INTRODUCTION

Since the 1950s, bentonite has been obtained from numerous deposits in the Cabo de Gata volcanic region (Almería, SE Spain) (Fig. 1). The mineral, which is of high quality, with over 90% smectite, is extracted by open-cast mining and left to dry beside the quarries. Drying is encouraged by the arid climate of the area (less than 250 mm/year precipitation) which makes extraction economically viable.

In all over 130,000 tonnes/year of bentonite are extracted at present. It is mainly used in decolouring and clarifying oils and wines, in pharmaceutical and chemical products, etc. Recently these bentonites have been studied with a view to use as filling and sealing materials in the storage of radioactive waste, and the favourable results obtained suggest an encouraging future for the bentonites of the area.

The Cabo de Gata volcanic outcrops form part of a more extensive volcanic area mainly submerged beneath the Alboran Sea. The principal emerged outcrops of this area are found in the south-east of the provinces of Almería and Murcia, on Alboran Island and in North Africa (Fig. 1A). The origin of these volcanic rocks is associated with the geotectonic dynamics of the Western Mediterranean during the Neogene. Of the several hypotheses suggested regarding this dynamics, that which best fits the regional geological, geophysical, palaeomagnetic, geochemical and petrological data is that of a continental collision prior to an extensional process occurring in several stages according to the different phases of magmatism (Fernández Soler, 1992).

Radiometric dating of the volcanism at Cabo de Gata indicates ages of 15 to 7 Ma (Bellon et al., 1983; Di Battistini et al., 1987). This is calc-alkali volcanism with rocks whose compositions range from andesites to rhyolites, with predominance of andesites and dacites (López Ruiz y Rodríguez Badiola, 1980; Bordet, 1985; Fernández Soler, 1992). The most common type of structure is dome-fields, which constitute clearly distinguishable volcanostatigraphic units containing abundant pyroclastic episodes (pumice) made up of rhyolite and dacite (Fernández Soler, 1992). The development of domes is related to regional fracturing.
Fig. 1 A: Neogene volcanism in the Alboran Basin (Western Mediterranean). B: Location of the bentonite deposits in the Cabo de Gata area: Cortijo de Archidona (CA), Los Trancos (LT) and Morrón de Mateo (MM).
systems in which multi-vent emissions were important (Fernández Soler & Muñoz, 1988). The emission of large quantities of pyroclastic materials led to the formation of large calderas, sometimes over 5 km in diameter, that led to the formation of the gold deposits in the Rodalquilar area (Rytuba et al., 1990; Cunningham et al., 1990).

Carbonate beds containing abundant marine fossils frequently intercalate the different volcanic episodes (Fuster et al., 1965; Saavedra, 1966; Bordet, 1985) which, together with the presence of hydromagmatic volcanic facies, indicates that much of the volcanicity took place in shallow or coastal submarine conditions (Fernández Soler, 1992). However, the presence of Upper Tortonian - Lower Messinian palaeosoils in the northern part of Cabo de Gata confirms that at least during this period the volcanic rocks were emerged above their present height of 200 m (Delgado, 1993). Later in the Messinian the volcanic highs of Cabo de Gata were covered with reefal materials (Esteban, 1979; Armstrong et al., 1980; Dabrio & Martín, 1979; etc.). More recently, in the Pliocene and Quaternary, the area was uplifted and the Betic Cordilleras were folded (Reault, 1985), which led to exposure of the area to weathering and erosion (Fig. 1B).

Throughout the geological history of the region the Cabo de Gata volcanic rocks have been exposed to marine and meteoric environments, but the late volcanic activity also created hydrothermal systems in which marine and/or meteoric water, or even magmatic water, may have played a role. Different chemical solutions at different temperatures therefore took part in the alteration processes of the volcanic materials. Acid-sulphate solutions mainly produce silica, alunite, jarosite and kaolinite by alteration (Friedrich, 1960; Lodder, 1966; Martín Vivaldi et al., 1971; Puy et al., 1974; etc.) and have occasionally been related to the gold-deposits in the area (Sänger-von Oepen et al., 1989, 1990; Rytuba et al., 1990), whereas neutral or slightly acid solutions would have caused the most important bentonite deposits in the area (Reyes, 1977; Linares, 1985, 1987; Caballero et al., 1985a; etc.).

