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Porous modified bentonite as efficient and selective catalyst in the synthesis of 1,5-benzodiazepines

Mercedes Muñoz · Gabriel Sathicq · Gustavo Romanelli · Silvina Hernández · Carmen I. Cabello · Irma L. Botto · Mickael Capron

Abstract The synthesis of 1,5 benzodiazepine using natural and modified Argentinean bentonite (pillared layered clay and porous clay heterostructure) as catalysts through a condensation reaction between *o*-phenylenediamine (*o*-PDA) and excess of acetone as reactive and solvent at room temperature is reported. The catalysts were found to be highly active and selective, affording a high yield of the corresponding benzodiazepine. The effects of the modification of the natural bentonite and reaction conditions, such as temperature, time and amount of catalyst were investigated. The catalysts were also successfully employed for the preparation of other derivatives of 1,5-benzodiazepine using substituted *o*-PDAs and ketones. In all cases, the reactions are highly selective and are completed within 1–3 h. The catalyst showed excellent activity in all cases, showing 86–90% isolated yields of the corresponding derivatives of 1,5-benzodiazepine. The easy work-up procedure and the recyclable catalyst make this methodology attractive for large-scale operations.

Keywords Bentonite · Modified bentonite · Catalysis · Heterogeneous · 1,5-Benzodiazepines

Carmen I. Cabello is a Member of CIC-PBA and Facultad de Ingeniería, UNLP.

M. Muñoz · G. Sathicq · G. Romanelli (✉) · S. Hernández · C. I. Cabello (✉)
Centro de Investigación y Desarrollo en Ciencias Aplicadas "Dr. Jorge J. Ronco" (CINDECA), CCT CONICET La Plata, Universidad Nacional de La Plata (UNLP), 47 No 257, 1900 La Plata, Argentina
e-mail: gpr@quimica.unlp.edu.ar

C. I. Cabello
e-mail: ccabello@quimica.unlp.edu.ar

I. L. Botto
Centro de Química Inorgánica (CEQUINOR)-CCT CONICET La Plata, Universidad Nacional de La Plata (UNLP), Calles 47 y 115, 1900 La Plata, Argentina

M. Capron
Unité de Catalyse et chimie du solide (UCCS), UMR-CNRS 8181, Université des Sciences et technologies de Lille, 59655 Villeneuve d'Ascq, Cedex, France

1 Introduction

The research and utilization of clay minerals have a long history. Clays and their derivatives have become indispensable materials in many fields such as high-technology areas and industrial and agricultural production [1–3].

As reported by Li and coworkers, although clay minerals are natural catalyst materials, many disadvantages such as poor thermal stability and wide pore-size distributions limit their application. To bridge the gap between the properties of clay and the need for catalysts in the industry, materials based on modified clay minerals are necessary [4].

The layered alumino-silicates with ability to swell always contain negative charges on their layers because of the isomorphous substitution of the central atoms in the octahedral/tetrahedral sheet by cations of lower valence. These negative charges have to be compensated by inorganic cations (e.g., Na^{+} and Ca^{2+}). These inorganic cations are exchangeable and can be replaced with polycations and organic cations, and the resulting materials are denoted as pillared layered clays (PILCs) and organoclays, respectively. The PILCs show affinity toward hydrophilic inorganic compounds and the organoclays toward hydrophobic organic compounds [5–7].

In a recent paper Run Liang Zhu and coworkers (2009) reported that to make the clay minerals possess the

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properties of both organoclays and PILCs, researchers used both organic and inorganic polycations for intercalation into the clay structure, and the resulting materials were referred to as inorganic–organic clays (IOCs). In this sense, previous reports showed that IOCs could be more effective in the sorption of organic pollutants and oxyanionic contaminants from water [8–12].

Natural and modified clays find extensive applications in organic synthesis. These materials, unlike other conventional catalysts, enjoy considerable advantages such as ease of handling, recyclability, low cost, and easier modulation of acidity levels by suitable exchange of cations, thus contributing to the main subject of "Green Chemistry" [13].

On the other hand, benzodiazepines and their polycyclic derivatives constitute an important class of heterocyclic compounds that possess a wide range of therapeutic, pharmacological and industrial properties [14, 15].

Many members of the benzodiazepine family have wide applications in medicinal chemistry such as central nervous system agents, anti-inflammatory, anticonvulsant, antianxiety, antidepressive, sedative, and hypnotic agents, and analgesics. Benzodiazepine derivatives also found commercial use as dyes for acrylic fibers in photography [14, 15].

Particularly, 1,5-benzodiazepines are valuable synthetic intermediates for the synthesis of various fused ring systems such as triazolo-, oxadiazolo-, oxazino- or furanobenzodiazepines [16–19]. In the last decade, the area of pharmacological applications of 1,5-benzodiazepines has been expanded to several diseases such as cancer, viral infections and cardiovascular disorders [20].

Due to their wide range of biological and industrial applications in the synthesis of organic chemistry, the development of mild and efficient protocols continues to be a challenging endeavor [21].

A general way to construct the ring skeletons of 1,5-benzodiazepine is via reactions of *o*-phenylenediamines (*o*-PDA) with ketones, α,β-unsaturated carbonyl compounds, or β-haloketones [22].

Many reagents with acidic properties have been reported in the literature for the synthesis of 1,5-benzodiazepines, including $BF_3.Et_2O$ [17, 23–31].

As mentioned by De et al. [25], many of these processes suffer from one or other limitations such as drastic reaction conditions, low yields, tedious work-up procedures, relatively long reaction times and co-occurrence of several side reactions. Moreover, the main disadvantage of almost all existing methods is that the catalysts are destroyed in the work-up procedure and cannot be recovered or reused.

