side of the obstacle. Where the velocity is high, scouring is initiated also on the downstream side and the resulting hole is always relatively large (Nemec et al., 1982, Fig. 4). These initial depressions are typically horseshoe-shaped. The evolution of the initial depression into a true pothole influences, in turn, the evolution of the eroding vortex.

The varying shapes of the large number of potholes examined for this study are consistent with the following evolutionary scheme. During the first stage of erosion, scour holes are shallow (Fig. 2, Type A). Progressively, as vertical erosion becomes increasingly important, the pothole deepens. At this stage, depth and diameter remain roughly in proportion (Type B). The rotary action of the water, and progressive abrasion by sand and rock particles, increases the size of the pothole. There comes a time when the flow energy is inadequate to lift rotating rock particles and, as a consequence, scouring becomes less effective in the upper part of the pothole (Type C). Gradually, a more cylindrical shape evolves with the diameter at the top remaining more or less constant and a central knoll forming on the floor (Type. D). The top diameter of a number of large potholes was carefully remeasured after an interval of ten years. No change in this diameter had occurred.

As the typical pothole continues to evolve, downward erosion is gradually matched and exceeded in importance by hydraulic scouring which begins to extend the lower part of the hole in a lateral direction; the diameter of the base increasingly exceeds that of the top as the hole becomes more bulbous (Type E). Typically, the walls show a horizontal grooving. As time passes, the direction of river flow is increasingly reflected in the assymmetric erosion of the lower parts of the pothole (Type F). This assymmetry combines with any internal irregularities to cause a new generation of eddies and vortices to develop inside. These lead to the development of second-order scours, niche caves and tunnels which decorate the walls of the ever increasing and, by now, very complex forms. At this stage, potholes increasingly tend to coalesce.