THE CABO DE GATA BENTONITES

Over 30 bentonite outcrops have been described in the Cabo de Gata area. They developed on different types of volcanic rocks in the Sierra de Cabo de Gata and the Serrata de Nijar and have been the subject of numerous studies concerned with determining the technical, mineralogical and chemical characteristics of the bentonites and the processes involve in their genesis (González García & Martín Vivaldi, 1949; González García & Beutelspacher, 1956; Martín Vivaldi et al., 1956; Martín Vivaldi & Linares, 1968; Mackenzie, 1957; Linares, 1963; 1985; 1987; Linares & Martín Vivaldi, 1962; Linares et al., 1972; 1987; 1993; Reyes, 1973; 1977; Reyes et al., 1974, 1978a,b; 1979a,b,c; 1980a,b; 1987; Augustín, 1973; Terrer, 1974; Leone et al., 1983; Caballero, 1982; 1985; Caballero et al., 1983; 1985a,b; 1992; Delgado, 1993; Delgado & Reyes, 1993).
By virtue of the high number of outcrops studied and their distribution throughout the Cabo de Gata area, Caballero et al. (1985) distinguished 3 zones in which the bentonites have similar characteristics (Table 1):

- Serrata de Níjar
- Northern Sierra de Cabo de Gata
- Southern Sierra de Cabo de Gata

For these authors the relative homogeneity of the bentonites in each of these areas depends not only on the type of rock undergoing alteration, but also the chemical composition and temperature of the alteration solutions.

In all three cases, the mineralogy is made up of high percentages of phyllosilicates (average 86%). However, it should be remembered that the results of Caballero (1985) expressed in Table 1 refer to 286 samples from different sites, some of which are of little economic interest. The commercially exploited bentonite therefore has even higher percentages of smectite. The bentonites of the southern part of Cabo de Gata present a lower phyllosilicate content and occasionally high quartz, tridymite and zeolite contents. The crystal size of the smectites is in general very varied. There is only some grouping of values around 24 Å in the Serrata de Níjar, in contrast to the variety and higher average values in the other two areas. The crystallinity index presents high average values (0.84) typical of hydrothermal smectites (Reyes, 1977).

The chemical composition of the bentonites in the northern part of Sierra de Cabo de Gata contains anomalous Fe₂O₃ and MgO contents in comparison with the other areas. The low Fe values in these bentonites are due to the fact that the degree of alteration of the bentonites is the highest in the whole region, which implies loss of iron, since intensity of alteration correlates inversely with Fe content, as pointed out by Caballero et al. (1991). On the other hand, the relatively high MgO contents could be explained not only by supply of this element in the original alteration solutions (Caballero, 1985), but also because the volcanic materials in this area, in particular the bentonite deposits, are covered by reefal carbonate beds made up of Mg and dolomite-rich calcite. The water involved in the meteoric diagenesis of these materials could have provided considerable quantities of magnesium (Delgado, 1993). It is also significant that the Mg contents of the smectites in all three zones are very similar (around 5.7%) and therefore the high MgO values of the bentonite in the northern zone would partly be due to the high smectite content.
<table>
<thead>
<tr>
<th>Mineralogy</th>
<th>North S. Gata</th>
<th>S. Nijar</th>
<th>South S. Gata</th>
<th>Region Mean</th>
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<tr>
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<td>T</td>
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<td>0.82</td>
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<td>MgO</td>
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<tr>
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<td>Si(IV)</td>
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<td>7.4-7.9</td>
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<td>Al(IV)</td>
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<td>0-0.8</td>
<td>0.318</td>
<td>0-0.6</td>
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<td>Al(ML)</td>
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<td>2.3-3.3</td>
<td>2.706</td>
<td>2-3.1</td>
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<td>Mg(V)</td>
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<td>0-3.1-6</td>
<td>1.059</td>
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<td>Fe(V)</td>
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<td>0-0.5</td>
<td>0.472</td>
<td>0-1.2</td>
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<tr>
<td>X⁺</td>
<td>0.942</td>
<td>0-5-1.2</td>
<td>0.663</td>
<td>0-4-1</td>
</tr>
</tbody>
</table>
The only significant differences in the very smectite-rich < 2μm fraction are found in the Fe contents, which are higher in the Serrata de Níjar and the southern part of Sierra de Cabo de Gata. The H2O+ content in Serrata de Níjar is also lower than the other two areas. Only the samples exclusively made up of smectite were used in calculating the structural formulae. The samples from the northern part of Sierra de Cabo de Gata presented lower Fe(VI) and Al(VI) contents and higher values of the total charge.