In this paper we report a facile method for the synthesis of 2,3-dihydro-1*H*-1,5-benzodiazepines by the condensation of *o*-phenylenediamine with ketones catalyzed by a natural and modified bentonite. The influence of the intercalation agent was also examined.

The original material used was bentonite (hereafter denoted as B), extracted from an Argentinean deposit, and three types of bentonite modified by intercalating inorganic and/or organosilane cations into clay layers: (a) Pillared layered clays (PILCs) by using hydroxy-Al(III) cation (hereafter denoted as Al_{13}); (b) Porous clays heterostructure (PCHs) by using organic and organosilane cations; (c) Inorganic–organic clays (Al_{13}–PCHs) by modification of PILCs using organic and organosilane cations [32–35]. All modified systems were thermally treated at about 773 K to obtain materials of high specific areas.

2 Materials and methodology

2.1 Materials and reagents

All solvents and chemicals were Aldrich (>98%).

2.2 Catalysts synthesis

The selected bentonite clay was extracted from an Argentine deposit as original material which was enriched in the Montmorillonite fraction by Stokes' method previously described [33]. This specie is a 2:1 alumino-silicate laminar structure which belongs to the group of smectites. Its structure is composed of two layers of tetrahedral $(Si,Al)O_4$ connected to another layer formed by ions $Al(O,OH)_6$ in octahedral coordination in which part of Al is substituted by Mg, Fe, etc. ions. These 2:1 layers are negatively charged, in the clays the neutrality is maintained by exchangeable cations such as: Na^+ or Ca^{++} [5–7].

The pillared species with oligomer Al_{13} (PILCs) was obtained by using an Al_{13} Keggin polycation solution $[AlO_4Al_{12}(OH)_{24}(H_2O)_{12}]$ according to the procedure described in the literature [33, 34].

The heterostructured bentonite (PCH materials) was obtained in two stages using: (I) hexadecyl-trimethyl-ammonium bromide (HDTMA-Br) to obtain B^+, and (II) a mix of dodecylamine (DDA) and tetraethylorthosilicate (TEOS), in the ratio B^+/DDA/TEOS, 1/20/150 to obtain a porous structure after heating to 550 °C, as was reported [32, 35]. Finally, a third material was obtained by modification of a PILC species that was additionally treated following the same two stages for PCH materials in the ratio B^+/DDA/TEOS, 1/20/150, as previously mentioned.

2.3 Catalyst characterization

The ICP.AES (Inductively Coupled Plasma-Atomic Emission Spectroscopy) analysis was carried out by $LiBO_2$/$Li_2B_4O_7$ fusion (ACME Lab).

X-ray powder diffraction (XRD) patterns were recorded by a diffractometer Philips PW 1710 using Cu Kα radiation (Ni filter), 20 mA and 40 kV in the high voltage source, and scanning angle between 2 and 60° of 2θ at a scanning rate of 2° per min.

Environmental scanning electron microscopy (ESEM) with EDS analysis was performed using a Microscope ESEM Quanta 400 with dispersive energy system for microanalysis, EDAX Apollo 40.

Textural analysis (BET) was performed by N_2 adsorption–desorption at 77 K using a Micromeritics ASAP 2010 analyzer. The samples were preheated under vacuum in two steps of 1 h at 100 °C and 1 h at 200 °C. BET specific surface area, were obtained from adsorption data in the relative pressure range 0.05–0.2. BJH pore size distribution [36], were obtained from data of the desorption branch of the isotherm micropore analysis by *t* test [37], adopting the Harkins and Jura reference curve [38] and total pore volume by Gurvitsch rule [39].

Nuclear magnetic resonance spectroscopy was employed by ^{27}Al magic angle spinning (MAS) NMR technique. Experiments were carried out on a Bruker ASX400 (9.4 T) spectrometers operating at ^{27}Al Larmor frequencies 104.3 MHz using 4 mm MAS probehead. ^{27}Al-MAS NMR spectra were recorded by using a single pulse acquisition with small pulse angle $\pi/12$ to assure a quantitative excitation of the central transition [40] and recycle delay of 5 s. ^{27}Al-MAS NMR spectra were referenced at 0 ppm relative to a 1 M $Al(NO_3)_3$ aqueous solution (pH $\sim$ 1).

2.4 Catalytic reaction procedure

2.4.1 *Preparation of 2,2,4-Trimethyl-2,3-dihydro-1H-1,5-benzodiazepine*

The catalytic benzodiazepine synthesis was performed in a batch reactor immersed in a thermostatted bath with magnetic stirrer. A solution of the *o*-PDA (2 mmol) in acetone (4 mL) and catalyst (25–150 mg) was warmed at the corresponding temperature. Aliquots of the reaction mixture were withdrawn at intervals of time. Each sample was approximately diluted with 1 mL of ethanol. Conversions and product identification were determined with a Perkin Elmer GC–MS.

2.4.2 *General procedure for the synthesis of 2,3-dihydro-1,5-benzodiazepines*

The 2,3-dihydro-1,5-benzodiazepines synthesis was performed in a batch reactor. The catalyst (100 mg) was added to a ketone solution (56 mmol) of the corresponding *o*-PDA (2 mmol), and then warmed at 56 °C for about 1 h. The progress of the reaction was followed by thin layer cromatography (TLC) using 20–40% EtOAc in *n*-hexane as eluent. When the reaction was completed, the catalyst was recovered by filtration. The organic solvent (ketone excess) was evaporated and the crude product purified by recrystallization from *n*-hexane or by column chromatography on silica gel using EtOAc: *n*-hexane as eluent. All the yields were calculated from isolated products. All the condensation products are known compounds and adequately characterized by ^{1}H-NMR, ^{13}C-NMR, GC–MS and melting point. The catalyst was regenerated by washing with acetone (2 × 5 mL), dried under vacuum and then reused.