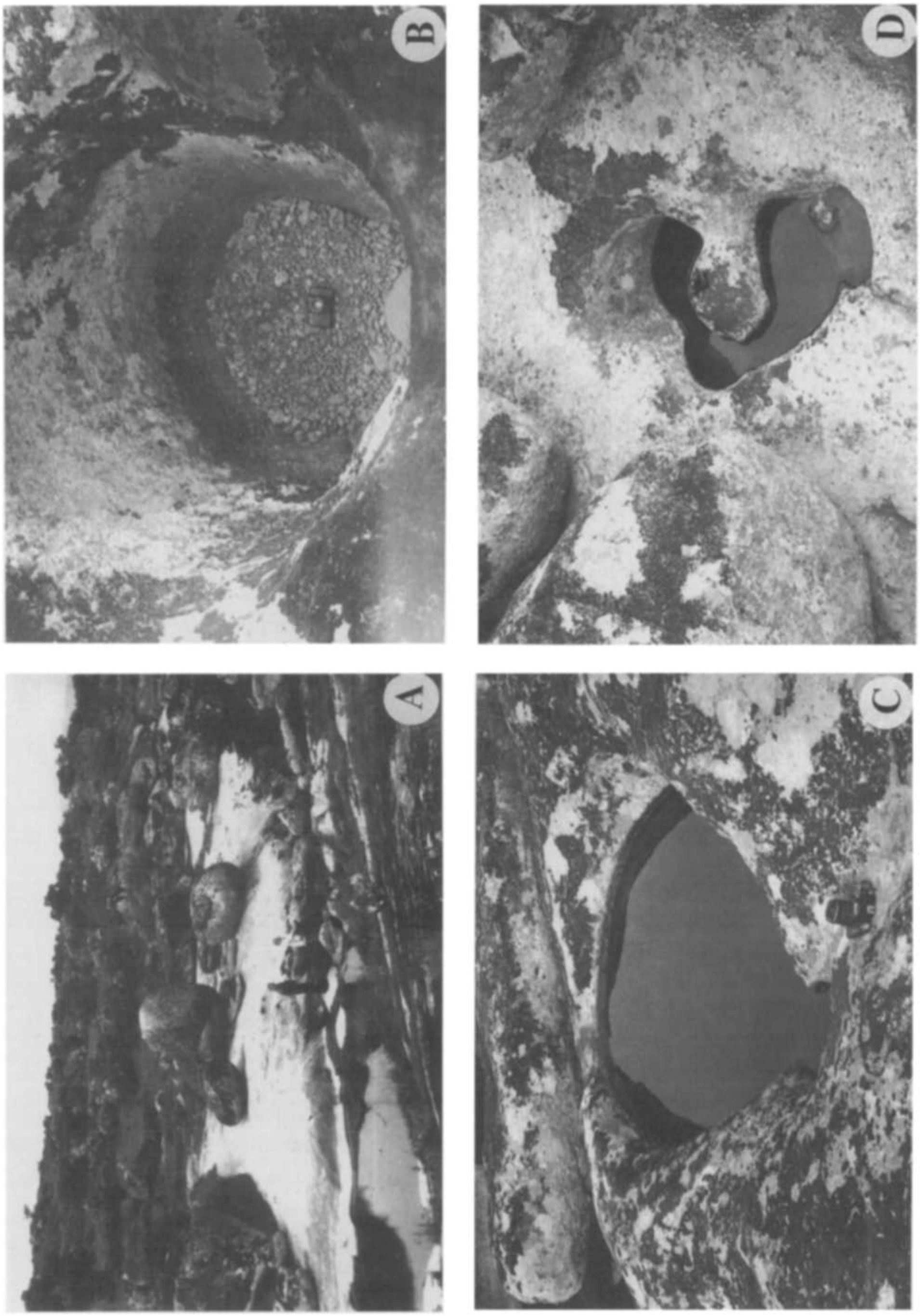

Fig. 3. The Salor River. (A) The terrace with large granite boulders. (B) Early-stage, cone-shaped Type B pothole. (C) Late-stage Type E pothole. Though filled with water, the walls can be seen to slope outwards. (D) Three coalesced Type C potholes.

3. Occurrences of potholes

3.1. The Salor River (Cáceres)

The Salor River flows in a steep-walled axial channel cut into a wide, relatively flat granitic terrace with gently inclined marginal scarps. Large (3–5 m) granite boulders, derived from the adjacent highlands, lie scattered about on this terrace (Fig. 3A).

Early pothole forms (Types A, B; Fig. 3B) are developed in the main channel and also on the terrace. More evolved potholes (Types C, D; Fig. 3D) are concentrated at the inner edge of the terrace. Spectacularly, bulbous and complex forms (Types E, F; Fig. 3C) are preferentially located closer to and on the margins of the main river channel.

3.2. The Tormes River (Salamanca)

The cross section of this river valley compares with that of the Salor River. The single granitic terrace, however, lacks the scattered granite boulders of the former locality (Fig. 4A). Here, the more complex E–F types are not in the river channel itself but some meters away on the marginal terrace. These separate the simpler C and D potholes (Fig. 4B) which lie closer to the river channel from the more primitive A–B potholes which occur further away on the terrace.

Near the Roman bridge in Puente del Congosto, a single horseshoe-shaped pothole probably developed where a boulder once stood (Fig. 4C). Some small horizontal holes also cut into vertical rock surfaces here (Fig. 4D).

3.3. Cornalvo (Badajoz)

The winding course of the Muelas stream is filled with granitic boulders (Fig. 5A). Despite this, two relatively narrow terraces bordering the river channel are well marked. Shallow and symmetrical A and B potholes are relatively abundant on the upper terrace (Fig. 5B). C and D potholes occur mainly on the lower terrace (Fig. 5C). Large E potholes and more abundant F potholes are developed on the lower terrace close to the river channel; these may be large enough to walk inside (Fig. 5D). Significantly, cylindrical D potholes, and to a lesser degree, C and E holes are much reduced in number here.

3.4. The Jerte River (Cáceres)

In the stretch of this river that is called "La Garganta del Infierno", a V-shaped valley lacking terraces and boulders (Fig. 6A), eight, very large (10–15 m) F-type potholes are to be found. These large holes contain smaller potholes of every type (Fig. 6B, C). The very large potholes are sited at the bases of a series of waterfalls, the positions of which are influenced by a series of faults in the bed rock. Some large (5 m) C and D potholes occur on the valley walls (Fig. 6D). Early-stage A and B holes also occur on the valley walls about 5 metres above the present water level.