The bentonites also present different colouring in each of the three areas. In the northern zone they are white or grey, in contrast to predominantly ochre or greenish colours in the southern zone and a variety of colours in the Serrata de Níjar, where strong reds, whites and greens are frequent, among others. It was found that these colours are closely related to the contents of certain trace elements such as copper, nickel, cobalt, etc. (Linares et al., 1972, 1987).

GENESIS OF THE BENTONITE DEPOSITS

Alteration processes are encouraged in rocks with high contents of volcanic glass because of the poorly ordered internal structure and the abundance of intermolecular spaces. If suitable physical conditions are also present, such as high temperatures, high permeability and porosity allowing fluid circulation, the extent and rate of the process is considerably increased.

The most important bentonite deposits in the Cabo de Gata volcanic region were produced in those zones where several of these factors coincided. They mainly developed on highly porous vitrophydic rocks or tuffs in places where the specific surface area and permeability increased because of crushing of the rock along faults and around dome intrusions. In the latter case, the rock would have been subjected to a thermal effect for a relatively short time, which would have added to the mechanical effect of the intrusion on the surrounding rock. Areas of faulting and contact between pyroclastic and massive materials have played an important role in the hydrogeology of the region, in many cases forming inlets and outlets for water (springs at different temperatures). This water would have made the alteration sufficiently intensive and widespread to form the bentonite deposits.

This type of bentonite deposits associated with the intrusion of igneous bodies have been described by several authors (Cavinato, 1957; Grim & Güven, 1978; Kawano & Tomita, 1991; etc.). In this case the low δ18O values of the silica in the fissure fillings of the deposits or surrounding areas indicate that it formed at higher than environmental temperatures (50-120°C), which agrees with initiation of hydrolysis in a hydrothermal environment (Delgado, 1993). The temperature of the alteration solutions then decreased, probably quite quickly and, in some cases, to environmental temperature, as shown by the high δ18O values obtained by Reyes (1977),

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Leone et al. (1983) and Delgado (1993) for smectites from different deposits in the region. This proposed genesis fully agrees with the enthalpy calculations of the processes of hydration and smectite formation carried out by Linares (1985), which indicate that once the alteration processes had begun, and because of their exothermic character, a phenomenon of autopropulsion would have occurred leading to total destruction of the rock.

Caballero et al. (1985) deduced the composition of the water responsible for alteration on the basis of the soluble anions and cations and the change cations in the bentonites. In the Serrata de Nijar the water was chloride-sulphate-calcic type, whereas in the northern part of the Sierra de Cabo de Gata it was calcium bicarbonate in type. This concurs fully with the chemical composition of the subterranean water at present extracted from the Campo de Nijar aquifer, which is chloride-sodium-magnesium type with a strong sulphate component (Junta de Andalucía, 1988). The type is also the same in the recharged aquifers in Sierra Alhamilla and Sierra Cabrera located to the north of the deposits and which probably provide recharge water for these alteration solutions. As regards the northern zone, the calcium bicarbonate composition of the water seems to be due to supply of these elements by dissolution of the overlying reefal carbonates (Delgado, 1993). The solutions all present a high Mg content (Martín Vivaldi & Linares, 1968; Reyes, 1977; Caballero et al., 1985), thus encouraging smectite formation (Martín Vivaldi & Del Pino Vazquez, 1956; Harder, 1972).

The deduced composition of these solutions therefore indicates that the water causing alteration was meteoric (Reyes, 1977; Caballero et al. 1985; Linares, 1985), which concurs with the very negative $\delta^{2}H$ values obtained by Delgado (1993) for different bentonites. In any case, and taking into account both the geological history of the region and the high number of deposits, we may not, at least initially, discount the possible intervention of sea water or a mixture of fresh and sea water in some deposits (Delgado & Reyes, 1993; Delgado, 1993).

Apart from the composition of the alteration solution, genesis is also fundamentally affected by the chemical composition and texture of the original rock and by the loss of material occurring throughout the process. By means of mass balance calculations, Caballero et al. (1992) thus found that material loss occurs during alteration processes as a result of the action of important amounts of water providing Fe, Ca and Mg and removing Si, Na and K. The mineralogical composition of the products of alteration, which is mainly smectite, indicates genesis in a system with a high number of mobile components (Linares, 1985). Lower mobility of certain elements may only be found in some deposits with high zeolite, cristobalite and feldspar contents in the southern area of the Sierra de Cabo de Gata.
DESCRIPTION OF THE STOP SITES

Stop 1. The Cortijo de Archidona bentonite deposit (Serrata de Níjar)