2.4.3 *Characterization of selected benzodiazepine, 2,2,4-Trimethyl-2,3-dihydro-1H-1,5-benzodiazepine*

White solid m.p. (124–125 °C [41] 125–126 °C); ^{1}H-NMR (400 MHz, TMS, $CDCl_3$) δ 1.35 (s, 6H, $-CH_3$), 2.22 (s, 2H, $-CH_2$), 2.37 (s, 3H, $-CH_3$), 3.44 (br, 1H, –NH), 6.60–6.72 (m, 4H, Ar); ^{13}C-NMR (100 MHz, TMS, $CDCl_3$) δ 171.5, 140.5, 138.0, 126.6, 125.4, 121.9, 121.5, 68.2, 45.3, 30.5, 29.5; MS (EI) m/z 188 (45), 173 (100), 132 (66), 131 (28), 92 (12).

3 Results and discussion

3.1 Catalysts characterization

The chemical analysis of natural clays was carried out by the ICP.AES method, and these results are shown in Table 1. They are in good agreement with those obtained by EDS (both on dry basis). The surface analysis of modified systems was carried out by ESEM-EDS microscopy (Table 1); the chemical treatment showed a SiO_2/Al_2O_3 ratio variation. This ratio decreased to its half value after the treatment with Al_{13} oligomer. Also, it increased 25 times with the surfactant and TEOS treatment. Besides,

Table 1 EDS (and *ICP.AES*) chemical data (both on dry basis) for pure and modified Bentonite

	Bentonite	PILC	PCH	Al_{13}–PCH
SiO_2	69.20 (66.04)	55.11	89.20	98.00
Al_2O_3	19.70 (21.57)	35.85	7.80	2.00
Fe_2O_3	5.00 (5.30)	6.33	1.90	–
MgO	2.60 (3.03)	2.55	1.10	–
Na_2O	3.50 (3.42)	0.16	–	–
CaO	– (0.44)	–	–	–
K_2O	– (0.20)	–	–	–
SiO_2/Al_2O_3	3.06	1.6	11.43	46.61

Ref.: corresponding to % in mass

Table 2 BET and pore data for pure bentonite and bentonite modified by different methods

	Area BET (m^2/g)	Total pore vol. (cm^3/g)	μ pore vol. (cm^3/g)	Pore size (Å)
B	22.5	0.016	0.005	29.60
PILC	243.7	0.220	0.015	35.60
PCH	705.0	0.546	0.270	17.54
Al_{13}–PCH	756.0	0.514	0.393	15.33

this ratio was significantly modified in the pillared clay (PILC) and subsequently functionalized (Al_{13}–PCH). Table 2 shows the textural parameters (pore size and surface areas) of the bentonite-based systems before and after the modification process. A noticeable increase of surface areas occurred by the inorganic, organic and organosilane incorporation [3].

The specific area of PCHs species was higher than that of PILCs which are in the limit of ultramicropores. The Al_{13} incorporation increased the microporosity and the micropore volume of bentonite.

Both PCH and Al_{13}–PCH resulted principally microporous solids where meso-pores were about 10% of the total pore volume (particle size > 20 Å, 98 $m^2\ g^{-1}$ in 705 $m^2\ g^{-1}$ total and 50 $m^2\ g^{-1}$ in 756 $m^2\ g^{-1}$ total respectively). The behavior of the adsorption–desorption isotherm in the range 0.1–0.3 P/P_0 was positively affected by the chemical modification of PCH with Al_{13}, (Fig. 1a, b) for this reason the area was increased from 607 to

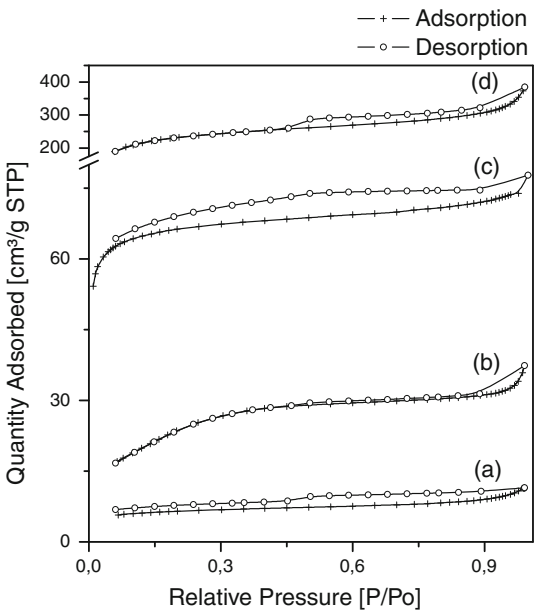


Fig. 1 Linear Plot for N_2 adsorption–desorption isotherms at 77°K of the Systems in study, (*a*) Bentonite, (B); (*b*) pillared- heterostructurated Bentonite (Al_{13}–PCH), (*c*) pillared Bentonite (PILC) and (*b*) heterostructurated Bentonite PCH