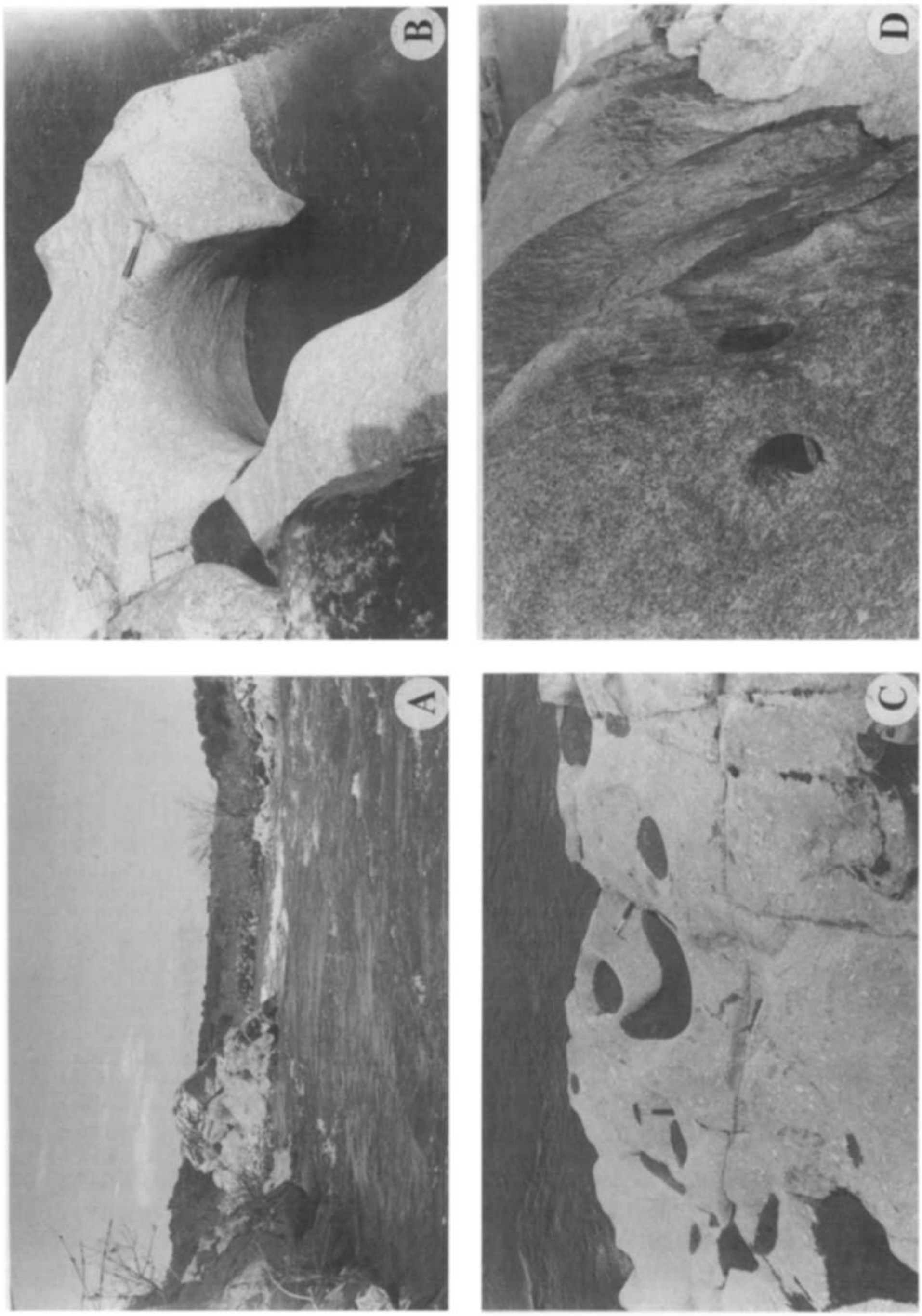

Fig. 4. The Tormes River. (A) Main river channel filled with water to the inner edge of the flat terraces. (B) Cylindrical Type D pothole breached by the river. (C) Type A and B potholes, including a typical horse-shoe form, at the inner edge of the terrace. (D) Typical horizontal hole close to present river channel.