The Serrata de Níjar consists of a number of hills forming a horst 12 km long by an average width of 1.5 km. It is delimited by two parallel NE-SW fractures that situate it parallel to the Sierra de Cabo de Gata. The most outstanding geological feature is the intense fracturing to which the rocks have been subjected, predominantly striking N70E - N90E, N100E - N120E and N45E (Bordet, 1985) and which formed the flower structure of the Serrata de Níjar in the Pliocene and Quaternary (Montenat et al., 1987). Considerable volumes of volcanic rocks outcrop in the area, together with materials of the Betic substratum and Triassic-Jurassic dolostones and limestones (Leal et al., 1971). In the southern part there is an extensive, white and grey-coloured ignimbrite outcrop composed of rhyodacites, mainly made up of ash and pumice fragments. Dacitic and andesitic breccias also appear in this zone, together with vitrophyds and massive amphibolitic andesite rocks, the latter being the most abundant rocks in the northern part of the Serrata de Níjar (Bordet, 1985; Fernández Soler, 1992).

The Cortijo de Archidona bentonite deposit is located in the southern part of the Serrata de Níjar (Fig. 2). The geometry of the quarry follows two directions of maximum alteration coincident with the fracturation zones. The main bentonite mass coincides with a fault striking NW-SE and is where the most intensive mining has taken place. A second zone containing a lower volume of material coincides with a fault striking NE-SW. The bentonitised materials are dark-coloured vesicular rhyodacitic glasses and light-coloured ignimbrites. Alteration processes were encouraged by the intense breccification of these materials in the fracture zones, which in turn also allowed passage of the alteration solutions. The isotopic composition of different quartz fissure fillings indicates that solutions must have initially operated at temperatures from 50 to 100°C or even higher, which later fell to environmental levels as shown by the high $\delta^{18}O$ values of most of the montmorillonites in this deposit (Delgado, 1993). Study of the cations and anions that can be extracted from the bentonite showed that the alteration water was of the chloride-sodium sulphate type (Caballero et al., 1985).

The bentonite is soapy in appearance, with predominantly bluish-green colouring, although ochres, reds, pinks and whites are also common. These highly plastic materials show signs of being extruded, possibly because of reactivation of some of these faults towards the end of the Quaternary and/or lithostatic pressure of the overlying materials. At present 3000 to 4000 tonnes/year of highly homogeneous bentonite are extracted from this site, with over 92% montmorillonite concentrated in the clay (89%) and silt (5%) fractions, 615 m²/g surface area and 92 meq/100g change capacity (Linares et al., 1993). The minority minerals accompanying
Fig. 2 Block diagram (1.8 km x 2 km) showing the geological surroundings of the Cortijo de Archidona bentonite deposit (Serrata de Nijar).
the montmorillonite are quartz, cristobalite, plagioclase, calcite and biotite. Only calcite and

cristobalite are related to the alteration processes, while the others are inherited from the altered
rock (Caballero et al., 1983; Linares et al., 1993). The chemical composition of the bentonites as
studied by Caballero et al. (1983) and Linares et al. (1993) is similar to the average values for the
Serrata de Nijar given in Table 1. The only difference is the higher MgO contents resulting from
the high montmorillonite content in the samples from this deposit.

The average structural formula can be calculated from the chemical composition of the
smectites collected in two samplings carried out at different stages of exploitation of the site:

\[(\text{Al}_{2.73}\text{Fe}_{0.52}\text{Mg}_{0.86})(\text{Si}_{7.71}\text{Al}_{0.29})\text{O}_{20}\text{OH}_{4}X_{0.83}\]  (Caballero et al. 1983)

\[(\text{Al}_{2.78}\text{Fe}_{0.33}\text{Mg}_{1.03})(\text{Si}_{7.77}\text{Al}_{0.22})\text{O}_{20}\text{OH}_{4}X_{0.81}\]  (Linares et al. 1993)

These smectites can be classified as Wyoming-type, according to the classification by Schultz
(1969) because of the layer charge lower than 0.85 and the percentage of tetrahedral substitution.