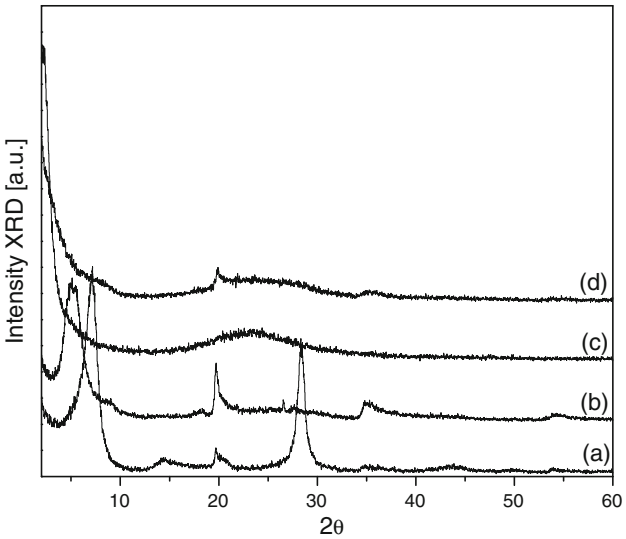


Fig. 2 Comparative XRD patterns for (*a*) B, (*b*) PILC, (*c*) Al_{13}–PCH and (*d*) PCH

706 $m^2\ g^{-1}$ and the micro-pore volume from 270 to 393 ML g^{-1}. This implies an increases in ultra-micropores or narrow meso-pores volume. The IUPAC convention assigned a limit of 20 Å to micro-pores dimension. On the other hand, PCH systems have an intermediate behavior between micro-porous materials, such as zeolites and pillared clays (pores < 10 Å), and meso-porous materials (MCM-41, pores > 20 Å) [42, 43].

The XRD patterns are shown in Fig. 2. The pattern for selected bentonite clay (B) belongs to the Montmorillonite (PDF 291498) species. It is possible to observe that d_{001}-values (basal spacing) of clay-based compounds increased from d ~ 12 Å ($2\theta = 6.7°$) for pure bentonite to d ~ 18 Å ($2\theta = 4.7°$) for PILC material due to the expansion associated to the Al_{13} incorporation. The PCH formation involved a different process because the surfactant and TEOS treatment affect the total surface, they given an increase of BET surface area and a decrease of crystallinity.

^{27}Al-MAS NMR is a powerful tool to provide information on the aluminum environment in the bulk material. Figure 3 shows the ^{27}Al-MAS NMR spectra of pure bentonite. The simulation of these spectra using DM Fit program [44] was performed, allowing us to obtain the isotopic chemical shift (δ_{iso}) and quadrupolar parameters (C_Q and η_Q) characteristic of ^{27}Al local environments.

The ^{27}Al-MAS NMR spectrum of bentonite (Fig. 3) present two components, one centered at 62.5 ppm (7% of the total signal) and other at 9.1 ppm (93% of the signal) corresponding to Al(III) tetra and octahedral coordinated respectively. This fact is in coincidence with the structural characteristics.

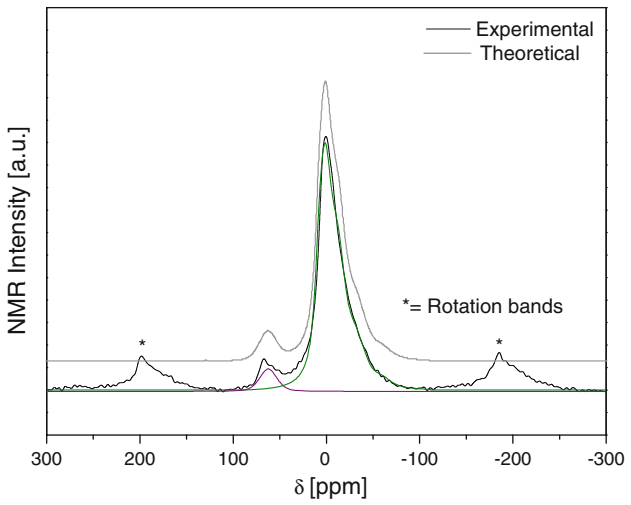


Fig. 3 ^{27}Al NMR (MAS) spectra for pure bentonite (*black line*). The *grey lines* correspond to spectral deconvolution

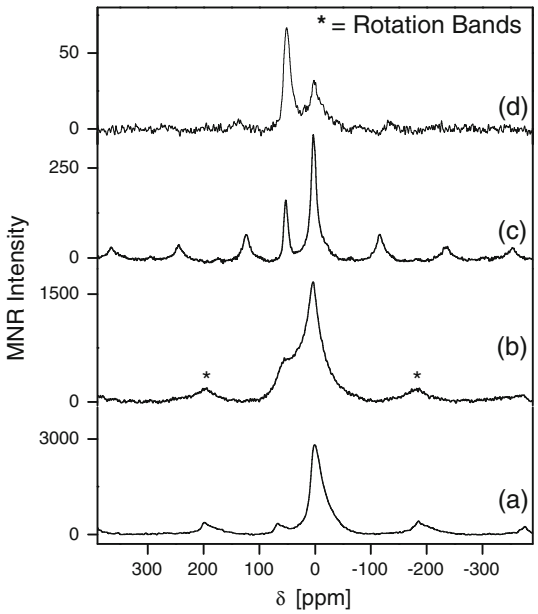


Fig. 4 ^{27}Al NMR (MAS) spectra for: (*a*) B, (*b*) PILC, (*c*) PCH and (*d*) Al_{13}–PCH

The ^{27}Al-MAS NMR spectrum of the PILC system (Fig. 4b) was composed by two bands, just as for the pure bentonite, one localized at 53.6 ppm and another at 3.4 ppm attributed to tetra and octahedral coordinated Aluminum respectively. The Al quantification by integration of the signals gave a value of 15 and 85% respectively of the total signal. This fact showed an Al tetrahedral coordinated increment in 7 to 15%, from pillaring Al_{13} agent.