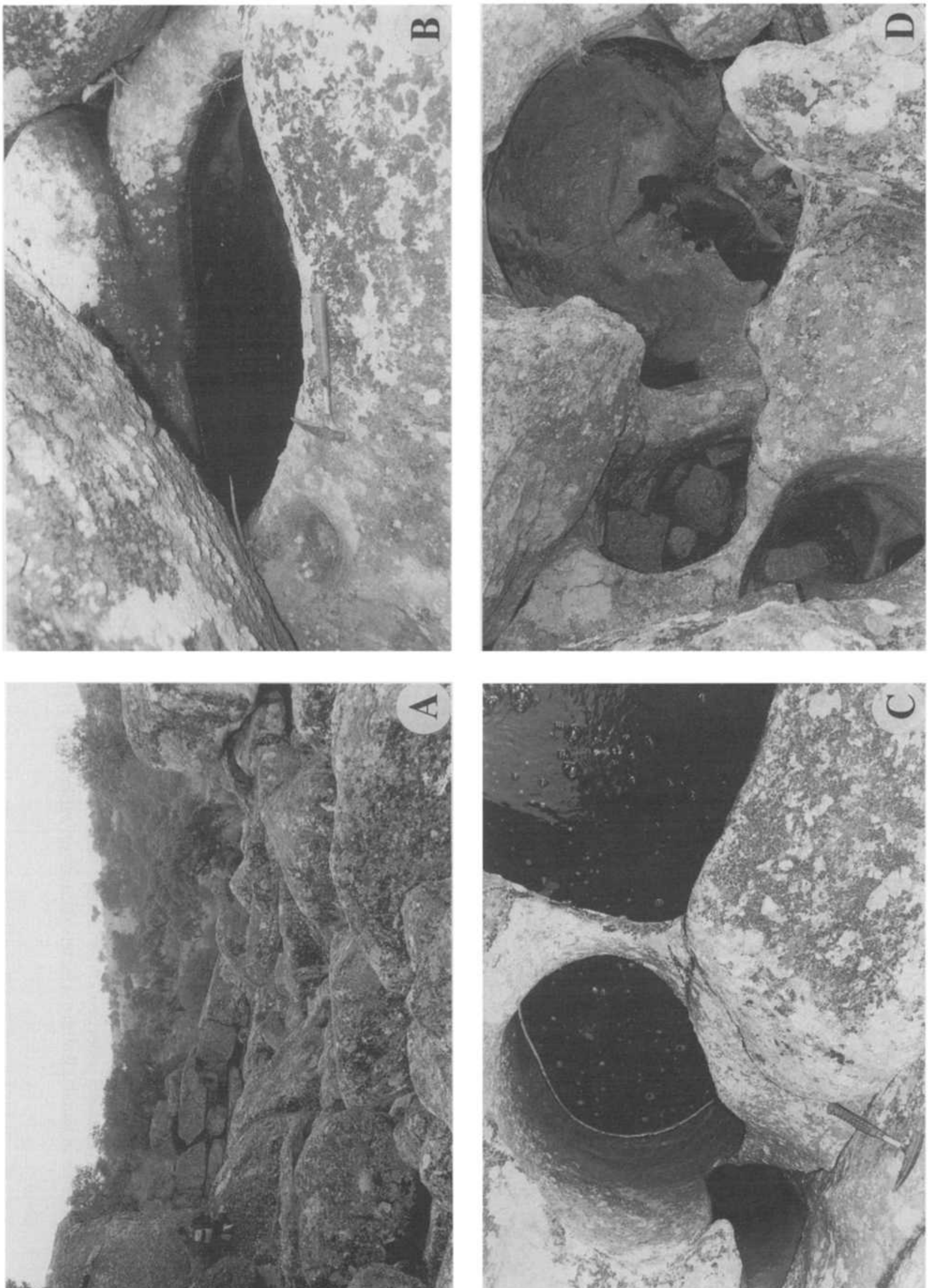

Fig. 5. Cornalvo (Muelas River). (A) Granite boulders in the river channel with terrace above. (B) Small early Type A pothole (left of hammer) and large Type E pothole. (C) Type D pothole breached by main river channel. (D) Large complex Type F pothole viewed from above.