Stop 2. The Los Trancos bentonite deposit (North Sierra de Cabo de Gata)

A unit of white or grey-coloured tuffs outcrops extensively in the northern part of the
Sierra de Cabo de Gata. Referred to as the El Plomo unit by Fernández Soler (1992), it is over
100 m thick, ignimbritic and composed of rhyodacites. These pyroclastic materials were intruded
by a field of dacite-andesite domes, which cut and partially cover them. The domes caused
deformation of the materials into which they intruded and also the enclosure of sedimentary and
tuff pebbles in the massive material (Sanchez Cela, 1968; Bordet, 1985; Fernández Soler, 1992).
These volcanic materials were exposed to subaerial environments during the latest Tortonian-
earliest Messinian, when weathering caused the formation of soils and red calcareous
conglomerates (Delgado, 1993). Seawater later covered the area and reefal carbonates deposited
on the volcanic highs, forming thicknesses of over 200 m and fossilising the volcanic materials
(Dabrio et al. 1978; Esteban, 1979, Esteban & Ginner, 1980; Armstrong et al. 1980; etc.).

The bentonite deposits in the northern part of the Sierra de Cabo de Gata mainly
 correspond to areas where the white tuff has been intensely altered because of the presence of
fracture zones or dome intrusion, forming alteration aureoles similar to those described in Japan
by Kawano & Tomita (1991) and Inoue et al. (1992). The Los Trancos deposit is located in this
context and represents the largest in the whole area, as over 120000 tonnes/year are extracted
from it. The bentonite is located on over 1 km of the dome margin. This band of altered tuff
varies in width from 10 to 50 m and its thickness can exceed 60 m. This important bentonite
deposit has been protected from erosion by a sedimentary covering made up of continental and
marine carbonates (Fig. 3).
Fig. 3 Block diagram (0.8 km x 1.46 km) showing the geological surroundings of the Los Trancos bentonite deposit (Northern zone of the Sierra de Gata).
Deformation and breccification of the tuff during dome intrusion must have played an important role in the genesis of the bentonite. The corresponding thermal effect of these processes could have initiated devitrification. This deposit also presents important vertical fractures filled with calcite at times over 50 cm thick. 10 to 30 cm nodules occasionally appear in association with these fractures, made up of millimetric calcite spherules that seem to indicate the presence of a hot spring (Delgado, 1993). This suggests that the bentonitisation is related to the outlet of bicarbonate water through fractures in the contact zone between the pyroclastic materials and the massive rocks of the dome. This composition fully concurs with that inferred by Caballero et al. (1985) on the basis of soluble cations and anions found in the bentonites. The isotopic composition of the smectites and the calcite fillings indicate slightly higher than environmental equilibrium temperatures (Delgado, 1993).

The economic and scientific importance of this deposit has led to several studies being made in the past 30 years, which have revealed the characteristics of the bentonite throughout the quarry, as well as the distribution and geometry of the altered materials. The first studies were made by Linares (1963) and Martín Vivaldi & Linares (1968), who detected the high smectite contents (92%). This feature, together with the change capacity values (97.8 meq/100g) and the specific surface (795 m²/g), gives rise to the considerable economic interest of the deposit. The data obtained by subsequent studies (Reyes, 1977; Reyes et al., 1978a,b, 1979; Linares et al., 1993; Delgado, 1993) provide similar results, which is indicative of the homogeneity of the bentonite throughout the deposit. We need only comment on the high percentages of the silt (50%) and sand (11%) fractions, which are mainly made up of smectite (Linares et al., 1993). The structural formulae of the smectites sampled in the successive stages of mining are:

\[
\begin{align*}
&\text{(Al}_{3.18}\text{Fe}_{0.32}\text{Mg}_{0.69})\text{(Si}_{7.36}\text{Al}_{0.64})\text{O}_{20}(\text{OH})_{4}\text{X}_{0.77} \quad (\text{Martín Vivaldi & Linares, 1978}) \\
&\text{(Al}_{3.18}\text{Fe}_{0.17}\text{Mg}_{0.76})\text{(Si}_{7.53}\text{Al}_{0.45})\text{O}_{20}(\text{OH})_{4}\text{X}_{0.89} \quad (\text{Reyes, 1977; Reyes et al., 1978a,b}) \\
&\text{(Al}_{3.02}\text{Fe}_{0.26}\text{Mg}_{0.87})\text{(Si}_{7.59}\text{Al}_{0.41})\text{O}_{20}(\text{OH})_{4}\text{X}_{0.84} \quad (\text{Linares et al., 1993}) \\
&\text{(Al}_{3.06}\text{Fe}_{0.21}\text{Mg}_{0.79})\text{(Si}_{7.74}\text{Al}_{0.26})\text{O}_{20}(\text{OH})_{4}\text{X}_{0.85} \quad (\text{Delgado, 1993})
\end{align*}
\]

These formulae show variability due to the presence of different percentages of interstratified smectite-kaolinite (Cuadros et al., in preparation). The 100% smectite samples are of the Wyoming type.
Stop 3. The Morrón de Mateo bentonite deposit (South Sierra de Cabo de Gata)

The Morrón de Mateo deposit is the main bentonite outcrop occurring in the vicinity of the dacitic dome known as the Morrón de Mateo (161 m) located near Los Escullos village (Fig. 4).