PCHs are Si rich, so the lower amount of Al in the system, gave ^{27}Al-MAS NMR bands much less intense (Fig. 4c). However, a noticeable increase in the ratio Al tetrahedral to Al octahedral was observed in Al_{13}–PCH system. It is well known that the low coordination stability and electronic deficiency of the Al(III) in tetrahedral environment produces Brønsted acid sites. These results were in according to the processes of modification made. In these processes an increase of AlO_4(tet) groups occurs from the interaction of TEOS since the SiO_4 units can be replaced by AlO_4 groups from the Al_{13} phase. TEOS can be considered a precursor of active species Al-tetrahedral. For this reason the AlO_4(tet)/AlO_6(oct) ratio is favored by TEOS–Al_{13} as evidenced by NMR. These factors therefore favor the presence of Brønsted sites.

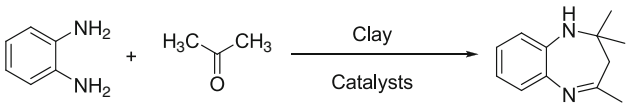
3.2 Catalytic tests

The 1,5-benzodiazepine synthesis involving the condensation of *o*-phenylenediamine (*o*-PDA) and acetone is illustrated in the reaction Scheme 1. Before attempting a detailed catalytic work, a "non-catalytic" reaction between *o*-PDA (2 mmol) and acetone (4 mL) was examined and it was observed that under the experimental condition (56 °C, 4 h), no formation of 1,5-benzodiazepine was detected, indicating that from a practical point of view the reaction is not taking place in the absence of a catalyst.

The condensation of *o*-PDAs and ketones was reported to be catalyzed by acid or bases [23–31]. Natural bentonite (B) was first tested for the catalytic condensation between *o*-PDA and acetone at 56 °C for 3 h. The GC yield of 1,5-benzodiazepine was 98% and no other secondary products were observed, indicating that oxidation reaction did not take place under these reaction conditions. The GC–MS analysis confirms that, under our experimental conditions, 1,5-benzodiazepine is obtained selectively [MS (EI) m/z (%) 188 (45), 173 (100), 132 (66), 131 (28), 92 (12)].

3.2.1 *Effect of reaction temperature and time on catalyst performance*

The effect of temperature plays an important role in the catalytic synthesis of 1,5-benzodiazepine. It was examined between 20 and 56 °C in the absence of solvent by using B as catalyst. The results are illustrated in Fig. 5. The



Scheme 1 Synthesis of 1,5-benzodiazepine from *o*-PDA and acetone using different clays as catalyst

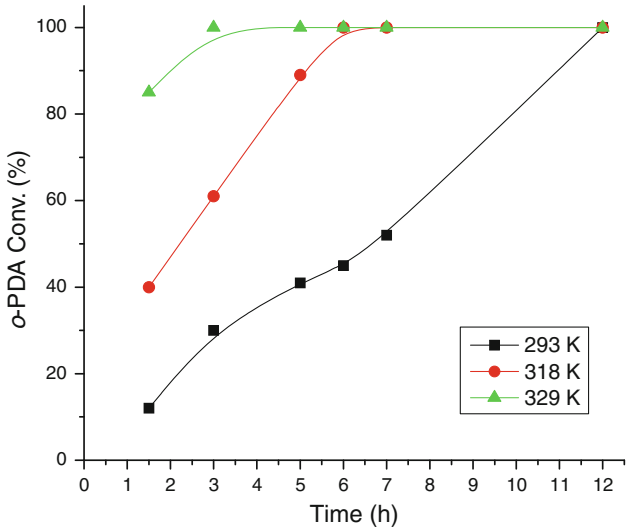


Fig. 5 Effect of reaction temperature and time on catalyst performance using bentonite (B)

reaction was carried out using *o*-PDA (2 mmol), acetone (4 mL) and catalyst (100 mg). The effect of temperature increase in the 1,5-benzodiazepine conversion, was observed from 30% for a reaction at 20 °C, to 100% at 56 °C (time 3 h), which meant an increase of 3.3 times. At intermediate temperature (45 °C) and similar reaction time, a conversion of 60% was obtained. For this reason, 56 °C was employed as the ideal temperature to continue with the analysis of other reaction variables.

3.2.2 *Effect of the amount of catalyst*

On the basis of the optimal reaction conditions (*o*-PDA, 2 mmol; acetone, 4 mL and B catalyst at temperature of 56 °C) the effect of the catalyst amount was studied. Different samples of B catalyst (25, 50, 100 and 150 mg) were tested. The results show that 100 mg is an optimal quantity of catalyst to obtain the best yields (see Fig. 6a, b). When the experiment was carried out employing 150 mg of B catalyst, similar conversions were obtained, and a small amount of an unidentified secondary product was detected.