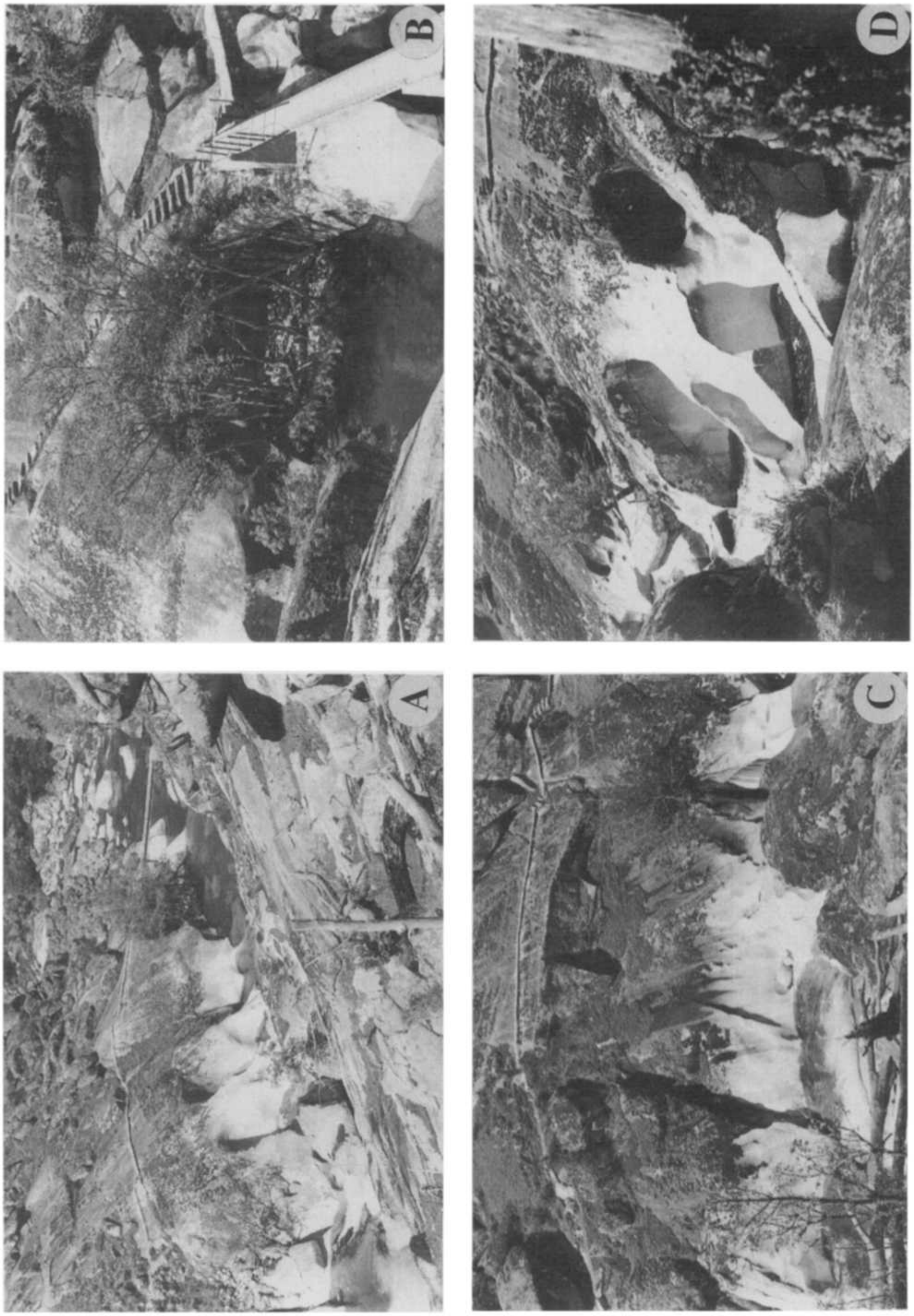

Fig. 6. Jerte River (Garganta del Infierno). (A) V-shaped valley with large potholes in a cascade (see text). (B) Large Type F pothole (detail from below bridge in A). (C) Type F pothole in waterfall sump which is related to visible faults. (D) Cylindrical Type D and assymmetric Type E potholes at margin of river channel.