Alteration took place in a unit of pyroclastic materials several km$^2$ in area and over 50 m thick, in which pumice fragments are abundant. Base surge and co-surge falls hydromagmatic facies are present in some zones, with the typical alternating distribution of sandy and pumice beds which, together with marine carbonate intercalations, indicates deposit in a shallow marine environment (Fernández Soler, 1987; 1992). These materials known as the Morrón de Mateo Formation by Fernández Soler (1987) are bounded to the south by the Los Frailes caldera, where, according to Cunningham et al. (1990), they also appear as intracaldera tuff known as "middle tuff".

Intrusion of the Morrón de Mateo dome not only formed an aureole of intensely altered pyroclastic materials, but also caused a rise in temperature of the diagenesis affecting the marine carbonates. Initially intense devitrification of the volcanic rocks occurred, leading to the formation of quartz veins whose isotopic values indicate temperatures of around 150°C (Delgado et al., 1992; Delgado, 1993). The temperature of the system then fell to below 100°C, under which conditions the most extensive (in space and time) alterations took place, giving rise to the bentonite and affecting the last phases of diagenesis of the carbonates, in both cases with the intervention of seawater (Delgado, 1993). Later, with subaerial exposure of the zone, meteoric water circulated through pores and fractures, precipitating carbonates whose oxygen and carbon values clearly indicate a meteoric source, and partially modifying the $\delta^{2}H$ values of the smectites (Delgado & Reyes, 1993; Delgado, 1993).

The bentonite quarried at this site is not as homogeneous as that at Cortijo de Archidona or Los Trancos. This is due, on the one hand, to the heterogeneity of the pyroclastic materials that underwent alteration, in which, apart from the pumice beds, sandier beds appear with abundant lithic fragments. On the other hand, the lower mobility of the elements gave rise to more phases during alteration, noticeable features being the high quantities of cristobalite and zeolite. This meant that the smectite contents are lower (72%), which naturally affects the lower values of specific surface (476 m$^2$/g) and change capacity (77 meq/100g). The other minerals (quartz, hornblende, plagioclase, cristobalite, zeolite, feldspar, etc.) that make up the silt (2%) and sand (26%) fractions are present in much higher proportions than in the other two sites (Linares et al., 1993).
Fig. 4 Block diagram (1.9 km x 2 km) showing the geological surroundings of the Morrón de Mateo bentonite deposit (Southern zone of the Sierra de Gata).
The structural average formula of the samples taken at different stages of quarrying can be calculated from the chemical composition of the smectite:

$$(\text{Al}_{2.26}\text{Fe}_{0.87}\text{Mg}_{1.00}\text{Si}_{7.79}\text{Al}_{0.21})\text{O}_{20}(\text{OH})_4X_{0.82}$$  (Augustin, 1973)

$$(\text{Al}_{2.35}\text{Fe}_{0.67}\text{Mg}_{1.17}\text{Si}_{7.79}\text{Al}_{0.21})\text{O}_{20}(\text{OH})_4X_{0.83}$$  (Caballero, 1985)

$$(\text{Al}_{2.57}\text{Fe}_{0.56}\text{Mg}_{1.11}\text{Si}_{7.62}\text{Al}_{0.38})\text{O}_{20}(\text{OH})_4X_{0.91}$$  (Linares et al., 1993)

$$(\text{Al}_{2.33}\text{Fe}_{0.76}\text{Mg}_{1.03}\text{Si}_{7.73}\text{Al}_{0.26})\text{O}_{20}(\text{OH})_4X_{0.87}$$  (Delgado, 1993)

The smectites have been classified according to the formula provided by Linares et al. (1993), who exclude the samples containing mixtures of di- and tri-octahedral smectites. Therefore, according to the classification by Schultz (1969), the layer charge value of over 0.85 and contents lower than 50% due to tetrahedral substitution mean that these smectites are Tatatila and Chambers type. Their octahedral iron content places them in the field of the non-ideal montmorillonites as defined by Schultz (1969) and Brigatti (1983).

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