3.2.3 *Effect of modified clays*

All catalysts used presented a conversion of 100%. However, if we use the modified systems instead of bentonite (B), the reaction is completed in shorter time. It is possible to observe in Fig. 7 that when using PCH and Al_{13}–PCH as catalytic systems, the reaction time is much shorter than for PILC and even shorter for B. This time decrease in which the process is completed can be correlated with the increase in the specific area of the systems (Table 2), where a larger

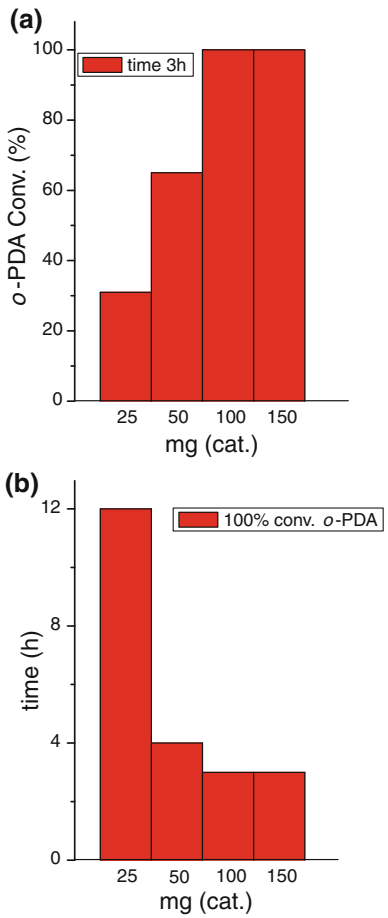


Fig. 6 **a**, **b** Effect of the amount of B as catalyst

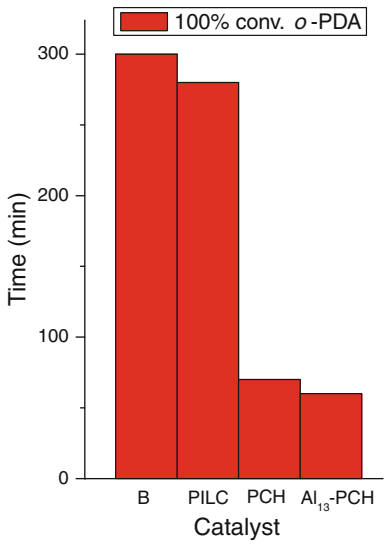


Fig. 7 Comparative catalytic effect between B and modified clays

specific area may allow a better availability of Brønsted acid sites from both Al/Si–OH bonds and tetrahedral aluminum ions, responsible of good catalytic activity. In

addition, this effect can be correlated with the highest SiO_2/Al_2O_3 ratio of PCH and Al_{13}–PCH systems, which results in a larger amount of Al/Si–OH sites [13, 45].

3.2.4 Reuse of the catalyst

The reuse of catalysts is central to their utility. In order to investigate the reusable properties of the catalysts, regeneration experiments were performed and the results are shown in Fig. 8. After reaction, the catalyst was regenerated by washing with acetone (2 × 5 mL), dried under vacuum at 50 °C for 5 h and then reused. The best catalysts, Al_{13}–PCH, were used for this test. They were reused twice, and it was observed that there was a minor loss in catalyst weight during each recycles (total loss 12%). For the Al_{13}–PCH catalyst, the isolated yields of 1,5-benzodiazepine were 88, 86, 87 and 85%, which showed the good reusability of this catalyst.