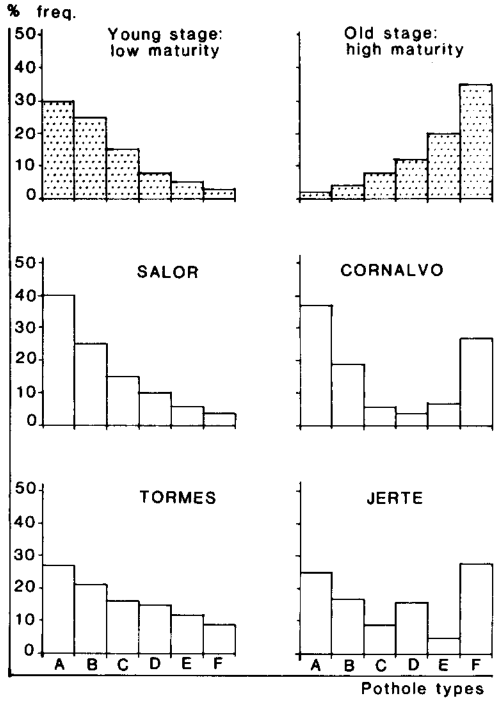

Fig. 7. Comparison of frequency distributions of potholes in four named river valleys compared with distributions expected in "young" and "old" stages of maturity.

The relative proportions of the different pothole types present vary from site to site. Calculated proprtions, based on field counts, are shown on Fig. 7.

4. Conclusions

The pattern of pothole maturity in a particular river valley can be used as a measure of the "erosional maturity" of the valley in the following way. All other things being equal, a pothole pattern involving many immature forms should characterize "young" stages in the erosion of a bedrock surface and, conversely, a preponderance of mature pothole forms should be a feature of "older" stages (Fig. 7).

Knowing the proportions of the various pothole types in the four areas studied (Fig. 7), this simple rule allows the following conclusions.

(a) The Salor River valley represents a "young" erosional stage; immature pothole forms predominate and the largest potholes are sited close to the present river channel.

(b) The present valley of the Tormes River displays a similar relatively "young" evolutionary stage. The positioning of the large mature potholes above the present river level suggests that the water level in this river was, for a considerable time in the past, higher than it is today.

(c) In the Cornalvo, significant numbers of large F-type holes suggests an "old" evolutionary stage. Large numbers of smaller primitive potholes suggest a more recent erosional overprint. The paucity of intermediate forms is an important support for this conclusion.

(d) The Jerte River valley represents, essentially, an "old" evolutionary stage overprinted by "younger" erosional event(s). However, in this case, the local geological structure — a series of parallel faults — played an important role in the development of some large sumps (F-type potholes) at the bases of waterfalls.

In the evolutionary history of a river channel, pothole formation is rightly recognized as a most potent method of downcutting. At any given moment, however, they are a morphological detail. Other than recognizing the abrasion they reflect, they may tend to be ignored. However, their geometries may allow a point in the history of a river, i.e., its present maturity, to be precisely defined. In addition, the spatial locations of potholes in river valleys reveal past and seasonal water-levels.

This preliminary study in W Spain suggests that a more complete and quantitative knowledge of pothole development in the rivers of the region could profitably complement and refine the findings of other methods of geomorphological measurement.

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References

Allen, J.R.L., 1971. Transverse erosional marks of mud and rock: their physical basis and geological significance. Sediment. Geol., 5: 167–385.

Baker, V.R., 1978. Large scale erosional and depositional features of the Channeled Scabland. In: V.R. Baker and D. Nummedal (Editors), The Channeled Scabland. Field Confer. Guide, N.A.S.A., Washington, DC, pp. 81–115.

Corretgé, L.J., 1983. Las rocas graníticas y granitoides del Macizo Ibérico. In: Geologia de España, Tomo I, Libro Jubilar J.M. Rios, Inst. Geol. Min. de España, pp. 569–592.

Jackson, R.G., 1977. Genesis of fluvial bedforms. In: Program and Abstracts of the First International Symposium on Fluvial Sedimentology, Calgary, Alta., pp. 15–16.

Lorenc, M.W. and Saavedra, J., 1980. Remarks on the pothole erosion at the Tormes River (Salamanca Province, Spain). Acta Geol. Hisp., 15: 91–93.

Nemec, W., Lorenc, M.W. and Saavedra, J., 1982. Potholed granite terrace in the Río Salor valley, western Spain: a study of bedrock erosion by floods. Tecniterrae, 50: 6–21.