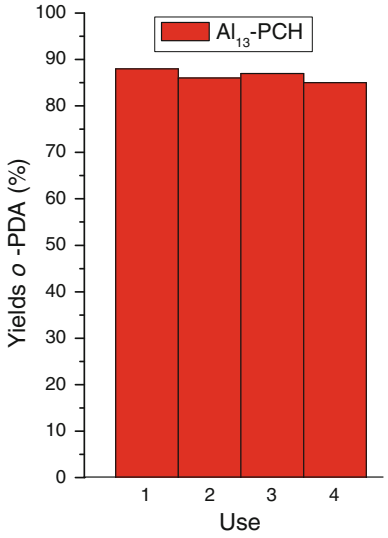


Fig. 8 Al_{13}–PCH catalyst reuse

Scheme 2 Possible mechanism for the formation of 1,5-benzodiazepines

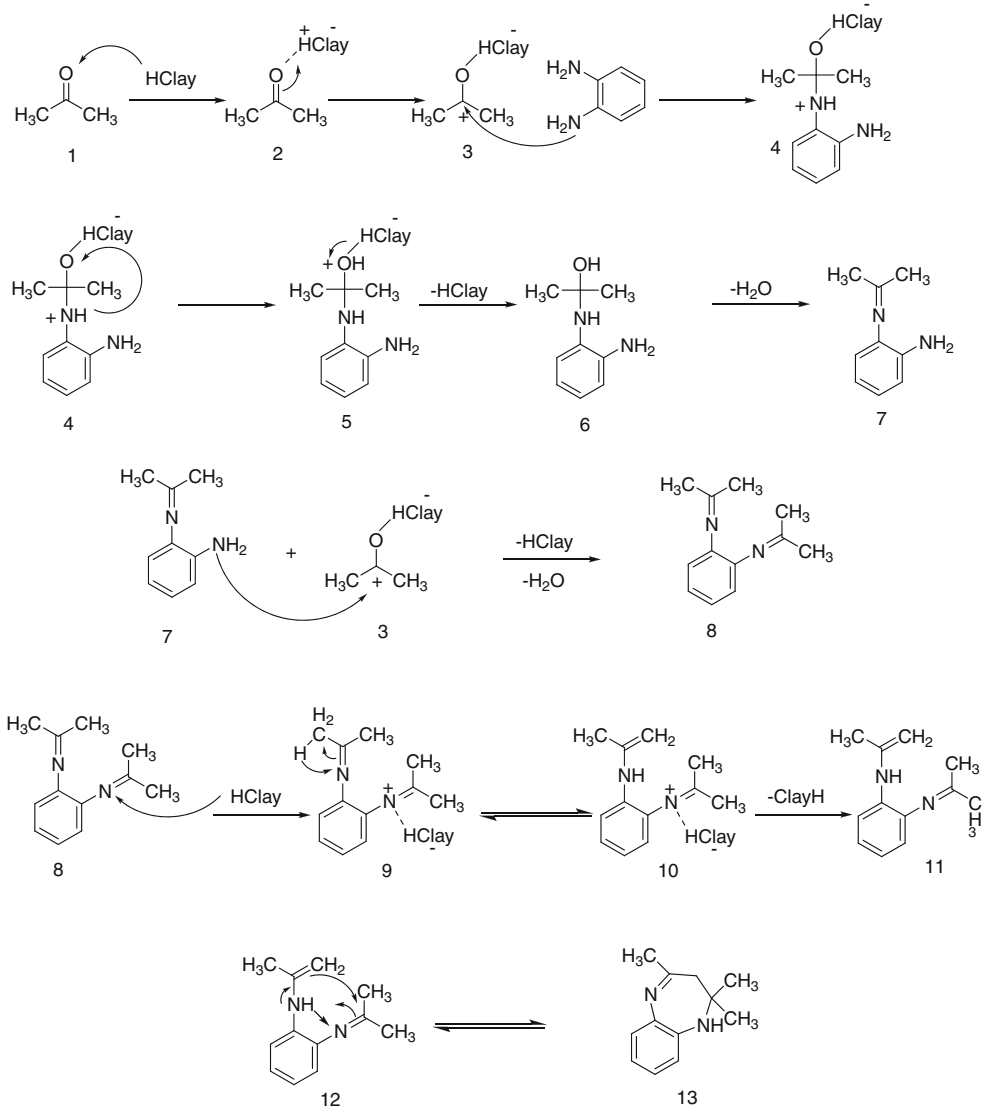
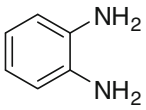
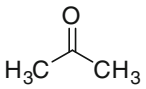
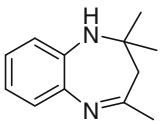
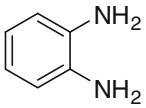
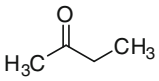
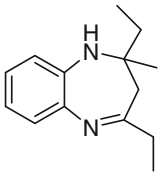
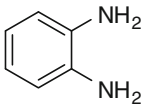
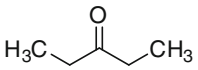
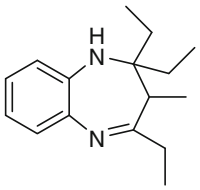
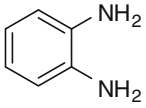
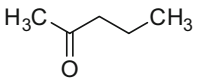
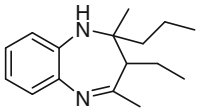
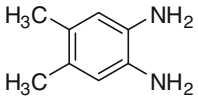
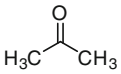
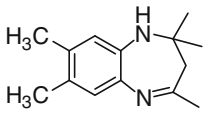


Table 3 Synthesis of 2,3-dihydro-1*H*-1,5-benzodiazepines using Al_{13}–PCH catalysts

	o-PDA	Ketone	Benzodiazepine	Yield (%)[a]
1				88
2				86
3				85
4				83
5				89

Reaction conditions: *o*-PDA, 2 mmol; ketone, 55 mmol; catalyst (Al_{13}–PCH, 100 mg); 56 °C; 1 h

[a] Isolated yields based on *o*-PDA

3.2.5 Reaction mechanism

Mechanistically, a possible pathway for the formation of 1,5-benzodiazepines involves the formation of Schiff base (in Scheme 2), which undergoes 1,3-hydrogen shift to form enamine; the intramolecular hydrogen shift gives the desired product.

3.2.6 Preparation of substituted 1,5-benzodiazepines

To explore the general validity of the process previously described, a series of 1,5-benzodiazepine derivatives were prepared under the optimal conditions. The reactivity of different *o*-PDAs and ketones was tested under the same conditions. Results of the obtained yields are listed in Table 3. The results showed that, in general, the reactions were clean and products were isolated by liquid column chromatography in pure form without further purification (^{1}H and ^{13}C-NMR). The reaction is very selective and no competitive side reactions were observed (GC).

4 Conclusions

Different materials based on chemically modified Argentinean bentonite were prepared and characterized. These were used as regenerable solid catalysts in the mild and convenient synthesis of 1,5-benzodiazepines by the reaction of *o*-PDAs with ketones.

Clays and their modified forms can provide environmentally friendly alternative catalysts for liquid Brønsted acids. Particularly the Al_{13}–PCH system showed high specific area with Brønsted sites from a favorable AlO_4(tet)/AlO_6(oct) ratio as evidenced by ^{27}Al-MAS NMR spectra. The simple experimental conditions and the efficient reusability and recovery of modified bentonite become these materials as promising catalysts for this type of organic synthesis.

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References

1. Z. Ding, H.Y. Zhu, P.F. Greenfield, J. Colloid Interface Sci. **209**, 193–199 (1999)
2. C. Ooka, H. Yoshida, K. Suzuki, T. Hattori, Appl. Catal. A Gen. **260**, 47–53 (2004)
3. H.Y. Zhu, Z. Ding, J.C. Barry, J. Phys. Chem. B **106**, 11420–11429 (2002)
4. H. Mao, B. Li, X. Li, L. Yue, Z. Liu, M. Wei, Ind. Eng. Chem. Res. **49** 583–591 (2010), and references cited herein
5. P. Yuan, H. He, F. Bergaya, D. Wu, Q. Zhou, J. Zhu, Micropor. Mesopor. Mater. **88**, 8–15 (2006)
6. R. Zhu, T. Wang, F. Ge, W. Chen, Z. You, J. Colloid Interface Sci. **335**, 77–83 (2009)
7. R. Zhu, L. Zhu, J. Colloid Surf. Sci. **322**, 27–32 (2008)
8. T. An, J. Chen, G. Li, X. Ding, G. Sheng, J. Fu, B. Mai, K. O'Shea, Catal. Today **139**, 69–76 (2008)
9. A. Elmchaouri, R. Mahboub, Colloids Surf. A **259**, 135–141 (2005)
10. J.Q. Jiang, C. Cooper, S. Ouki, Chemosphere **47**, 711–716 (2002)
11. J. Ma, L. Zhu, J. Hazard. Mater. **136**, 982–988 (2006)
12. K.R. Srinivasan, S.H. Fogler, Clays Clay Miner. **38**, 277–286 (1990)
13. R.S. Varma, K. Pitchumani, K.P. Naicker, Green Chem. **95** (1999) and references cited herein
14. J.K. Landquist, in Comprehensive heterocyclic Chem., eds. by A.R. Katritzky, C.W. Rees (Pergamon, Oxford, 1984), Vol. 1, pp 166–170
15. H. Schutz, *Benzodiazepines* (Springer, Heidelberg, 1982)
16. A.M. El-Sayed, A. Khodairy, H. Salah, H. Abdel-Ghany, Phosphorus Sulfur Silicon Relat. Elem. **182**, 711–722 (2007)
17. K. Nabih, A. Baouid, A. Hasnaoui, A. Kenz, Synth. Commun. **34**, 3565–3572 (2004)
18. G.K. Nagaraja, V.P. Vaidya, K.S. Rai, K.M. Mahadevan, Phosphorus Sulfur Silicon Relat. Elem. **181**, 2297–2806 (2006)
19. K.V.V. Reddy, P.S. Rao, D. Ashok, Synth. Commun. **30**, 1825–1836 (2000)
20. C.W. Kuo, C.C. Wang, V. Kavala, C.F. Yao, Molecules **13** 2313–2325 (2008) , and references cited herein
21. J.S. Yadav, B.V.S. Reddy, G. Satheesh, G. Srinivasulu, A.C. Kunwar, ARKIVOC **III**, 221–227 (2005)
22. X.Q. Pan, J.P. Zou, Z. Huang, W. Zhang, Tetrahedron Lett. **49** 5302–5308 (2008), and references cited herein
23. J.A.L. Herbert, H. Suschitzky, J. Chem, Soc. Perkin Trans. **1**, 2657–2661 (1974)
24. M. Curini, F. Epifano, M.C. Marcotullio, O. Rosati, Tetrahedron Lett. (42) 18 3193–3195 (2001) *Corrigendum to* Tetrahedron Lett. 42 (2001) 3193–3195 Tetrahedron Lett. (42) 27(2001) 4593
25. S.K. De, R. Gibbs, Tetrahedron Lett. **46**, 1811–1813 (2005)
26. J. Wu, F. Xu, Z. Zhou, Q. Shen, Synth. Commun. **36**, 457–464 (2006)
27. W. Zhong, Y. Zhang, X. Chen, Tetrahedron Lett. **42**, 73–75 (2001)
28. G. Sabitha, K.B. Reddy, M.N. Reddy, J.S. Yadav, Adv. Synth. Catal. **346**, 1447–1453 (2004)
29. R. Varala, R. Enugala, S. Nuvula, S.R. Adapa, Synlett **7**, 1009–1014 (2006)
30. M.M. Heravi, V. Zadsirjan, F.K. Behbahani, H.A. Oskooie, J. Mol. Catal. A Chem. **259**, 201–204 (2006)
31. D.I. Jung, T.W. Choi, Y.Y. Kim, I.S. Kim, Y.M. Park, Y.G. Lee, D.H. Jung, Synth. Commun. **29**, 1941–1951 (1999)
32. M. Benjelloum, P. Cool, P. Van Der Voort, E.F. Vansant, Phys. Chem. Chem. Phys. **4** 2818–2823 (2002), and references cited herein
33. A. Gil, L.M. Gandia, M.A. Vicente, Catal. Rev. Sci. Eng. **42** 145–212 (2000), and references cited herein
34. J.T. Kloprogge, L.V. Duong, R.L. Frost, Environ. Geol. **47**, 967–981 (2005)
35. F. Kooli, P. Cheng Hian, Q. Weirong, S.F. Alshahateet, C. Martin, V. Rives, Clay Science 12 Sup. **2** 295–300 (2006), and references cited herein
36. E.P. Barrett, L.G. Joyner, P.P. Halenda, J. Am. Chem. Soc. **73**, 373–375 (1951)
37. B.C. Lippens, J.H. de Boer, J. Catal. **4**, 319–323 (1965)
38. W.D. Harkins, G. Jura, J. Am. Chem. Soc. **66**, 1366–1373 (1944)
39. L.J. Gurvitsch, Phys. Chem. Soc. Russ. **47**, 805–827 (1915)
40. A. Samoson, E. Lippman, Phys. Rev. B, Condens. Matter **28** (1983) 6567
41. W. Yi, C. Cai, J. Fluor. Chem. **130**, 1054–1058 (2009)
42. A. Galarneau, A.T. Barodawalla, J. Pinnavaia, Nature **374**, 529–531 (1995)
43. R.S. Murray, J.P. Quirk, Langmuir **6**, 122–124 (1990)
44. D. Massiot, F. Fayon, M. Capron, I. King, S. Le Calvet, B. Alonso, J.-O. Durand, B. Bujoli, Z. Gan, G. Hoatson, Magn. Reson. Chem. **40**, 70 (2002)
45. R.S.Varma, K. Pitchumani, K.P. Naicker, Green Chem. **1** 95 (1999), and references cited herein